MECHANICAL
ENGINEERING

DYNAMIC SYSTEMS & CONTROL
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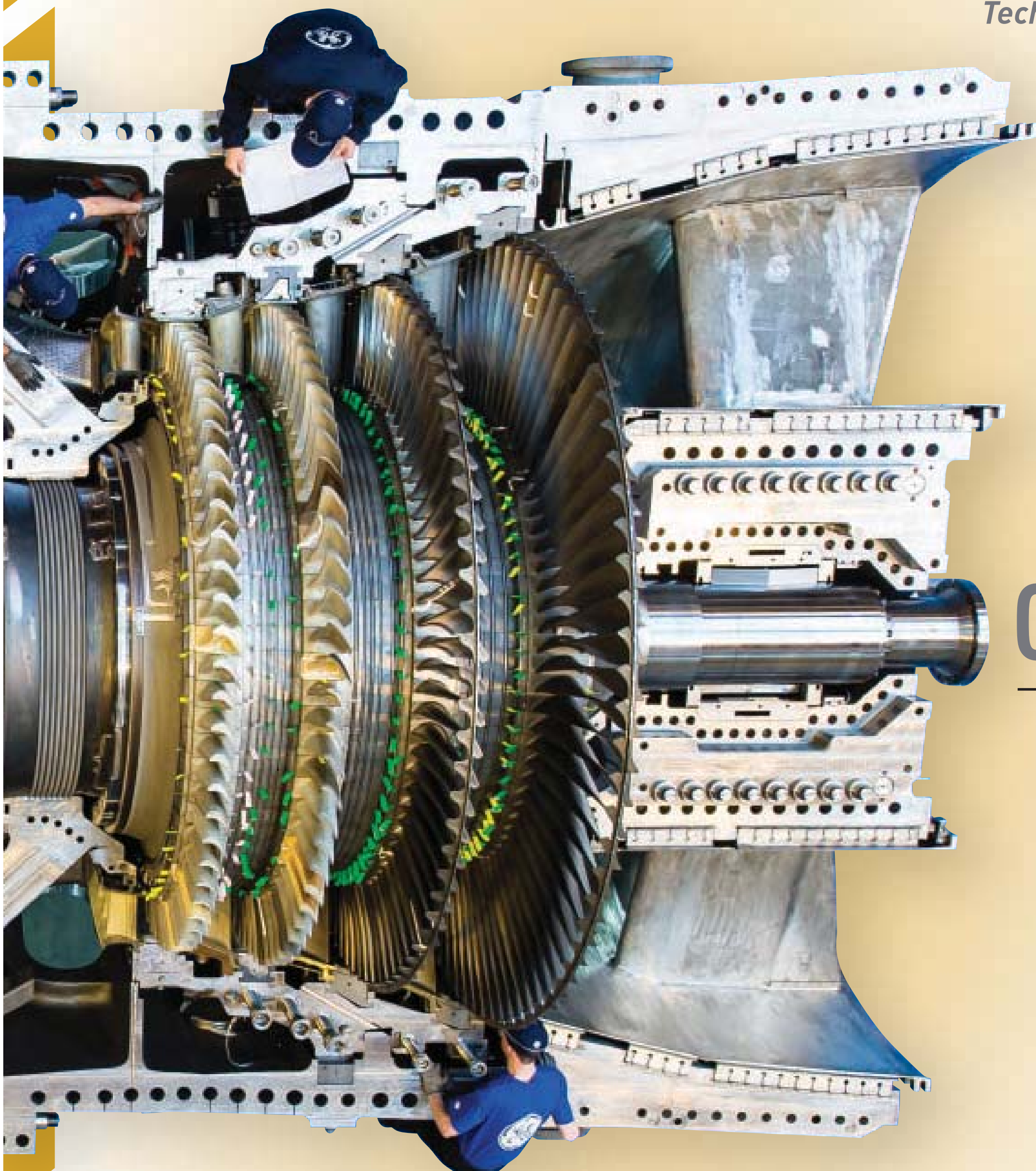
No. 06
139

Technology that moves the world



REVERSAL OF FORTUNE

Production of gas turbines for electric generation takes an unexpected turn.

Danielle van Zadelhoff

3-D-PRINTED DEATH MASKS

VESPERS, A SERIES OF 3-D-PRINTED death masks on display at London's Design Museum, depicts the place where the human body of ancient times intersects with advanced technology. The Mediated Matter Group at the MIT Media Lab creates biologically inspired design fabrication tools that serve as a bridge between the natural and the man-made environments, and designed the masks.

VISUALIZING GREENER SPECIALTY METALS

The specialty metals industry loses hundreds of millions of dollars a year to the inefficiencies of one crucial but poorly controlled secondary purification process known as vacuum arc remelting (VAR). A Department of Energy-developed monitoring technology known as arc position sensing may be the first step forward from VAR in 65 years.

TOP 5 ROBOT JOBS IN MANUFACTURING

Smarter, smaller, more collaborative robots are being used on factory floors to perform more delicate and complex tasks, including assembly and inspection.

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

5 GREEN TECHNOLOGIES THE U.S. HAS NOT ADOPTED

American technology gets greener every year and holds its own when compared to other countries. But when it comes to smaller advancements, at the individual, household, and municipal level, many eco-friendly technologies that have blossomed overseas have yet to take hold in the U.S. Among them are thermosiphons and cogeneration units.

THOUGHT-CONTROLLED ROBOT ARM

There now is a way to make robots obedient to thoughts without the requirement of brain surgery.

NEXT MONTH ON ASME.ORG

NUCLEAR POWER: SAFETY AND RELIABILITY

Dr. Jovica Riznic of the ASME Nuclear Engineering Division discusses safety developments in the nuclear power industry, with particular attention to his home country of Canada.

SAILING TOWARD CHEAP ENERGY

A British Columbia startup thinks one of the oldest methods of capturing energy may be the answer to providing cheap electricity to developing nations as well as the developed world. The system is based on sails, which capture energy from the wind to propel boats.

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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

AS SILOS CRUMBLE INNOVATIONS GROW

On a scale of 1 to 10, how's 2017 trending for you so far? Ask me that question about the state of innovation and I'll say that in the first six months of this year it feels as though we are drinking from a fire hose. The technological breakthroughs never stop.

So sometimes it's hard to choose what to cover. But we can rely on the lens of the vast organization that publishes the magazine, ASME. A couple of years ago our Board of Governors selected five broad areas as the Society's focus points: clean energy, advanced manufacturing, robotics, bioengineering, and pressure technology. Each area is rich in evolving technologies.

Clean energy, which includes nuclear power, has enormous potential to supplement legacy fuels in the coming decades. Data from the U.S. Energy Information Administration shows that while some 60 percent of global energy demand is still met by burning coal and petroleum fuel, the market for clean energy is large and growing. Moreover, these ascending systems often spin off new technologies of their own, such as the emerging energy storage market which is expected to reach $400 billion by 2020.

New technologies in digital and additive manufacturing are transforming traditional manufacturing, and the business model is changing with it. Consider that the number of workers needed to produce $1 million worth of products fell to 6.5 in 2016 from 25 in 1980. Yet not all these changes take a quarter of a century to play out. Among manufacturers of hearing aids, for instance, 3-D printing took over the market for customized earpieces in only 18 months. Additive manufacturing is also growing in sectors such as aerospace, automotive, energy, and fashion.

Robotics is divided into industrial robots and service robots, and both are growing more capable and easier to use as prices fall. This makes industrial robots much more appealing to smaller manufacturers. Service robots include drones, autonomous vehicles, healthcare robots, and security systems. Traditionally, this market was driven by military drones, but commercial applications have grown to include warehouse management and unmanned monitoring of everything from vineyards to infrastructure—even photo shoots at weddings.

Since the 1950s, the burgeoning area of bioengineering has seen tremendous technology gains. Life-saving and life-enhancing devices from pacemakers to prosthetics have improved the lives of millions of people. Today, engineers are leveraging the explosion of knowledge about biology to create technologies such as tissue engineering and organ preservation that combine biological systems with mechanical engineering knowledge.

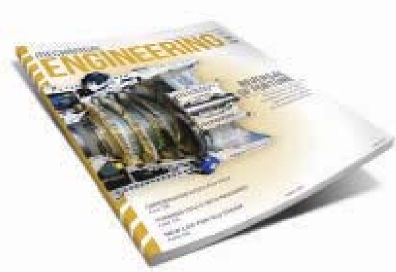
In pressure technology, the efficiency of pumps and valves continues to improve. Moreover, new materials such as carbon fiber are replacing metal cylinders in composite pressure vessels. Composite pressure vessels are also expected to find wide application in hydrogen and compressed natural gas storage, especially in vehicles.

Many of these innovations demonstrate how the silos that once permeated engineering have almost completely crumbled. The result is a new wave of possibilities. Today, teams of interdisciplinary engineers are working hand-in-hand with nonengineers to turn that potential into practical products and technologies. The results already amaze me. I can't wait to see what happens in the next six months. ME

FEEDBACK

What do you consider to be today's ascending technologies? Email me.

falcionij@asme.org



LETTERS & COMMENTS

APRIL 2017

Reader Laudenat praises Lee Langston for his discussion of compressor stall.

« One reader touts the advantages of waste-to-energy plants, while another warns about the human cost of automation.

LEAD DESIGNER

To the Editor: In the October 2016 issue, I noticed that evolution is cited as the reason that biomimicry is so successful in helping to solve engineering problems ("Can 3-D Printing Go Green?" by R.P. Siegel).

In every example given, the mechanisms or systems found in nature are stronger, more efficient, quicker reacting, or more sensitive than the man-made engineered systems being developed. Mr. Siegel states, "Life has evolved for billions of years while solving myriad problems associated with thriving on this planet."

I find this to be quite counterintuitive.

No one would suggest that if you gave a team of engineers unlimited time to solve a problem or design a system, they could sit back and do nothing since the solutions and designs would materialize out of thin air.

On the contrary, we understand that vast amounts of planning, resources, and effort are necessary to develop well-engineered solutions to problems.

Yet, by citing evolution as the means by which nature's unfathomably complex designs are created, the writer proposes that nothing more than random chance and time are necessary to create the amazing systems and structures found all around us.

I enjoy reading how nature is repeatedly used as the inspiration for innovative new engineered systems, but I am unable to honestly come to the same conclusion presented—that evolution, and not a supremely capable Creator, is the source of nature's incredible designs.

Matt Highstreet, P.E., *Sacramento, Calif.*

WASTE NOT

To the Editor: The article by Bucky Kitto and Larry Hiner in the February 2017 issue ("Clean Power from Burning Trash") presented a compelling argument for waste-to-energy (WTE) as a viable component of a national strategy for clean renewable power in America. I would like to extend my sincere thanks and appreciation to the many mechanical engineers, both abroad and in the U.S., who have been diligently advancing the state of the art for the modern WTE industry over the past 25 years.

I am a longtime member of ASME with 27 years of experience in the waste-to-energy industry, and I believe modern WTE should be the preferred option for anchoring an integrated solid waste management system.

In addition to providing an efficient, proven, and affordable approach for communities to responsibly manage waste within their jurisdiction, WTE also maximizes the production of renewable energy from waste, producing two to three times the energy that can be recovered from capture of methane gas from landfills. The volume of waste is minimized and the ash can be recycled by local construction aggregates and feedstock for manufacturing of Portland cement.

What's more, WTE has minimal land use impacts. A waste-to-energy facility can meet the current and future needs of a community on 25 to 50 acres, far less than the hundreds, and in many cases, thousands of acres which have already been consumed by landfill disposal.

Paul L. Hauck, P.E., *Tampa, Fla.*

ONE OF HIS BEST

To the Editor: In my career in the power generation business I have been associated with both aircraft and industrial gas turbine operation. I consider the Lee S. Langston article in the April 2017 issue, "Out Through the Intake," to be an outstanding contribution to the general engineering community to explain stall and surge in gas turbines, discuss the consequences of these events, and describe current industry activities to help mitigate stall events in various applications of gas turbines.

The article provides professionals associated with the operation of gas turbines a more in-depth understanding of the compressor stall process and an understanding of the ramifications of stall and surge in an operating environment.

Lee Langston is a frequent contributor to *Mechanical Engineering* and his articles are always of great interest and relevance to the mechanical engineering community. This was one of his best. I look forward to his next article with great anticipation.

The ASME continues to lead many important conversations regarding mechanical engineering issues in *Mechanical Engineering* magazine; the entire staff deserves a "shout out" for a job well done.

Richard T. Laudenat, P.E., *East Haddam, Conn.*

REPLACEMENT BRAINS

To the Editor: Jeffrey Winters's Trending article on automation ("By the Numbers: Taking the Tasks," April 2017) is well done and most interesting. However, he relies on a McKinsey study that states, "rather than being a job killer, the wide deployment of automation will boost productivity."

This is sugar coated. The Luddites were wrong about the industrial revolution but AI had not been born. The high productivity of future economies will be with maximum chip control and minimal human input.

Not only is human muscle being replaced, but also human thought, decision-making, and learning as well. An inexpensive Watson on a chip will upend how we live. For example, only this morning, a headline in *The Wall Street Journal* read, "BlackRock Shake-up Favors Computers Over Humans." Seven stock fund managers will lose jobs.

Self-driving vehicles will obsolete millions of taxi and truck drivers. Job opportunities for paralegals and associate lawyers are declining already. Brick-and-mortar store sales clerks are being ousted by Amazon. Customer service is now provided by algorithm (rather badly to be sure). The trend lines are plain.

We engineers are complicit in bringing about a world where employment will be minimal.

Future society must be organized differently, if it is not to be dystopian. A guaranteed annual wage for all is probable. Intellectual activities and what we today consider leisure activities will be the stuff of daily life. Along with some work for the few, probably an engineering elite.

Edward J. Kaliski, PE, *New York, N.Y.*

NOX IN EXHAUST

To the Editor: In his April 2017 rebuttal to my letter in the August 2016 issue, Shawn McCullough stated that many standards apply to jet aircraft emissions. But McCullough missed my point: There are no numerical restrictions on NOx discharge. NOx represents only .05 percent of jet exhaust, but since it has 300 times the greenhouse effect of CO_2 the combined exhaust from jets is 2.5 times that of CO_2 alone.

Climate scientists have generally dismissed the effect of NOx on climate change and global warming. However, in 2015 jet aircraft released 600 million tons of CO_2 into the upper atmosphere. Combined with NOx, the greenhouse gas equivalent of total aircraft emissions is 1.5 billion tons, and it is increasing by around 5 percent per year. In addition, these gases can stay in the upper atmosphere for as long as 100 years.

NASA, NOAA, or some other agency should go up seven miles and measure how much greenhouse gas is up there.

Henry Huse, *Norwalk, Conn.*

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.

SHAPE SHIFTING

ENGINEERS DEVELOP A MEANS TO CONTROL THE CURVATURE OF PLASTICS USING JUST INK AND HEAT.

Researchers have designed and built small, self-folding structures for years. But the shapes that they could design have always been limited by the straight-line hinges embedded into the material. Geometric solid shapes like cubes and pyramids were easy; more complex, flowing shapes were impossible.

Now, a team of engineers at North Carolina State University in Raleigh has developed a technique using black ink to make 2-D plastic sheets curve into 3-D structures, such as spheres, tubes, bowls, and even more complex shapes. Michael Dickey and Jan Genzer, professors of chemical and biomolecular engineering at N.C. State, published their paper in the Royal Society of Chemistry journal, *Soft Matter*.

"The project really started with (students Russ Mailen and Amber Hubbard) just trying different ink patterns in the lab. We thought it would be interesting to use thermoplastics since they are used for many applications in everyday life," Dickey said. "We want to create materials that are initially flat and then transform into 3-D objects in response to some stimuli, such as light, heat, or microwaves."

To make their curved shapes, the team used a conventional inkjet printer to print bold, black ink lines onto a pre-strained plastic sheet. The printed sheet was then cut into a pattern and placed under a heat lamp. The black lines absorbed more energy from the light than the rest of the material, and the plastic heated and contracted at those points, creating a hinge around which the sheet can deform.

"Consider the challenge of wrapping a soccer ball with wrapping paper. It is impossible to do without crumpling the paper," Dickey said. "The only way is with material that can deform. We are essentially using the ink to dictate where the sheet deforms in response to light, and create curvature."

By varying the width of the printed hinges, the researchers can adjust the

Engineers have used black ink and a heat lamp to induce sheets of thermoplastic to fold and curl into complex shapes (top and below).
Images: N.C. State University

length and speed of the folds.

Dickey and Genzer were inspired by nature: natural shapes rarely incorporate crisp folds. The team was also encouraged by watching children, who play with self-folding materials without any preconception.

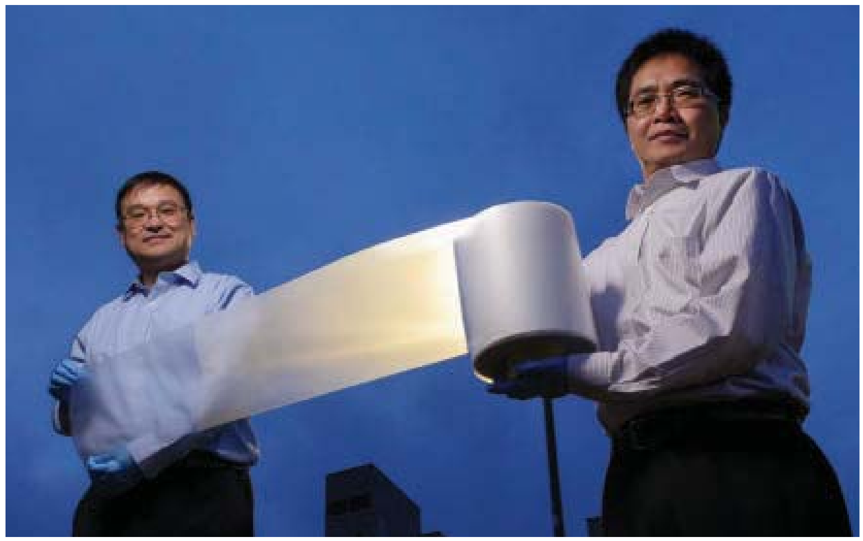
"We realized the ink did not have to be confined to a line, but could be more complex," Dickey said.

By using thermoplastics rather than softer materials (which some researchers have tested as foldable material), Dickey's team was able to develop strong, stiff objects. After the heat lamp is removed, the objects will still hold their shape, another advantage of thermoplastics over soft materials, which deform easily. That rigidity is essential for developing practical applications.

The team is now fine-tuning a predictive computational model that can create patterns to print on to sheets to produce functional objects that have both gentle curves and sharp creases.

"We want to control the deformation to create more interesting shapes like spheres," Dickey said. "It's more challenging to start with a desired shape, then figure out how to form it. How do you pattern ink to make something into the shape of a Pringles chip?" **ME**

MEREDITH STETTNER is a writer based in Jersey City, N.J.



Xiaobo Yin (left) and Ronggui Yang, holding their building-cooling material.
Photo: Glenn Asakawa/University of Colorado

VERY COOL ROOF

When the sun beats down on urban rooftops, it causes multiple problems. Dark roofing material absorbs the sunlight and heats up, increasing the cooling load on the building while adding as much as 80 °F to the surrounding air temperature. According to one study, between 5 and 10 percent of summer electricity load is used to compensate for this urban heat island effect.

While some energy experts recommend simply painting urban roofs white to reflect away sunlight, two engineers at the University of Colorado in Boulder have developed a new material that not only wards off light, but also enables the building to passively emit its own heat, reducing the building's total cooling load.

The engineers estimate that less than 20 square meters of the material on the roof of a single-family house could keep it cool on a summer day.

Mechanical engineering professors Xiaobo Yin and Ronggui Yang were looking at eco-friendly ways to cool thermoelectric power plants and improve their operating efficiencies as part of a $3 million ARPA-E grant. They hit upon the idea of using a metamaterial, which combines materials in a novel way to create something with properties not found in nature.

The engineers mixed minuscule silica glass spheres into a transparent thermoplastic polymer called polymethylpentene, or TPX. They then layered the mixture onto a thin sheet of reflective silver. Sunlight passes through the clear TPX, reflects off the silver, and then scatters back toward the sky due to the glass beads. Hardly any sunlight is absorbed.

At the same time, the silica beads radiate away some of the building's heat as infrared radiation. That sort of passive cooling, which

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Engineers are exploring the limits of mixed reality systems in design and inspection.
Image: Microsoft

MIXED REALITY CHANGES HOW ENGINEERS WORK

A bridge spanning the Delaware River that connects the New Jersey Turnpike with the Pennsylvania Turnpike was abruptly shut down earlier this year when inspectors on site discovered severe structural deficiencies. New mixed reality tools and equipment could have avoided that closure. Rather than working on site, engineers or inspectors would be able to view the bridge remotely through a visual headpiece to identify problems or collaborate with workers on site in real time. Using mixed reality tools, engineers in other disciplines could also work differently as the tools upend the design process.

Holographic computing is the gamechanger, and Microsoft's Hololens is the vanguard of the new order. The device is a wearable holographic computer operating on a specialized version of Windows 10. It enables users to interact with 3-D holograms generated from a separate processing unit that calculates where 3-D graphics exist in the user's physical space. Users can pin holograms to physical objects using gesture, gaze, and voice commands.

"This bridges the gap between digital and physical," said Aviad Almagor, director of mixed reality at Trimble, a Sunnyvale, Calif., developer of positioning products. The company was one of the first to develop an app for Hololens, called SketchUp Viewer, a version of its existing 3-D modeling platform for architects and engineers. "Its value in the field may be bigger than in the office. It completely changes the way you work on site."

As 3-D modeling has matured, engineers and researchers have been looking for methods to move 3-D models from the tether of 2-D screens and desktop or even laptop computers. The development of virtual and augmented reality met that challenge—to a point. Using headsets, virtual reality programs immerse the user in a virtual setting where you are not aware of the real, physical world around you. Augmented reality enhances the world by overlaying digital information on top of vision.

"WITH MIXED REALITY, YOU CAN TAKE THE CONTENT OUT OF 2-D AND INTO THE PHYSICAL WORLD."
AVIAD ALMAGOR, DIRECTOR OF MIXED REALITY AT TRIMBLE

Civil engineers, manufacturing engineers and others have been using virtual reality to design things like buildings and cars on monitors or large screens for some time. Firms have invested in CAVE technology, where design teams can view virtual images projected on the walls of a room and make design changes virtually, saving money on physical models and speeding up design.

Hololens improves on that, allowing the user mobility and the ability to collaborate remotely. Unlike virtual reality, it projects images onto the lenses where they are perceived to exist together with real-world elements. The images are interactive; using voice or hand commands, users can alter the images, or extract layers from within an object.

"As a technical achievement, this is by far the best," said Ioannis Brilakis, director of the Construction IT Laboratory at the University of Cambridge in England. Brilakis and his team worked with Trimble to develop two Holo-

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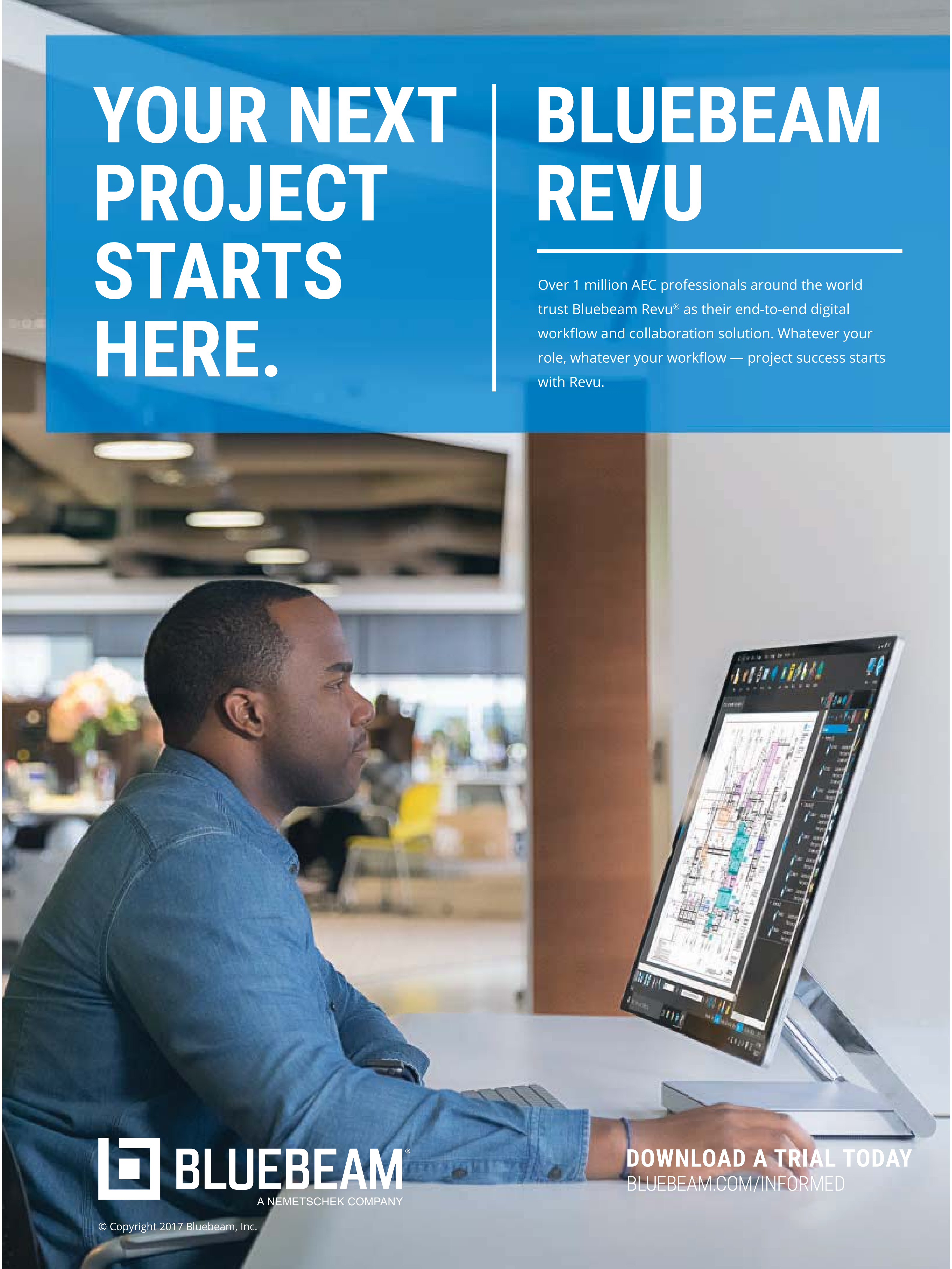
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A LOW-COST HEAVY-DUTY FARM TRUCK

The versatile AgRover is the Swiss Army knife of African farm machinery.

A newly minted workshop in Lagos, Nigeria, is manufacturing some of the most versatile farm trucks on the planet. AgRover is a three-wheeled vehicle built to solve a long list of problems on Sub-Saharan African farms. It can haul up to 900 kg (2000 lb.) of produce, water, or people at a top speed of 32 kph (20 mph). But it is also a multi-purpose platform. Farmers can open a panel on the truck to access its 4-8 kW diesel or gas engine and attach tools that perform specialized work around the farm.

"We have used it to power water pumps, maize grinders, and threshing machines. Anything that is belt- or pulley-driven. We've also used it to pull two-row planters and light tillage plows, either with a ball hitch or, with a dolly or some modifications, a three-point hitch," says David Wilson, co-founder of Mobile Agricultural Power Solutions (MAPS), the company behind the AgRover.

For now, MAPS makes only the vehicle, leaving attachments to third-party manufacturers. But custom attachments are in development at Purdue University in West Lafayette, Ind. MAPS recently spun off from the university's research program, the Purdue Utility Platform, to commercialize the AgRover. The company is now seeding manufacturing enterprises in Sub-Saharan Africa. Wilson estimates the vehicle could sell for about $5,000.

AgRover's design and manufacture check the boxes for responsible engineering for global development. To start, the idea for the vehicle originated with farmers in Cameroon. Its design and previous prototypes were a collaboration between African and North American farmers, engineers, and students. All its parts are locally available in the country of manufacture, and the business model depends on fostering local entrepreneurs with the capacity to build, sell, and repair what they make.

The AgRover was designed in collaboration with the farmers who would use it.

The AgRover began as an open-source basic utility vehicle, or BUV, designed and built by the Institute for Affordable Transportation, a nonprofit organization based in Indianapolis. In 2007, IAT shipped a BUV to the African Centre for Renewable Energy and Sustainable Technologies (ACREST) in Cameroon.

That early BUV model was made from new materials and recycled parts salvaged in the United States. Its composition made it difficult to repair and replace parts in Sub-Saharan Africa. ACREST requested a redesigned model, and John Lumkes, a professor of agricultural and biological engineering at Purdue, and his students responded.

"We now have vehicles in Cameroon, Guinea, Kenya, and Uganda," Lumkes says. "In Cameroon our partner [ACREST] has an order for five units from the government for refuse collection in urban areas, and we have multiple vehicles in service and used daily."

To meet the need for a smaller version of the AgRover, the Purdue team is in the midst of designing what they call the Mini-PUP. The team plans to continue developing the Mini-PUP and accessory tools to work with the AgRover.

In the meantime, the MAPS team, which is manufacturing the AgRover, hopes to expand production in Nigeria within the year. ME

ROB GOODIER is managing editor at Engineering for Change. To read more about development engineering, go to Engineeringforchange.org.

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TOOLS: MIXED REALITY

lens apps for the engineering/construction industry.

While engineers have embraced technology such as building information modeling and more, he says contractors and others have been slow to adopt the new technology. That is changing, and rapidly, he says. The apps his team has developed target bridge inspectors and engineers.

Microsoft's Hololens system projects 3-D images into physical space.

One app, called Project Monitoring, projects 4-D design models and places them over the actual structure as it is being built. An onsite inspector can view the models through Hololens and identify issues and solutions while an office-bound engineer fitted with the device sees the same image and advises.

The second app is for bridge inspections. Workers at the site take photos of the entire structure using digital single lens reflex cameras or laser scanners and upload the images to a cloud service. From there, engineers import them to the Hololens, which stiches the images together to build a comprehensive model of the entire structure. Using the Hololens, engineers or inspectors in the office can call on the full image, extract layers or details, and walk around the hologram to detect structural anomalies.

By using the app, engineers will reduce costs and time needed for accurate inspections, Brilakis said. He also pointed out that the ability to zoom in on different parts of the structure as well as small details not easily accessible for physical inspection promise better diagnosis.

"One question is, how much accuracy do you need?" Brilakis asked. "We've got it down to plus or minus five millimeters accuracy. We could get it to one millimeter. Do you really need that?"

"This is a new wave of technology," Almagor added. "From PCs to the internet to mobile devices, we've consumed data in the same way, on a 2-D screen. 3-D is now a must-have tool, from mining to manufacturing. For the first time now with mixed reality, you can take the content out of 2-D and into the physical world." ME

JOHN KOSOWATZ is senior editor at ASME.org. For more articles on engineering tools, go to ASME.org.

WHY PATENT?

You never know which ideas are **the most important to protect.**

The United States Patent and Trademark Office has now granted more than 9 million patents. The main idea behind pursuing a patent is to provide the legal basis to keep competitors from using your technology, but a recent study found that only about 2 percent of patents are ever used in litigation.

You couldn't fault a program manager, then, for questioning why his company strives for quality patents or even wondering why the company is incurring the significant costs associated with patenting the company's technology at all. The odds are, the patents will never be litigated, and if you do litigate there is also a fair chance your patent could be held invalid or not infringed upon.

I spend a fair amount of time building patent portfolios, conducting due diligence patent studies, and keeping my clients clear of charges of patent infringement. Based on that work, I have some good reasons for believing that patents are still a good thing.

For some technology companies, their intellectual property is often their most important assets. Banks and venture capitalists will want to inspect this IP before investing and a possible acquirer will surely be put off if there is no protection for the technology being purchased. I've seen deals fall through because, even though the technology at issue was highly coveted, the appropriate IP protection was simply not in place.

Second, a given patent may not be litigated against a competitor but it still might be reconnoitered by the competitor. I have been tasked many times to study a given patent (or patent portfolio) owned by a client's competitor.

I once had a client who wanted to develop a relatively simple kitchen product. The market was basically owned by one company with—count 'em—36 patents. Designing around one patent can be relatively easy. Designing around 36 patents is close to impossible. Two years later, the client concluded that designing around all 36 patents made for a product that didn't work very well and the project was scrapped.

Some patents, then, can cause competitors to shelve attempts at competing without any need for litigation. Those patents did their job.

I also have some clients who never manufacture anything. As technologists, their only revenue stream is licensing their patent rights.

Big corporations collectively generate billions in patent licensing revenue, sometimes licensing out patents covering technologies outside their core business sectors. Universities will often hold patents of ideas developed on campus, then license the patent to a startup—as often as not headed up by the professor or graduate student who hit upon the idea in the first place.

Even claims of infringement are often resolved through licensing rather than litigation. There is no hard data on the number of patent license agreements in existence but it is probably safe to say more patents are licensed than are litigated.

With all the bad press patents are getting lately, one might be tempted to rely on trade secrets. But trade secrets don't usually work with products. A competitor who reverse engineers your product, for example, rarely runs afoul of trade secret laws. Think you can encrypt or otherwise hide your secret sauce in your product? Think again: if it is that good, someone will figure out a way to expose it and then rip it off.

TRADE SECRETS DON'T USUALLY WORK WITH PRODUCTS. A COMPETITOR WHO REVERSE ENGINEERS YOUR PRODUCT, FOR EXAMPLE, RARELY RUNS AFOUL OF TRADE SECRET LAWS.

At the end of the day, the hard truth is that at the outset you never know which of your patents will be valuable enough to litigate.

Indeed, the aforementioned study concluded that (except for software) patents which were repeatedly asserted in infringement litigation lawsuits win more often than they lose. So, if you have 50 patents, the chances are that only one will ever be litigated. But it might be litigated a lot. As for the other 49, maybe they will do their job in other ways. ME

KIRK TESKA, the author of *Patent Project Management and Patent Savvy for Managers*, is an adjunct law professor at Suffolk University Law School and is the managing partner of Iandiorio Teska & Coleman, LLP, an intellectual property law firm in Waltham, Mass.

BETTER BLAST HELMETS FROM FLUID DYNAMICS

HELMETS DESIGNED USING computational fluid dynamics could help dampen shock waves and better protect soldiers from traumatic brain injuries.

Today's blast helmets do not adequately protect soldiers from high-pressure shockwaves produced when roadside bombs and other improvised explosive devices explode, and this failure has contributed to an epidemic of brain damage in the military.

Now, a team of engineers from North Dakota State University in Fargo has used engineering modeling software to show how blasts injure the brain despite the helmets—and to provide crucial clues for a much-needed helmet redesign that could protect soldiers from lasting brain damage.

Sixty percent of all traumatic brain injuries in soldiers are caused by blasts, and blasts injure via high-pressure shockwaves. These shockwaves injure the brain via a different mechanism than blunt-impact trauma. Like waves that reverberate around a swimming pool, shockwaves within the confines of a helmet can amplify each other to create powerful waves that move the brain within the confines of the head, said Mariusz Ziejewski, an NDSU professor of mechanical engineering

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Q&A ANDREW "BUNNIE" HUANG

AFTER EARNING A PH.D. in engineering from MIT, Andrew "bunnie" Huang wrote a guide to reverse-engineering Microsoft's Xbox game console. The ensuing legal battle turned him into a leading figure in the open-source hardware movement, which promotes the right to tinker with and modify products and which supports designs without manufacturer-imposed restrictions. Huang's latest book, *The Hardware Hacker: Adventures in Making and Breaking Hardware*, was published this year.

ME: The terms "open source" and "hacking" are common in software and computer systems. Do those terms change when you start to talk about hardware?

A.H: Mapping open-source concepts onto hardware is difficult. There's a notion in open source that you can build an entire toolchain and OS from source.

It's impossible to do that in hardware—ultimately, to build hardware, you need tools and machines, and the makers of those tools and machines are typically unwilling to share their blueprints. This limits the ability to independently replicate hardware "from source." As a result, the open-source hardware community has proposed the notion of "layers of openness," where one declares their design is open down to a certain abstraction layer. For example, a circuit board could be open to the schematic and layout layer, but the chips on it may be closed-source, and the tools used to draft the circuit board's design could also be closed source.

ME: Does the prospect of the Internet of Things make the right to control and modify gadgets more important than ever? The idea of being surrounded by Internet-enabled objects loyal to a third party seems a bit frightening.

A.H: Absolutely. The IoT and the prospect of updates being pushed to your gadgets—updates that can contain kill codes, planned obsolescence, lock-outs, and downgrades—means more than ever you should be vigilant and defend at the very least the right to opt-out of an update. While currently there are few instances of bad-faith updates being pushed by vendors, at some point the picture won't be so rosy. If you've pushed your entire identity, net worth, and social network into one vendor's cloud stack, you'll be stuck between a rock and a hard place when they decide they need more money to meet quarterly revenue targets.

ME: In your recent book, you write about visiting high-tech manufacturing plants and—of all places—a zipper factory. Do you think engineers would benefit from spending more time observing how humble objects are made?

A.H: Totally. I learn so much from the humblest of factories. When I take students to China to introduce them to manufacturing, I make a point, in fact, to show them some of the humblest shops, because that's where the real innovation lies. Using a six-axis Kuka robot and computer vision to solve problems is almost cheating, because you really can't afford to throw a six-figure hammer at every production problem. When you're selling products at razor-thin margins, efficiency and amortization matter, and the humblest factories know that better than anyone else.

ME: How much overlap is there between open-source hardware and the Maker Movement? Is it possible to have one without the other?

A.H: The Maker Movement is nominally about empowering everyday people to rediscover the art of building things. Without the ability to share blueprints, it would be hard to disseminate information. That being said, the U.S. is particularly fond of licenses and legal systems. In other countries and cultures, Maker-style activities thrive despite there being no proper "open-source hardware" license or community. In those cultures it's hard to enforce—and people don't care—about proprietary licenses as much.

ME: What lesson have you learned from hardware hacking that you might not have learned from a more conventional career?

A.H: The same toolbox you use to solve engineering problems can also be applied to solve certain classes of legal problems.

JEFFREY WINTERS

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CFD: BRAIN PROTECTION

who worked on the research.

The traditional helmets and face shields don't provide much help. They offer some protection from blasts that originate in front of the head, but for blasts coming from the side and back, they can actually make things worse, Ziejewski said.

To protect the head from shockwaves, the key is designing a helmet that prevents the wave from entering, Ziejewski said. "This is very different protection than we are used to thinking about when we think about a helmet."

To design a more protective helmet, Ziejewski and his colleagues first needed to test how today's helmets protect the brain from shockwaves. He and a team of engineers led by Hesam Sarvghad-Moghadam, a mechanical engineer at Harvey Mudd College in Claremont, Calif., developed a computational model to measure stress and strain on a structure.

In their computer model, the team simulated a TNT detonation producing a blast with the force of a car bomb a bit more than one-half meter from a soldier's head. When the simulated blast came from the front of the head, the use of a helmet and face shield together reduced the strain, or deformation forces, on the brain by 15 percent. When the blast came from the side of the head, the combined protective gear reduced the strain by 18 percent.

But for a blast from the back of the head, the protective gear actually increased the strain by 9 percent.

Using a helmet alone was worse: A blast from the side of the head increased strain by 39 percent compared with no helmet.

The team postulates that pressure waves can penetrate the protective gear through the gaps near the back and side of the head. As they do, the waves ricochet off the helmet and face shield and amplify, imposing more forceful pressure pulses on the head.

To better protect the head, Ziejewski thinks adding a shield at the back of the helmet could deflect shock waves away from the head. Alternatively, adding shoulder supports could offer additional protection against blast-induced brain acceleration. "We have to think of this like fluid dynamics and flow," he said.

Either way, computational models like theirs could point the way toward a redesign that accounts for the current deficiencies in protective gear, Ziejewski said. And helmets designed using fluid-dynamics principles could help slow the epidemic of traumatic brain injury in today's military. ME

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CHINA SHALE GAS BOOMS

China is known for its reliance on coal power, but the country is moving toward cleaner fuels. The Xinhua News Agency reported that production of shale gas reached 1.15 billion cubic meters in March, a 50 percent increase over the same month in 2016.

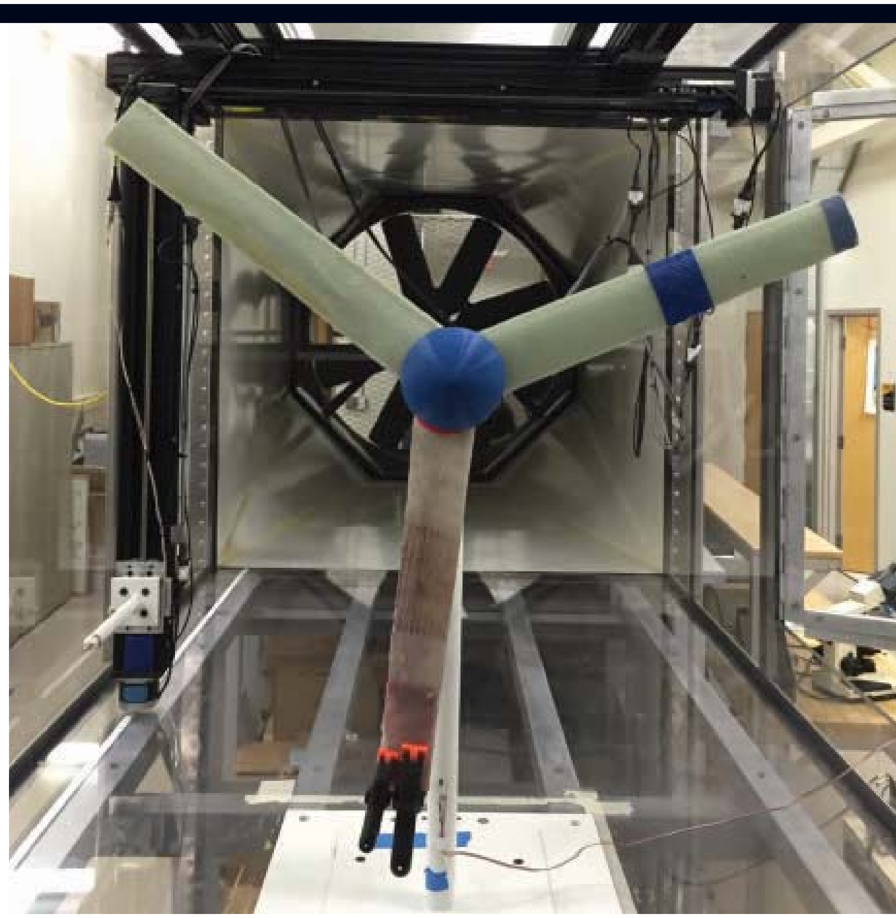
For the first three months of 2017, the country produced 2.67 billion cubic meters.

The country has expanded production in the Changning-Weiyuan national-level shale gas pilot zone in southwest China's Sichuan Province, run by the country's oil and gas giant, China National Petroleum Corp.

China hopes to tap a reserve of shale gas estimated to be more than 1.5 trillion cubic meters.

Total natural gas production in China—both conventional and unconventional—is projected to be 170 billion cubic meters this year. That's still less than one-quarter of U.S. gas production, but it will be enough to make China one of the top five gas producers in the world. ME

SELF-HEALING WIND TURBINE BLADE



The self-healing blade (at bottom) in a wind-turbine testing rig.
Photo: University of Wisconsin-Milwaukee

Extreme weather, lightning strikes, manufacturing defects, delamination: those are just some of the factors that cause about 3,800 wind turbine blades to fail worldwide each year. That number represents just one in 200 of the roughly 700,000 blades in operation, but a single failure can cost up to $1 million in repairs, especially if the turbine sits miles offshore.

Mechanical engineers from the University of Wisconsin-Milwaukee hope to put a dent in that number with a new self-healing blade system that mimics the human circulatory system.

The self-healing system, developed by UWM mechanical engineering professor Ryoichi Amano and his colleagues, has passed proof-of-concept tests, but still needs improvements before it can hit the market.

The team reported the results online in March in ASME's *Journal of Energy Resources Technology*.

"The idea was to mold flat material samples, test them by bending, and see if the material could heal itself," said Arun Kumar Koralagundi Matt, a UWM graduate student.

"I'd say it was a success."

Koralagundi Matt and his colleagues first made samples with several layers of plain-weave fiberglass like that used in many wind-turbine blades. They mixed Grubbs' catalyst, commonly used in synthetic organic chemistry, with an epoxy resin, and evenly dispersed it throughout the fiberglass.

The researchers then filled ultrathin borosilicate glass capillary tubes as long as a fingernail with a liquid "healing agent" that causes the epoxy to harden when the two come into contact in the presence of Grubb's catalyst. They then laid the tubes lengthwise in different layers and sections of the fiberglass, depending on the test.

"Ideally, the tubes should act like blood vessels throughout the body," said Koralagundi Matt, who has since graduated and is now working as a product engineer at Carnes, an HVAC systems manufacturer in Madison.

The researchers then used a universal flexing machine and standard tensile tests to gauge the strain, stress, and other properties of the material.

As soon as they heard the fiberglass crack, the researchers ended each test and examined the areas of stress where the glass capillary tubes also broke. At that point, the healing agent would seep into the cracks near the tubes, react with the Grubbs' catalyst, and harden the epoxy.

The researchers also built and tested a wind turbine prototype, using two standard blades and one embedded with the self-healing system.

After stressing the blade and allowing it about an hour to complete the healing process, the material recovered about 90 percent of the flexural strength it had lost from fractures and other damage. That recovery was as good or better than that of similar self-healing materials and could add years to the life of the blade, Koralagundi Matt said.

Still, adding the tubes reduces the fiberglass's average tensile strength and flexural strength by 25 percent and 9 percent, respectively, and Amano's team is now figuring out how to add more tubes to the material without weakening it, and how to make the blades easy to manufacture as well, Koralagundi Matt said. **ME**

JEFF O'HEIR is a technology writer based in Huntington, N.Y.

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METAMATERIALS: COOLING

requires no electricity or water, is almost impossible to achieve in direct sunlight using normal materials.

"Controlling absorption of the sunlight is critical because you don't want the plastic to cook," said Yang, an ASME Fellow, noting that previous radiative cooling materials absorbed too much sunlight.

In field tests conducted in Arizona, the material had an average radiative cooling power of 110 W/m^2 over a 72-hour period and 93 W/m^2 at midday under direct sunshine. That power level is about the equivalent of the electricity generated by solar cells used under similar conditions. The material, however, provides continuous cooling.

"That's about the best you can get," Yin said of the results.

The material is 50 μm thick and is flexible enough to follow the contours of various structures and objects. Once the application process is fully developed, the engineers say the material could be mass-produced in rolls and used to cool power plants, data centers, cars, and outdoor electronic devices like security cameras.

"We can produce 100 square meters of this every hour in the lab, but that doesn't mean we're able to sell it today on Amazon," Yin said, referring to the challenges of commercialization.

The engineers, including Gang Tan, an associate professor at the University of Wyoming and a coauthor of the paper, recently published in *Science*, have filed a patent for the technology and plan to develop a 200 m^2 cooling system in Boulder sometime this year. ME

JEFF O'HEIR is a technology writer based in Huntington, N.Y.

VESTAS PLANS INDIA EXPANSION

Danish wind power giant Vestas is planning to triple its manufacturing capacity in India, with an announced addition to its plant in Ahmedabad over the next two years.

After the expansion, the Vestas plant there will be able to produce 600 MW worth of equipment.

India added around 5.4 GW in wind power capacity in 2016, increasing the country's total wind power generation capacity to 28 GW. The government has set a goal of adding another 32 GW over the next five years.

Vestas began building carbon-fiber wind turbine blades at its facility in Ahmedabad, in western India, in March. ME

TWO-HEADED PRINTING

Rize's printer produces parts that require no post-processing. Similar technology will enable it to make earbuds with rigid interiors and flexible exteriors.
Photo: Rize Inc.

NEW ADDITIVE MANUFACTURING technologies are entering the market at a rate almost too fast to track. This month, we visit two labs developing innovative 3-D printers. One is working on a flexible system to eliminate post-processing, while the other has a unit that produces printed circuit boards.

Post-processing is 3-D printing's dirty secret, Frank Marangell likes to say. Marangell is president of Rize, a startup whose 3-D printed parts need little or no post-processing.

The problem comes from growing parts layer by layer. To improve their stability during growth, printed parts often include external supports. Even after cutting the supports away, it may take two or three hours to smooth a part by sanding or bathing in a solution.

"In some companies, post-processing is a production bottleneck," Marangell said. It is also expensive, since users are required to manage any post-production waste in an environmentally safe manner.

Rize's founder and chief technology officer, Eugene Giller, wanted to eliminate that bottleneck. Giller's vision was to create a system that would let users snap clean parts off from their supports. To reach that goal, Giller and his colleagues had to develop a 3-D printer, the Rize One, with two printing heads.

The first head applies a proprietary polyolefin polymer that resembles ABS, a standard industry polymer, but costs half as much.

MAKING POST-PROCESSING A SNAP

THE LAB Rize Inc., in Woburn, Mass. Frank Marangell, president; Eugene Giller, chief technology officer.

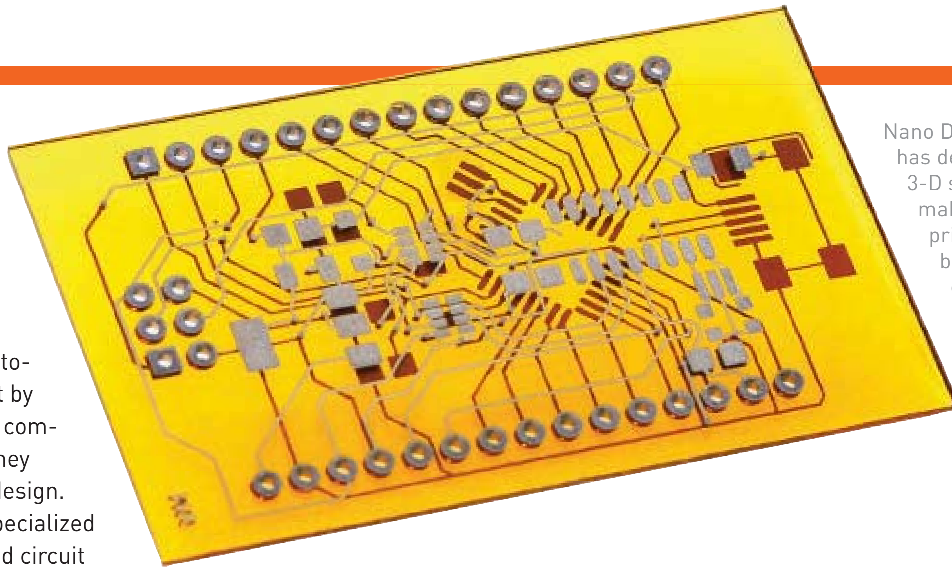
OBJECTIVE Produce a 3-D printer that makes photorealistic color parts with a range of mechanical properties in a single part.

DEVELOPMENT The Rize One printer builds parts that snap off cleanly from supports and require no post-processing.

The second print head is more interesting. It applies a chemically active ink to the support structure just before the part itself is printed. That ink weakens the bond between the support and the part, so that when users flex the part, it snaps off the support cleanly, leaving behind a smooth, level surface.

Similar print heads could deliver colored inks. Giller plans to build a system with three heads, each capable of delivering two colors, to make photorealistic pictures. So far, he has mastered a blue dye that diffuses into the fully dense matrix, allowing users to print text directly onto the part.

Giller is also working on additives to modify material properties, such as flexibility, only where they are deposited. Printers applying those additives could make customized hearing aids with rigid interiors and soft exteriors. **ME**



Nano Dimension has developed a 3-D system to make multilayer printed circuit boards that can survive soldering. *Photo: Nano Dimension*

When engineers build circuit prototypes, they start by wiring together chips and components manually. Then they outsource the debugged design. This is because it takes specialized equipment to make printed circuit board prototypes and manage the process' waste stream.

It seems like a perfect application for 3-D printing, but most printers cannot handle it. No wonder. PCBs are multilayer combinations of insulating materials and electrical conductors. Wires, or traces, run across layers and up and down the holes between them. It takes precision deposition and specialized materials to make consistent parts.

An Israeli startup, Nano Dimension, has developed an inkjet deposition system designed to manage those tasks. The new Dragonfly 2020 prints traces as thin as 80 to 100 μm, and interconnections down to 150 μm across. This is not as good as the best PCB processes, but it is well within the range of commercial PCBs, chief business officer Simon Fried said.

The Dragonfly does this by using two print heads. One applies the board's insulating body, and the second lays down the traces.

Both rely on advanced chemistry. The silver inks use a technology developed by Hebrew University's Shlomo Magdassi, that lets Nano Dimension control the shape and size distribution of 10-100 nm silver nanoparticles suspended in a solution.

The particles are fine enough to deposit on the PCB using a piezoelectric inkjet head. Because of their nanoscale size, the nanoparticles require less heat to sinter into a solid silver electrical trace. The researchers would prefer to work with copper, but it oxidizes too easily and loses conductivity.

The second print head applies the insulating layer as a spray of liquid resin that solidifies when activated by ultraviolet light. 3D System's stereolithography printers use a similar UV-sensitive resin. Nano Dimension's resins are strong electrical insulators that can withstand soldering temperatures to 350 °C.

Although it takes "several hours" to print a 10-layer PCB, that's far less time than it takes to produce a circuit manually and send it out to make prototypes, Fried said. **ME**

ALAN S. BROWN

PRINTING CIRCUITS ON THE FLY

THE LAB Nano Dimension, Ltd., Ness Ziona, Israel. Sharon Fima, chief technology officer; Simon Fried, chief business officer.

OBJECTIVE Create a 3-D printer that can manufacture multilayer printed circuit board prototypes that can withstand soldering.

DEVELOPMENT The Dragonfly 2020 3-D printer can produce a complex 10-layer PCB with electrical traces 80-100 μm wide.

INTELLIGENTLY CONTROLLED PROSTHETICS

A NEW MODEL FROM the U.K. will allow amputees to pick up their foot and walk up slopes.

The human ankle and foot has a combined 26 bones, 33 joints, and 100 tendons, ligaments, and muscles, making it one of the most complex parts of the body. Creating a prosthetic that mimics the behavior of so many moving parts is no easy feat, and designing a robotic system is even more complicated. But a new prototype developed in the United Kingdom is paving the way for some 40 million amputees worldwide walk again.

The new prosthetic, developed by U.K. prosthetics maker Chas A. Blatchford & Sons and University of Bath researchers, combines an electric hydraulic system with an intricate pattern of sensors that give the model a level of intelligence not yet available on the market. These components allow amputees to climb slopes effortlessly and plant their foot firmly on the ground without dragging it behind, a common problem for all lower-limb prosthetic wearers.

"The state-of-the-art lower limb prosthetics are sophisticated," said co-developer Andrew Plummer, who directs Bath's Centre for Power Transmission and Motion Control. "But they are passive. There's no energy input, and obviously, a normal human joint would not be passive. I think for a long time, there has been a desire to have intelligently controlled powered joints. But, it hasn't had any impact on the real products people can buy."

Plummer began collaborating with Blatchford five years ago to pursue a visionary approach: integrating the prosthetic with an electro-hydraulic actuation (EHA) unit, the same technology found in the F-35 jet fighter.

Hydraulic systems use a pump to pressurize a working fluid, which in turn moves a cylinder or similar actuator. Done right, it multiplies forces efficiently over a broad range without using cumbersome gears, pulleys, or levers. Unlike electric motors, hydraulic systems apply constant force or torque without continuous motor operation, and reverse direction almost instantly.

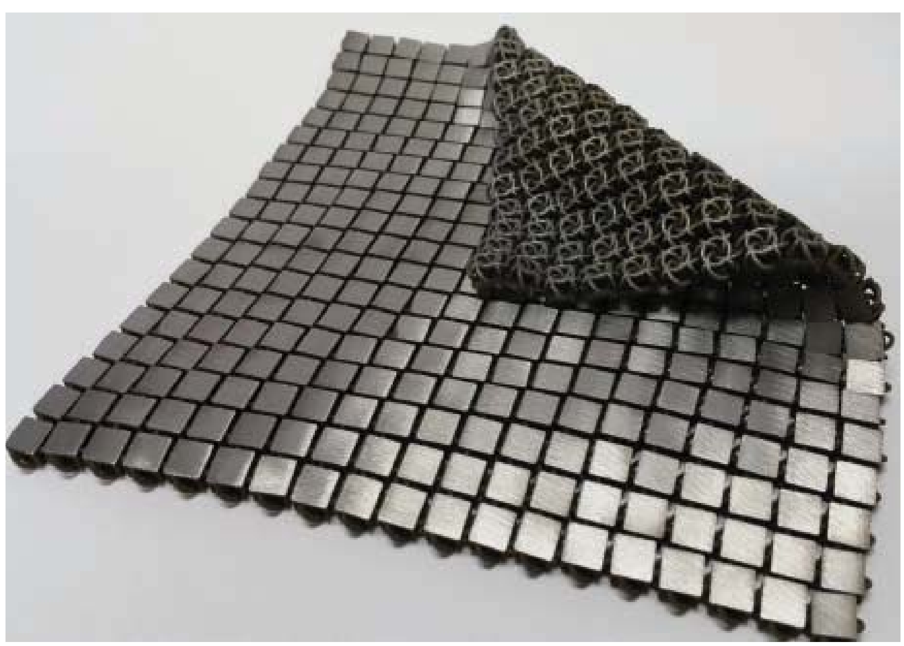
The problem with conventional hydraulics is that the pump, fluid, and actuator are three separate systems. Not only are they heavy and bulky, but also prone to leaks and spills.

EHA units, on the other hand combine those three elements within the same device. This reduces size, weight, and the need for maintenance. Its ability to retain pressure enables the prosthetic to conserve power while shifting fluidly between active and passive modes. The 48 V battery can last essentially an entire day, or, about 5,000 steps, Plummer said.

This is the key reason why the researchers chose EHAs over electric servomotors. "Other electric motorized prosthetics have to run all the time," said Jawaad Bhatti, a mechatronic engineer at Blatchford who worked on the device. "The EHA unit allows our prosthetic to only operate on the battery when it is

PRINTING WOVEN METAL

Weaving is one of humanity's oldest technologies, and additive manufacturing is one of the newest. NASA researchers recently announced that they had combined the two, unveiling woven metal fabrics that could be deployed—and even manufactured—in space. By using 3-D printing, researchers working out of the Jet Propulsion Laboratory in Pasadena, Calif., could create a material with different properties on each side. On one side, small metal squares provide a reflective surface that can ward off heat or focus radio waves, depending on how it's shaped. The other side consists of loops that were printed in a way so that they interlock without assembly. The fabric looks a bit like chain mail, and in fact one potential application is as a tough outer layer for astronaut space suits. ME



needed. With the electric ones, if the battery dies you can't walk at all. With ours, it just goes into passive mode and still functions quite well."

The researchers calibrate the sensors to the amputee's gait very precisely. Sensor data then goes to a computer equipped with a complex algorithm that allows it to respond rapidly to changes in stride and speed, powering up the EHA unit to help the amputee lift his or her foot off the ground.

"By studying the natural human walking gait, we've established that there are certain points within the gait cycle that are important for power input," Plummer said. "The key one is what we call 'toe off.' It's basically what's springing you forward at the end of the step. As you extend your ankle, you push forward. That being missing in a conventional prosthetic is quite a big drawback."

Without that push, amputees have to change the way they walk. This can lead to degrading damage in the leg, hips, and back—and even painful spasms or arthritis.

The engineers still have a few kinks to figure out. The most important involves fitting all the different components into a sleek, lightweight design. That starts with designing a smaller EHA unit to fit onto the joint of the ankle.

It also takes a lot of processing power to run the gait algorithm, so amputees currently carry the computer in a backpack. Ultimately, the researchers plan to incorporate it into the prosthetic.

"It really is one step at a time," Plummer said. "We have to refine the prototype, come up with a new one, and then another one. It's not a simple matter of just manufacturing it now."

The team hasn't announced a release date for the first product, but they are conducting human trials.

"Powered prosthetics like ours will allow amputees to behave more like people who don't have an amputation," Plummer said. "That's the driving force behind our research." ME

CASSIE KELLY is an independent writer. For more about biomedical engineering, visit aabme.org.

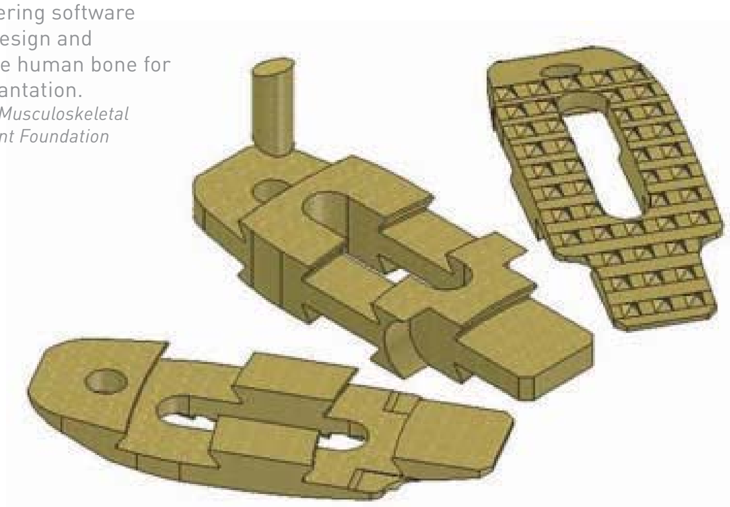
BIG NUMBER

18 million

TONS OF COAL CONSUMED IN THE UNITED KINGDOM IN 2016

BRITISH COAL HELPED SPUR the Industrial Revolution. But since the 1980s, the industry in the United Kingdom has been eclipsed by cleaner-burning North Sea oil and gas. A carbon-emissions tax is reducing coal consumption even more, with only 18 million tons burned in 2016, down 72 percent from 2012 levels. According to the consulting firm Carbon Brief, overall carbon-dioxide emissions in the U.K. last year were 381 million tons, equal to the nation's emissions in 1894.

DESIGNING BETTER BONE



Engineering software helps design and machine human bone for transplantation.
Images: Musculoskeletal Transplant Foundation

As a mechanical engineer for 13 years at the Musculoskeletal Transplant Foundation (MTF)—one of the nation's leading tissue banks—Manuel Olivos helped design and machine bone from deceased donors to fit each recipient and make tissue transplants more successful.

An innovative engineer, Olivos developed and helped patent a new method to design and assemble grafts that combine both of the two types of bone that we possess: compact, solid bone, also known as cortical bone, and spongy bone segments known as cancellous bone. To assemble the bone segments, he would custom-cut their ends, then join them together with a dovetail joint—an interlocking structure that carpenters use to join pieces of wood to make drawers or log cabins. Then he'd use a pin he developed to lock the bone pieces together, strengthening the implant further.

What Olivos never suspected was that he himself would be in the market for donated bone. For ten years, he had suffered from excessive headaches and neck pain, and after painkillers stopped working, his orthopedist recommended a spinal fusion.

Olivos's surgeon had already grafted bone donated by MTF into other patients. As it turned out, the bone he selected for Olivos's surgery was the very type of allograft, a graft from the same species, Olivos had designed and received a patent on.

"What made this allograft revolutionary was our ability to combine both cortical and cancellous bone. We were able to take the machining of bone to a whole new level," Olivos said.

Within six months of receiving the operation, Olivos was pain-free.

MTF was founded by surgeons in 1987 to provide better tissue for transplantation, and since then the organization has recovered tissue from more than 115,000 donors and distributed more than 7.5 million grafts for transplantations.

In the early days, surgeons used saws and other hand tools to machine donated bone into the right shape for transplantation, while MTF staff technicians used a three-axis hand-milling machine for this purpose, said Ray Ferrara, the organization's director of engineering for operations.

Over the last 20 years, they've been using engineering software to custom-design and machine the donated bone. Since 1996 they've used Solid Edge, the 3-D engineering design and simulation software from Siemens PLM, starting with Solid Edge v4. MTF's work represents an unusual application of the Solid Edge 3-D CAD software, which is typically used to design parts made of inert materials like metal, ceramics, and plastic.

Shaping bone for transplants is different. First, a surgeon requests donated bone for a specific purpose—for example, bone for spinal disc surgery like Olivos's fusion. MTF constructs a 3-D image of the bone needed to make a patient whole. After the surgeon and the MTF team discuss and tweak the model using SolidEdge's CAD capabilities, a design is locked in. Then they machine the bone using a custom-built CNC machine.

With spinal spacers like the one Olivos received, the fit of the spacer between the vertebrae must be geometrically precise. To achieve that precision, the MTF team tweaks bone-structure models in MasterCAM to precision before machining them, Ferrara said.

When they started custom-machining the bone, they were able to produce much more bone for transplantation. "Volumes really started to come up," Ferrara said.

"The bone is a donated gift, and we don't have much raw material to play around with," Ferrara said. "The whole goal is to use as much of it as possible."

To conserve the bone, the engineering they do is essential, Ferrara said. "Most people are fascinated that there is even engineering involved with tissue donation." ME

MEREDITH STETTNER is a writer based in Jersey City, N.J.

"OUR COMPUTERS ARE GETTING 10 TIMES FASTER every five years, and unless that trend breaks, it will only take 25 years until we have a recurrent neural network comparable with the human brain."

— German computer scientist Jürgen Schmidhuber, *quoted in the* Guardian *on April 18, 2017.*

ENGINEERS ARE ALSO CITIZENS

BY. R.M. GATES, PRESIDENT, AIR PREHEATER CORP., NEW YORK, N.Y.

The author, a past president of ASME, urged engineers to break out of their specialty focus and become engaged with the wider society.

It may seem that I am urging engineers to give up their jobs and devote themselves to politics, or at least to neglect their chosen profession for competition in another field already overcrowded with willing workers. Of course that is not at all my purpose. It is, rather, to suggest that too few engineers, as compared with members of other professions, are actively interested in public affairs as citizens of their respective communities and of the nation; that the engineering approach is too little utilized in the solution of problems of common concern outside of the conventional engineering field; and that engineers need to rethink their responsibilities as citizens in a society confused and floundering in efforts to adjust itself to new powers and new possibilities. Every engineer should find some time to give to civic responsibilities, and this without neglect of his professional duties. Engineering will benefit by the inspiration that grows out of these wider contacts.

One could find many engineers who have engaged actively in the life and service of their communities along lines having little or no relation to their professional activities. They have advanced philanthropy, worked in welfare activities, served as trustees of civic organizations or institutions, and led civic movements. They have maintained contact with the political machinery of their communities, served on political committees, and taken active parts in local political life.

But by and large is not a definite detachment from the political structure of our society—the basic structure, in a sense—the more common practice among engineers? In that detachment from the nontechnical world may be found the reason for some lack of recognition, by public authorities and by the people at large, of the variety of services which the engineering profession can render, and should be called upon to render, in the solution of community problems.

Since community organization is at the base of the whole structure of government, it is here that the engineer may well first try his wings as an active citizen. Responsibilities taken at this level lead to larger responsibilities he may be well qualified to take and may find satisfaction in taking. Thus an unfortunate gap in communication between our profession and the broad field of public service, unfortunate for the national welfare, may be gradually bridged.

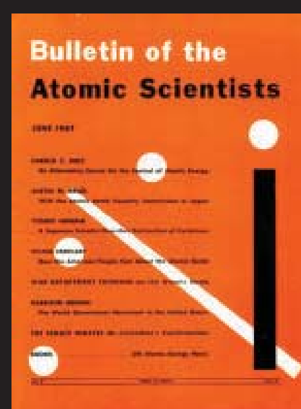
The Committee on Engineering Education, the Engineers' Civic Responsibilities Committee, and other committees of the Engineering Societies have been emphasizing this responsibility of engineers. They have recognized not only that engineering education must train prospective engineers as to their civic responsibilities but also that such education is futile if not followed up by active participation. The old adage that we learn by doing is no less applicable to the engineer as citizen than to the engineer as engineer. It is never, too late to begin. Indeed the responsibility increases as acquaintance, connections, and standing increase opportunity. ME

LOOKING BACK

The role of engineers in post-War America was being debated when this article was being published in June 1947.

ON THE CLOCK

How many minutes to midnight? Since it was first published in *Bulletin of the Atomic Scientists* in June 1947, the Doomsday Clock has tracked the waxing and waning of the threat of global nuclear war. The Clock was conceived by Chicago-based researchers who had worked on the Manhattan Project and has been maintained since 1947 by members of the *Bulletin*'s Science and Security Board. With global catastrophe as "midnight," the Clock's original setting in 1947 was seven minutes to midnight. It has been set both back and forward 22 times since, hitting two minutes (1953) and seventeen (1991). Since 2007, climate change and potentially harmful science and technology developments have also been reflected. This January, the Clock was advanced to 11:57:30, reflecting the rise of "strident nationalism" across the globe and the lack of political will to tackle climate change.



Cover of the June 1947 *Bulletin.* *Credit: Wikimedia*

BY THE NUMBERS: STARTING UP IN SMALLER CITIES

Can Tel Aviv, Stockholm, and Lagos go head-to-head with Silicon Valley?

STOCKHOLM, SWEDEN

Metropolitan population: **2.2 million**

Ecosystem value: **$15 billion**

Software engineer salary: **$55,000**

Early-stage funding per startup: **$325,000**

More is more. That's true when it comes to creating an environment that fosters startup companies.

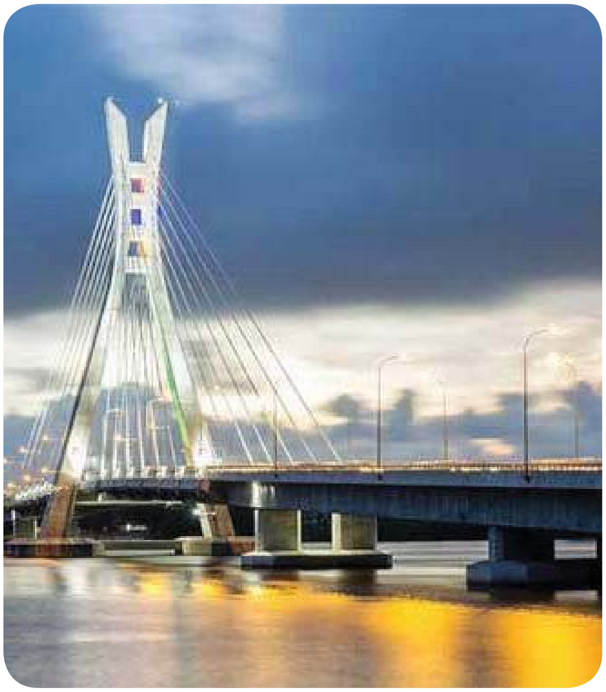
According to the research firm Startup Genome, the results of its recent survey of more than 10,000 startup leaders in 55 cities show that the best performing places bring together thousands of startups, billions in venture capital funding, and talent and experience from around the globe.

The firm's *Global Startup Ecosystem Report* discloses that startups in Silicon Valley, New York City, London, and Beijing dominate in terms of return for venture capitalists—a good measuring stick for which companies are the best performers.

Yet smaller cities on every continent have found a way to nurture startups.

Take Tel Aviv, the sixth-ranked tech ecosystem according to Startup Genome. Much like the early days of Silicon Valley, Tel Aviv used government and military investments to nurture its startup ecosystem. Today, the city is a global leader in cybersecurity and its roughly 2,500 tech startups exchange talent and ideas with more than 300 multinational R&D centers attracted by Israel's workforce.

Stockholm, ranked fourteenth, is another smaller city with big aspirations. The Swedish capital has produced more unicorns—the rare startup whose value reaches $1 billion—than any European city other than London. Because Sweden's domestic market is so small, Stockholm's 600 to 900 startups must grow internationally. Intriguingly, Stockholm startups report 75 percent fewer negative interactions with local corporations than startups in other European ecosystems.



LAGOS, NIGERIA

Metropolitan population: **21 million**

Ecosystem value: **$2 billion**

Software engineer salary: **$14,100**

Early-stage funding per startup: **$77,800**

TEL AVIV, ISRAEL

Metropolitan population: **3.7 million**

Ecosystem value: **$22 billion**

Software engineer salary: **$63,000**

Early-stage funding per startup: **$509,000**

Another city, Lagos, Nigeria, is by no means small—with more than 20 million people, it's the largest city in Africa—but its success demonstrates the portability of tech. The city's 400 to 700 startups generally focus on domestic opportunities created by Nigeria's explosive Internet growth. Lagos can provide access to experienced software engineers who earn one-quarter of the average global salary. That economic advantage has drawn the attention of Silicon Valley venture capitalists, who have funded several startups.

To be sure, Silicon Valley remains the top-performing tech ecosystem by a wide margin. It accounts for one-quarter of the world's unicorns and more than one-third of the money venture capitalists earn when they exit their investments. The region has the most experienced workforce, the deepest pockets, and the broadest reach into global markets.

And while Silicon Valley is outrageously expensive, the region still draws talent from around the world, including nearly half of its startup founders.

Yet challenges abound. Silicon Valley's recent growth came from prioritizing software over engineered products. Today, it needs engineering skills for robots, virtual reality, smart factories, and the Internet of Things—and it's not certain that Silicon Valley has the workforce to lead this next wave of development.

If a city like Tel Aviv, Stockholm, or Lagos can bring together a critical mass of engineering talent and entrepreneurial vigor, it may have a shot at becoming the Silicon Valley for the 21st century. ME

ALAN S. BROWN

CLEAN ENERGY

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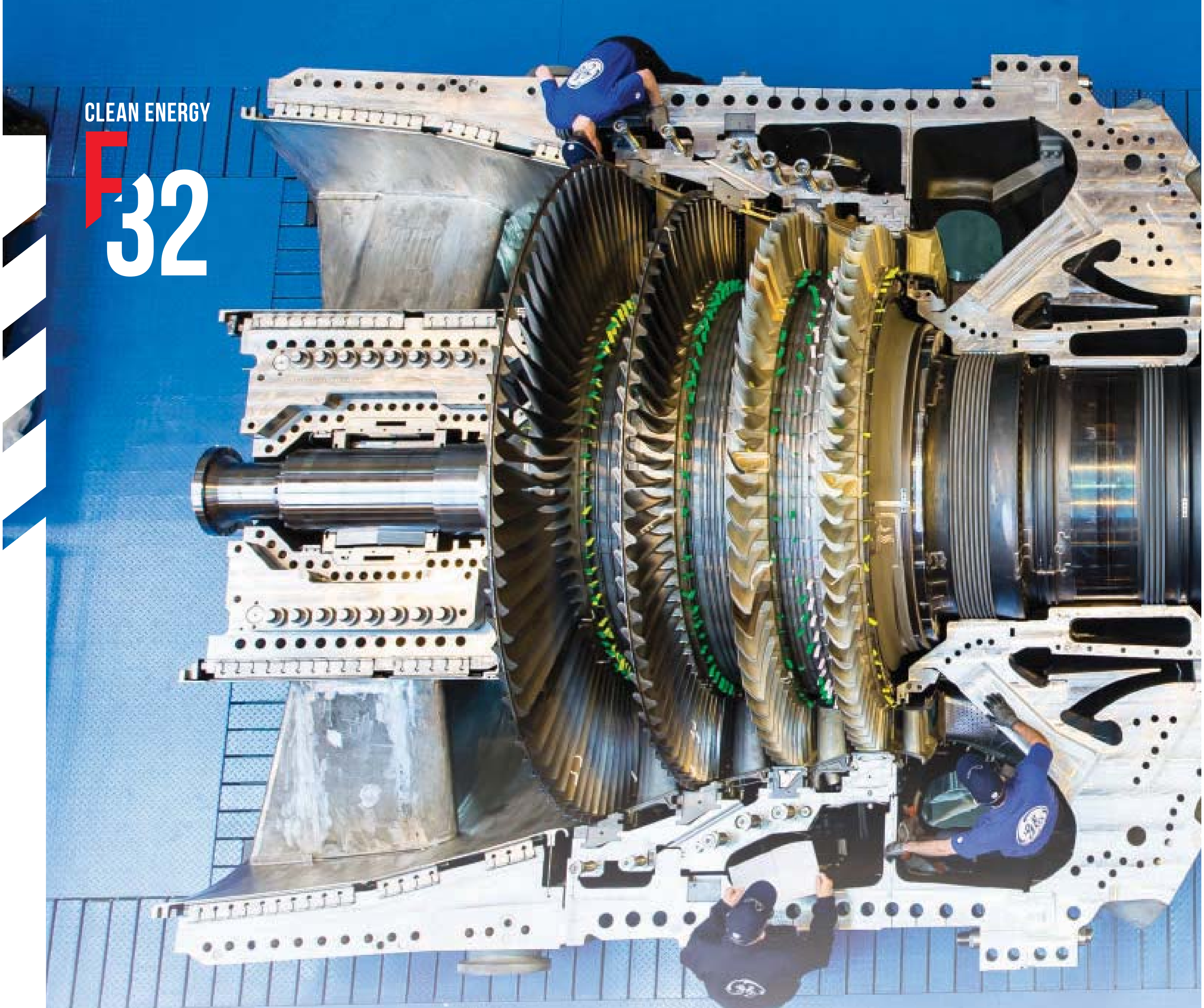
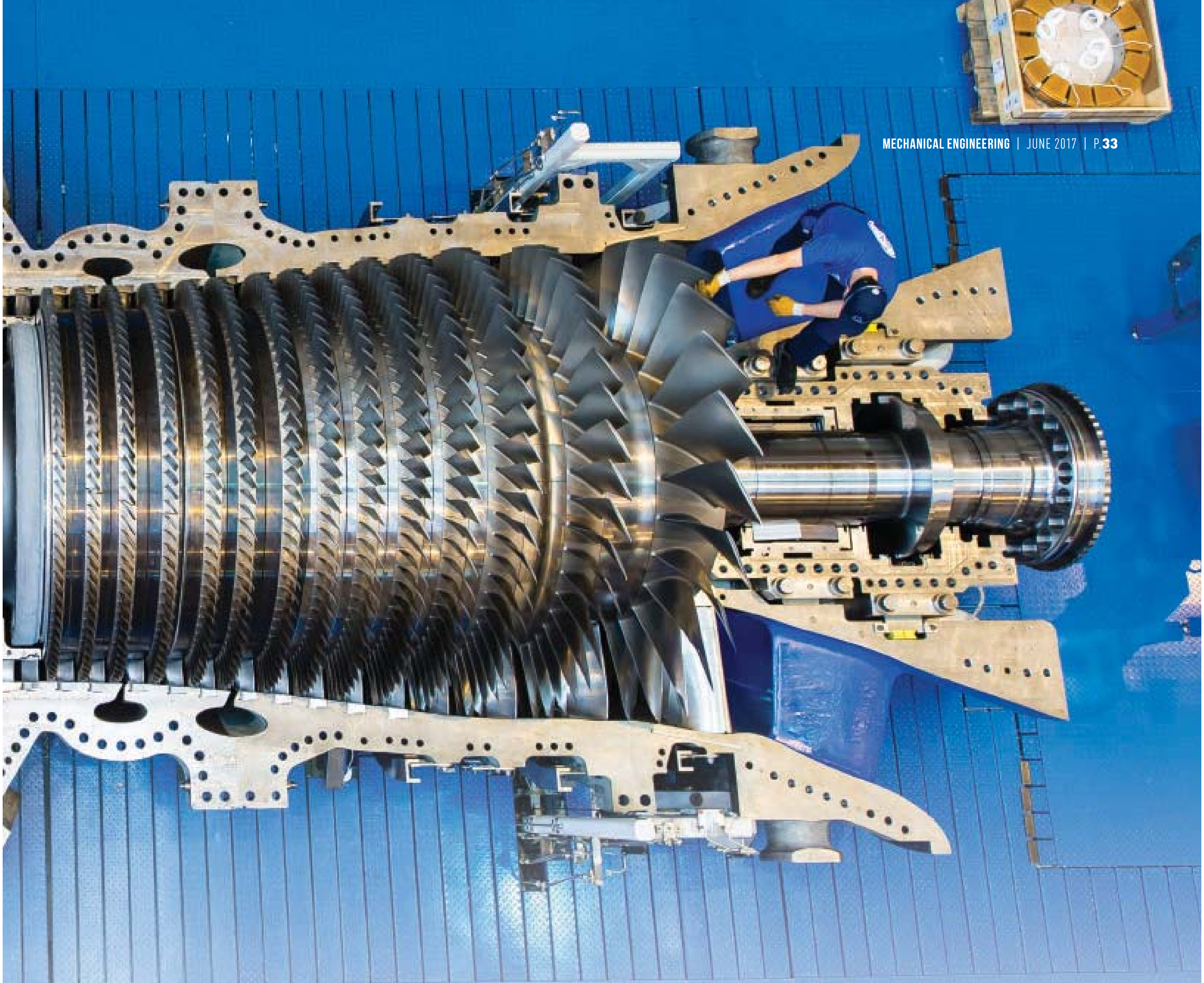


Running in Place

Gas turbines in the electric power industry are better than ever.

In today's electric generation market, that may not be good enough.

BY LEE S. LANGSTON



GE workers prepare the gas turbine that set an efficiency record as part of a combined cycle plant in Bouchain, France.

They are obscure today, but there was a time when Glenn Cunningham, Arne Andersson, and Gunder Hägg were household names. Those men, and dozens like them, were probing the boundaries of human performance as they sought to become the first person to run a mile in less than four minutes. After twenty years of gradually inching closer to the mark, the feat was finally accomplished on May 6, 1954, by the British runner Roger Bannister, who then held the world record for all of 46 days.

Over the past couple decades, engineers who designed and developed combine-cycle gas turbine generating plants have pursued their own records. Those plants comprise a Brayton-cycle gas turbine which sends its hot exhaust to a boiler to make steam to drive a Rankine-cycle electric power steam turbine. Thus, such plants wring two units of work from one unit of fuel.

By themselves, the largest single-cycle gas turbines are astonishingly efficient, with thermal efficiencies in the 30-to-40 percent range, going as high as 44 percent. But for years the goal for combined-cycle plants was to reach a thermal efficiency of 60 percent, which is about twice the efficiency of a standard steam turbine plant. As the major manufacturers in the market for gas turbines for electric generation, Siemens and General Electric poured money into the chase and put their reputations on the line.

The mark was finally set by Siemens at a plant in Irsching, Germany, in 2011, where the combined cycle SCC5-800H unit reached a thermal efficiency of 60.75 percent, with an electrical output of 578 MW.

The technology continues to improve, as does the output. Last year, General Electric reported 62.22 percent for its 9HA.01 combine cycle plant

Boeing's 737MAX is one of the first aircraft to use CFM's LEAP engine.

in Bouchain, France, with an output of 594 MW. And now manufacturers are targeting 65 percent thermal efficiency, approaching thermodynamic limits set by Carnot.

Even now, however, these large combined-cycle gas turbine units are the most efficient heat engines in mankind's thermodynamic history. As technological and engineering feats, those efficiency marks are impressive.

Looking at the current and future course of the gas turbine industry, however, there are signs that record-breaking efficiency together with rock-bottom operating costs will not be enough to actually grow the electric generation portion of the market.

High and Mighty

To get full sense of the direction of the industry—not just for electric power generation but also for marine and mechanical applications and jet engines for commercial and military aviation—each year I turn to Forecast International, a market research firm in Newton, Conn. FI computes for me a financial picture of the gas turbine industry, its history, current state, and forecasted future.

Using its computer models and extensive data base, FI's Stuart Slade has computed the value of worldwide gas turbine manufacturing production from 1991 to 2016, and has predicted values to 2031. (FI considers production figures to be more accurate than reported sales.)

In 2016, for instance, FI calculated the value of production for the total aviation market to be $66 billion, a small increase over the $65.6 calculated for 2015. That flat growth is due to a split in the two major sectors in the aviation market. The value of production for military aviation, where many innovations are first proven, declined to $7.5 billion in 2016, from $8 billion the year before and $8.4 billion in 2014.

Far larger is the commercial aviation sector, and that saw steady growth, to $58.6 billion in 2016 from $57.6 billion in 2015 and $56.4 billion the year before that. Indeed, commercial aviation accounts for more than 75 percent of the total gas turbine market.

What's more, that share is projected to rise, due to the booming market in commercial airliners. Between them, Boeing and Airbus built more than 1,400 aircraft last year, and about a third the price tag for each plane was devoted to the cost of the jet engines. FI projects that the worldwide value of production for commercial aviation gas turbines will increase by 33 percent over the next 13 years to reach $80 billion in 2030. *The Economist* reported recently that analysts believe engine companies will see more than $1 trillion in sales over the next two decades, and Forecast International's projections suggest that this is a conservative estimate.

If the projection for the jet engine market and the rest of the gas turbine industry are on the mark, by 2030 commercial aviation will account for 82 percent of the total value of production.

Right now, the major engine manufacturers are competing to win contracts for the latest single-aisle aircraft, the Airbus A320neo and Boeing 737MAX. Two new fuel efficient turbofan jet engines are dominating: the Pratt & Whitney geared fan PW1100G and the CFM International LEAP, each in the 20,000-to-30,000-pound thrust range.

Airlines are reporting some problems with the new engines, but nothing major. For instance, some early versions of the PW1100G engine required longer start-up times, but that issue seems to have been resolved. There have been no problems reported with the new, innovative fan drive gear system.

The Pratt & Whitney PW1000G is a high-bypass geared turbofan.

The promise of these new engines is greater efficiency, and both the PW1100G and the LEAP engines are meeting that promise. Airlines flying those new engines are reporting fuel savings of 15 percent on shorter flights and up to 20 percent on longer flights. Some are able to add new destinations—because of aircrafts' longer range with these fuel efficient engines. This, combined with significant engine noise reduction (especially with the P&W geared fan) is a technological win-win.

Reversal of Fortune

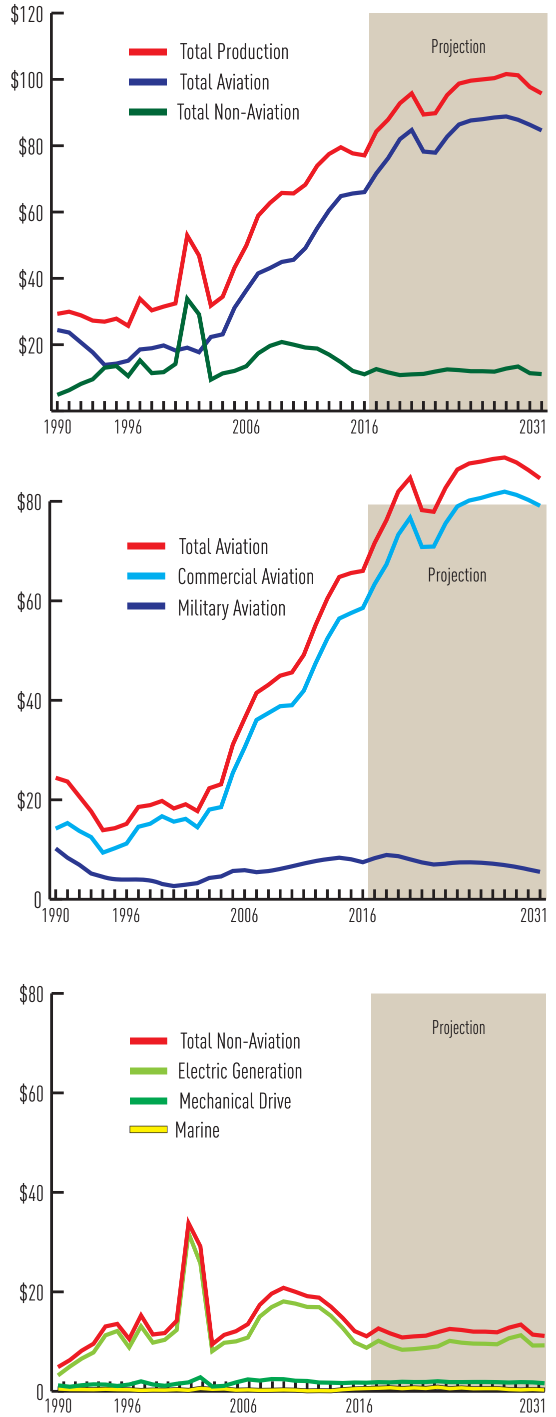
While the outlook for commercial aviation gas turbines is bright, the non-aviation segment is decidedly clouded. According to Forecast International, production of gas turbines for marine systems such as cruise ships has grown rapidly after a sharp decline in the Great Recession and the value stood at $580.9 million last year. Mechanical drives, such as those used along natural gas pipelines to power compression stations, had a value of production of $1.7 billion in 2016, about 2 percent less than the year before.

The largest portion of the non-aviation sector is made up of the electric power gas turbines we lauded at the beginning of this article. FI's data shows that the value of production for the electric power gas turbines was $8.8 billion in 2016, down from $9.8 billion in 2015.

This level of production is a stark departure from the robust projections from a few years ago, and Forecast International has even revised its value of production data from the previous few years based on production figures reported by manufacturers. The value of production was higher than previously reported before 2012, but is markedly lower since. In fact, the value of production in 2016 was almost $10 billion less than what FI projected this time last year.

What's more, the projections for gas turbines produced for electric generation are now similarly revised downward, erasing an astonishing $123 billion in value of production. Such revisions—and revised prospects—don't occur without reason. Based on input from FI's Stu Slade and other data, I believe that there are

Global Gas Turbine Value of Production (billions of 2017 dollars)



Note: Changes in the operational and economic priorities during the early years of the decade necessitated a revision of the basic forecast model in 2007.

several interlinked trends affecting orders.

To start with, while analysts have focused on the growing demand for electricity worldwide—a demand that gas turbines are poised to meet—the average output of each individual gas turbine unit is also increasing, and at a rate that's faster than that of electricity demand. "This means that the requirement for additional power can be met by fewer individual units," Slade said. "The growth of electricity demand is not translating into a proportional demand for new plants."

Next, the remarkable efficiency of combined-cycle plants is working against gas turbine production. The extra power that a combined-cycle plant can wring from a given unit of fuel comes from the addition of a steam-generation system and steam turbine, not a gas turbine. While that efficiency is good for utilities and great for the environment, it reduces the number of gas turbines that must be produced to generate the same amount of electricity.

There are a couple extrinsic factors, as well. According to Slade, in Europe and other parts of the world, the heavy emphasis on reducing emissions and resource consumption has resulted in large subsidies for the renewables sector. Indeed, Slade said, these subsidies are so great that it forces conventional power generation to be operated at a loss under certain situations.

As a result, new gas turbine power generation facilities have been mothballed on completion without ever generating a watt of power. A few years ago when I toured the Irsching power plant in Germany, a representative of E.ON, the plant's owner, told me that they were running it only a few hours a day in response to the unfavorable German rate structure.

"In the longer term," Slade said, "increasing power demand will be met by opening up these mothballed plants, thus causing the medium-term dip in demand. In effect, there is a bow-wave of reserve capacity that is limiting demand."

Finally, in spite of reports to the contrary, coal power is not dead. Many countries in Eastern Europe and Asia still rely on their coal resources and build coal-fired power plants when they need to add generating capacity. In the United States, the uncertainty over the long-term policy toward coal power has raised the prospect of plant owners essentially running their coal-powered generating assets into the ground, producing as much cheap (but dirty) power as they can, while they can.

All of this impacts the prospects for the gas turbine market.

The Case for Optimism

In recent years, the use of gas turbines for electric generation has had many boosters, myself included. The energy writer Vaclav Smil once listed the laudable aspects of gas turbines, among them: "They are exceptionally reliable and relatively easy to maintain; their service is almost instantly available: they can reach full load within a few minutes and hence are perfect for covering peak load or other sudden fluctuations in demand; because they are air cooled, they (unlike steam turbogenerators) do not require any arrangements for water cooling."

It is difficult to dispute that gas turbines provide some of the cheapest dispatchable power available to grid managers. The U.S. Energy Information Administration recently tabulated the latest estimates of costs of new U.S. electrical power plants, giving values of averaged levelized and overnight costs. Levelized cost of electricity represents the per-kilowatt hour cost of building and operating a new generating plant over an assumed financial life and duty cycle, thus giving an averaged cost of generating electricity over a period of years. Overnight cost per kilowatt is the cost of a construction project (i.e. the power plant) if no interest is incurred during construction, as if the project was completed "overnight."

The EIA looked at both simple and combined-cycle gas turbine power plants burning natural gas, as well as conventional coal and nuclear plants and renewables such as wind, solar, and hydroelectricity. Both types of gas turbine plants were cheaper to build (based on overnight costs) than any other power source, around half the cost of renewables, one-third the cost of a new coal plant, and at least one-sixth the cost of a nuclear plant. In terms of levelized cost of energy, combined cycle plants edged out all others, including wind—even though wind turbines have no fuel costs—and were about 40 percent cheaper than coal plants.

Gas turbine power plants also have the advantage of dispatchability which wind, hydroelectric, and solar often do not. A recent econometric study of renewable electric power implementation, led by David Popp at Syracuse University, concluded that in the 26 countries they looked at, the use of fast-reacting fossil technologies such as gas turbines to hedge against variability of electrical supply made it more likely to result in the successful investment and use of renewables.

The takeaway here is that gas turbine power plants are cost effective and can provide a necessary backup to the variability of renewable power plants.

To me, all that argues for better prospects for gas turbines in the electric generation sector than Forecast International projects. The electric grid is going to be ever more unsettled as new blocks of intermittent power are added. Gas turbines combine low cost and fast reaction time in a way that will enable the grid to handle winds dying down unexpectedly or unpredicted heavy clouds diminishing solar power output.

Even so, these revisions are a valuable lesson to engineers not to let their enthusiasm for a technology run ahead of the market forces that shape what does and doesn't get built. ME

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

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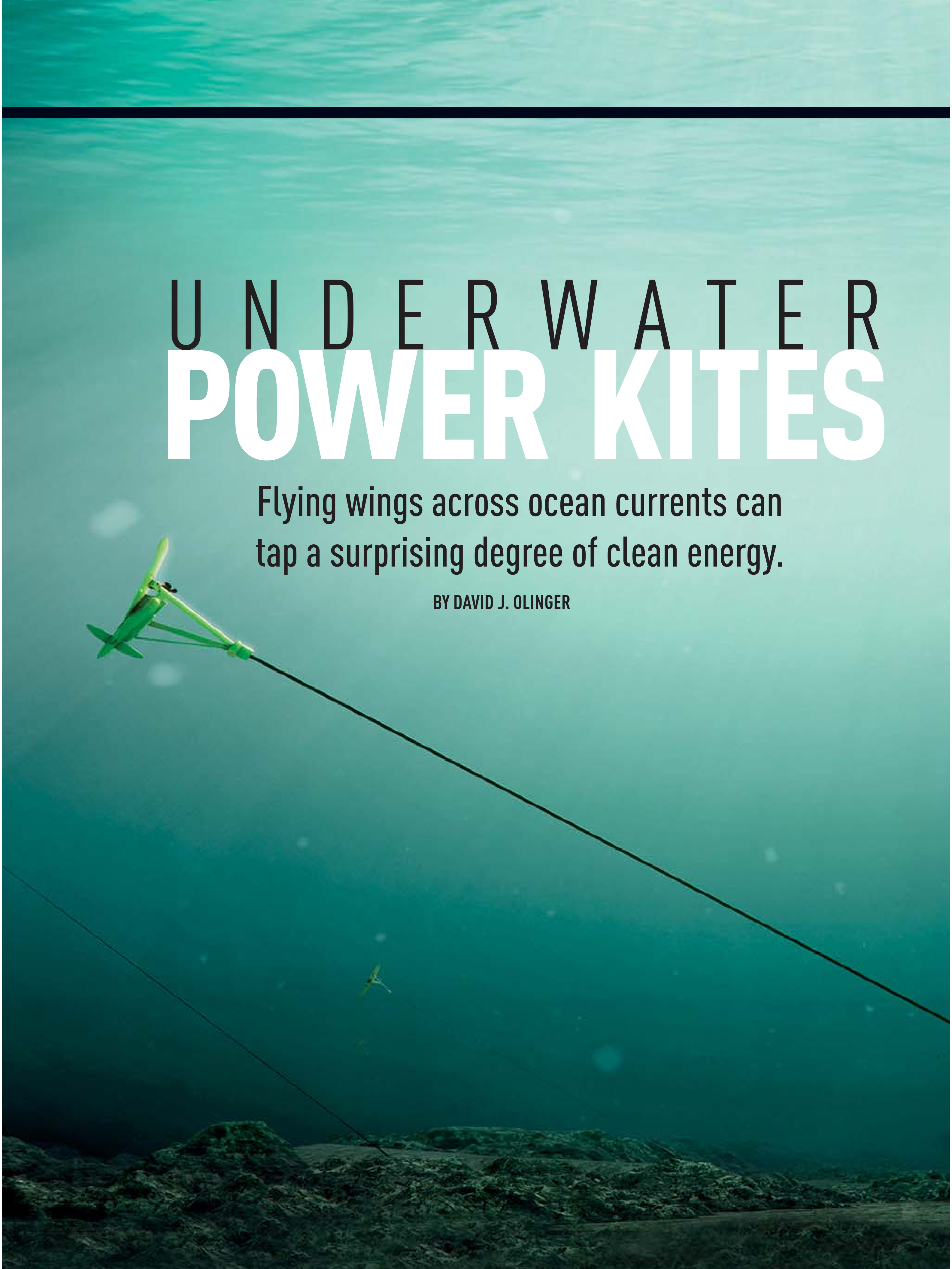


UNDERWATER POWER KITES

Flying wings across ocean currents can tap a surprising degree of clean energy.

BY DAVID J. OLINGER

A boat cuts across a placid lake, towing a water skier. As long as the skier points his skis in the same direction as the boat, their speeds match. But the skier swerves and starts to trace graceful curves behind the boat. Even though the skier and the boat are still connected by a rope, the skier's speed relative to the water increases, sometimes by as much as 50 percent.

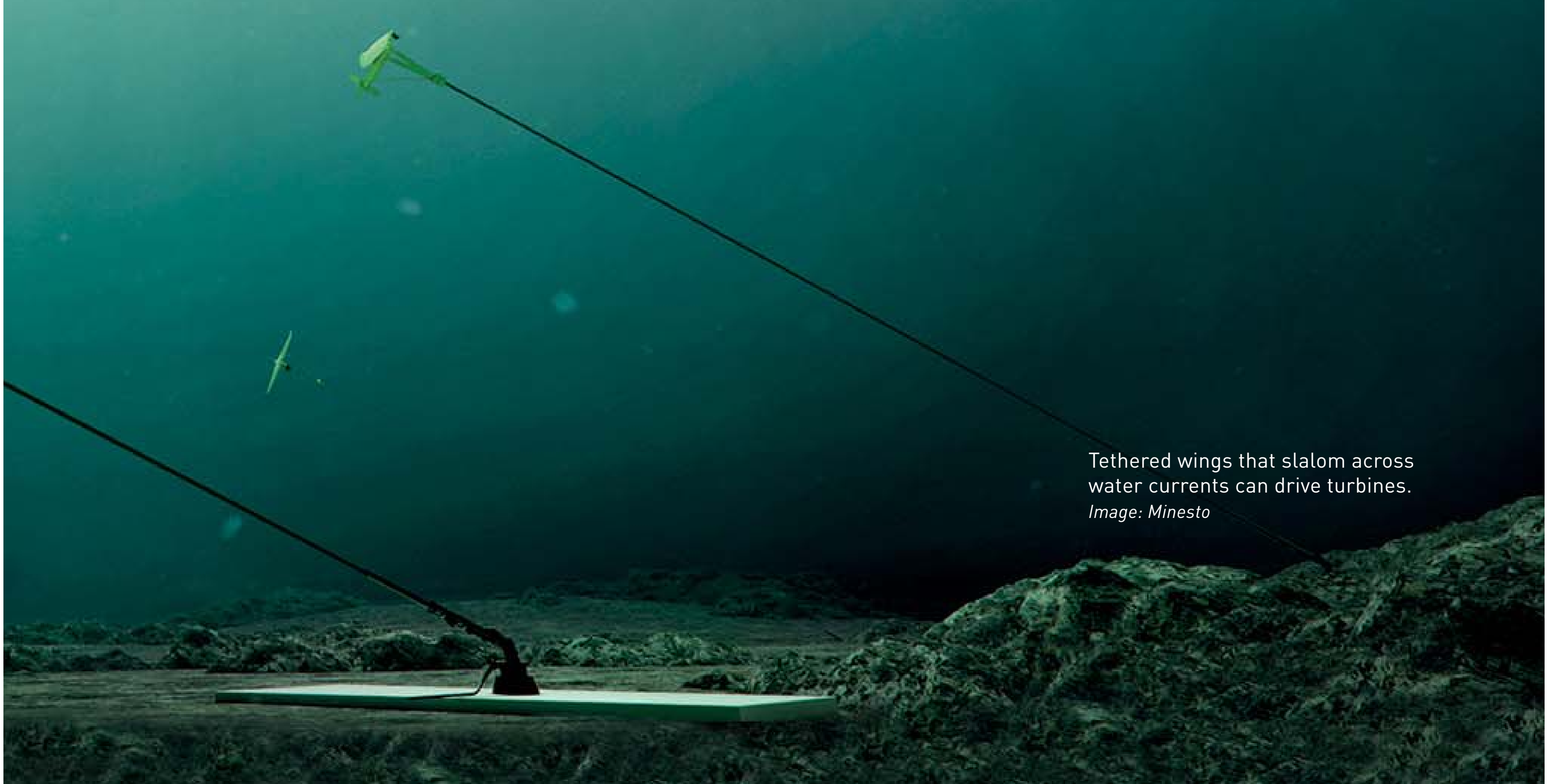
Objects at the ends of ropes or tethers can pick up surprising amounts of speed. A trapeze artist at the bottom of her swing can reach a speed of 20 mph while the balls on the end of an Argentinian bola swung by a gaucho circle at over 50 mph. Perhaps the most deceptive are kites. Miles Loyd, an engineer at Lawrence Livermore National Laboratory, showed as early as 1980 that a winged kite moving through the wind can travel at a velocity equal to the wind velocity times two-thirds of the wing lift-to-drag ratio. For a conservative lift-to-drag ratio of 9, the wing accelerates to six times the wind velocity.

A kite tracing arcs in a stiff breeze on a very long line can reach speeds close to one hundred miles per hour.

With those kinds of speeds comes the potential for harvesting power from the wind, or an ocean current.

For decades, researchers have been pursuing the concept of tapping hydrokinetic energy from ocean or tidal currents to generate electric power. Still, ocean-current (or hydrokinetic) energy conversion remains a largely unfulfilled promise. Virtually all of the existing generation units use fixed turbines mounted on the seafloor. These stationary generation units depend on the currents to spin their blades and crank their generators.

The amount of generated power is proportional to the cube of the water velocity flowing through the turbines; increase this velocity by 26 percent and the power doubles. The velocity—and the generated power—can be increased even more dramatically if the turbine, instead of standing still, can be put in motion so it can actively move through the current.

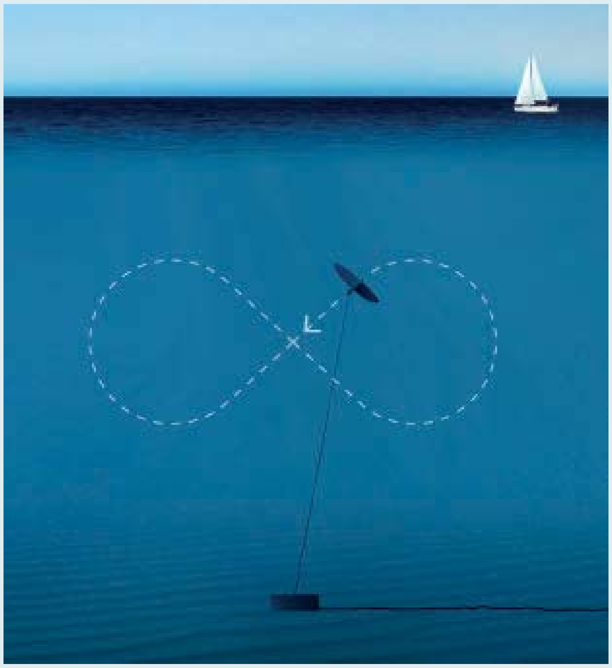


Tethered wings that slalom across water currents can drive turbines.
Image: Minesto

Flying Kites Underwater

All tethered hydrokinetic power technology is based on the same basic concept. A kite or wing is attached by a long rope to a fixed point, either a floating buoy or platform anchored to the seafloor. As a water current flows past the kite, it traces a figure-eight path through the water. The kite's speed relative to the water is much higher than the water current. That enables a turbine mounted on the kite to generate more power than can a turbine mounted on a fixed platform.

Image: Minesto



Mount the axial-flow turbine onto a wing-shaped kite, attach the kite to the end of a tether, and "fly" the kite underwater, tracing figure-eights across the flow of the current. The kite moves fastest when it slaloms through the current in this way, much like a water-skier. (In fact, high-performance hydrofoil water skis, which lift the skier off of the water to reduce drag, also use an underwater wing.) Electricity generated by the mounted turbine-generator is transmitted along the tether to a moored, floating buoy, and then onto the power grid.

This concept, now known as the Tethered Undersea Kite, or TUSK for short, was first conceived by Magnus Landberg, a researcher in Sweden, back in 2007. I have been part of a group researching the same idea at Worcester Polytechnic Institute for more than three years now, and we believe it has the potential to generate vast amounts of inexpensive, renewable power.

Applying Loyd's calculation for the maximum velocity of a crosswind kite, a turbine flying on a rigid-wing, underwater kite at six times the current velocity could generate 216 times as much power than a stationary turbine in the same current.

Power output is, of course, restricted by inefficiencies and the theoretical Betz limit for turbines, and this is not violated for power kites.

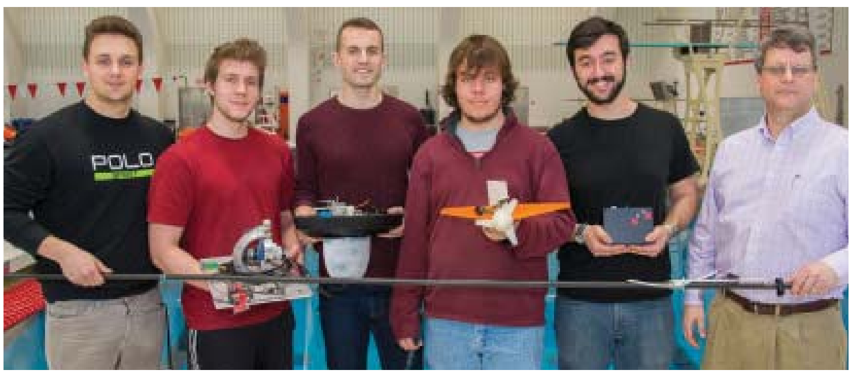
The kite moves fastest when it slaloms through the current in this way, much like a water-skier.

Flexible Flyers

I was first inspired to work on kite power after reading a June 1979 *Mechanical Engineering* article by Jitendra Goela, a researcher in India at the time, who has also consulted with our WPI research team. In the mid-2000s, when I discovered Goela's article, research teams around the globe were starting to design kite-based power systems, collectively known as Airborne Wind Energy, or AWE. Such systems use large fabric kites or rigid wings (with onboard wind turbines) that fly at the end of a flexible 300 m tether. At that altitude, kites can take advantage of faster, steadier winds than conventional wind turbines can reach, which means that more energy can be extracted from the wind with AWE systems.

AWE systems have faced some challenges. When the wind dies, an airborne kite will crash into the ground unless carefully controlled. It is likely that such systems will have to fly over unpopulated areas. The 300 m tethers attached to the kites are heavy and degrade the kite's flight performance.

About four years ago my research team began wondering whether the experience we had gained with AWE systems could be translated into the study of a power-generating system using "underwater kites." Like an airborne kite moving in a



A student team from WPI tested miniature versions of the underwater wing technology at a campus swimming pool.
Images: WPI

breeze, the wing in a TUSK system is able to travel at high speeds solely due to the ocean current flowing past the moored buoy and wing. No on-board propellers are required to generate thrust. In short, underwater wings act as current speed enhancement devices. As a result, they can be used in low-speed currents where conventional hydrokinetic turbines do not generate enough power to be economical.

And underwater kites may prove to be more practical than kites in air. Instead of crashing in a slack tidal current, for instance, an underwater kite will safely hang beneath the waves on its tether until the tide picks up again. The highest ocean current speeds are actually found near the ocean surface, so that TUSK tethers can be much shorter and weigh less.

Underwater kites look to be feasible to build using commercial available technology. Kites with wingspans of up to 15 m and areas of up to 35 m^2 that weigh about 10 metric tons can be constructed using carbon fiber or glass-reinforced plastics commonly used in boat hulls. Tethers with lengths of up to 100 m can be made from high-modulus polyethylene fibers, which have already been proven as AWE tethers and have sufficient maximum strength to withstand the large tether tensions (more than 1 million Newtons) predicted for underwater kites. Buoy and mooring requirements should be comparable to those for floating, offshore wind turbines. Practical control systems needed to autonomously manipulate the kite elevators, ailerons, and rudders can be designed.

We were quickly struck by the extraordinary potential of the idea. Ocean currents represent a remarkably concentrated source of energy—a current of 1-to-2 m/s has an available power density of about 1 kW/m^2, or about 800 times what is available in air moving at the same speed. A TUSK system with wing area of 30 m^2 operating in that current will produce about 300 kW of power. A school of 100,000 such wings operating in the world's ocean currents would generate 30 GW of power, enough for about a quarter of U.S. households. And by the way, a similar number of wind turbines, about 250,000, now spin in wind farms around the world.

Operating in marine environments is always a challenge, and the wings must be compatible with both passing ships and ocean life. But a design that allows for the wings to be reeled in and pulled out of the water for servicing should make it easier to perform maintenance on a TUSK system than on a fixed hydrokinetic turbine.

According to economic analyses conducted by other research teams, TUSK systems may be able to produce electricity at about half the current cost for fixed hydrokinetic turbines, and a bit below the cost of the power produced by off-shore wind turbines. Those researchers attribute the lower costs to improved power-to-weight ratios derived from replacing the inner blades and sup-

This scale-model power kite was tested in waters off the coast of Northern Ireland. *Image: Minesto*

port tower of a traditional turbine with a lightweight, low-cost tether. In essence, the wing sweeping a circuitous path through the water acts like the tip region of a traditional turbine blade, where most of the power is produced.

Operating in marine environments is always a challenge, and the wings must be compatible with both passing ships and ocean life.

Proof of Promise

A team of WPI students and faculty members, including myself and Michael Demetriou, began working to help see if TUSK could fulfill its early promise. An early model we created to solve ordinary differential equations for kite-tether dynamics showed encouraging power output estimates. That model incorporated the important physics that determine system performance, from hydrodynamic lift and drag to buoyancy forces and moments and cavitation effects on the blade tips of the lightweight axial-flow turbines. Solving the resultant differential equations in Matlab software provided outputs for such factors as instantaneous kite velocities, accelerations, and orientation in addition to system power output. The software also models control systems needed to create the desired slalom motion of the wing.

We also designed, built, and tested a small-scale TUSK kite and tether. The kite, fabricated with a 3-D printer, has a wingspan of 40 cm, weighs about one-half kilogram, and uses NACA 0005 airfoils for its wing. A scaled three-bladed turbine and micro-generator mounted at the front of the kite extracts energy. To simplify our early tests, a rigid, hollow carbon fiber rod is used for the tether instead of HMPE fibers. A single rudder adjusts the kite's yaw orientation to control its slalom motion. The kite can be manually controlled via a joystick, or with an autonomous control system still under development.

To save money, we had the clever idea of turning the swimming pool in WPI's Sports and Recreation Center into a water tow tank. We attached the tether and kite to a wheeled cart that we rolled along the pool deck to simulate an ocean current. This allowed us to system check our data acquisition instrumentation during brief slalom runs.

We next tested the model in a 6-meter-wide, two-meter-deep water flume at the Alden Research Laboratory in Holden, Mass., where we exposed it up to 1 m/s simulated currents. Proof-of-concept tests of the scale model were conducted in spring 2016, during which repeatable slalom motions were achieved, with kite trajectories and velocities measured. Future tests in the flume at Alden will further refine the scale model to better estimate the potential power output of full-scale TUSK systems.

The scale-model tests are supported by computational fluid dynamics simulations that we have developed in collaboration with Gretar Tryggvason at the University of Notre Dame. Those simulations use a numerical grid that moves with the kite wing, and partial differential equations (the Navier-Stokes equations) are solved at every grid point to determine the flow velocities and pressures near (and on) the wing as it moves.

Simulating the kite in this way allows us to better predict kite lift and drag, tether tension forces, kite trajectories, and power output than we could by using the ordinary differential-equation-based models we created earlier. Flow visualization studies allow us to picture the flow over the kite to better understand how it interacts with the current, and we can compare the results from the CFD simulations to those from our scale-model tests to help us better design new underwater kites.

No onboard propellers are required to generate thrust... (and) they can be used in low-speed currents where conventional hydrokinetic turbines do not generate enough power to be economical.

We are not the only ones looking into the feasibility of underwater kites. An European company, Minesto UK Ltd, founded in 2007 by Anders Jansson, has developed an advanced system it calls Deep Green. That system uses an underwater wing with upturned tips, a kite-mounted turbine, and a tether that runs to the ocean floor. Minesto has conducted long-term sea trials of quarter-scale kites, which have been underway off the coast of Northern Ireland since 2010. At the same time, researchers at the University of Strathclyde in Glasgow, working with Minesto, have considered potential risks during operation and maintenance of Deep Green. Minesto's next step is to implement a 500kW power plant off the coast of Wales in 2017.

A Canadian company, HydroRun Technologies Ltd., started developing its Freestream Glider technology for use in river currents back in 2012. Its underwater wing actually resembles a glider, complete with rudders and elevators on tail surfaces behind the wing. The glider is tethered to a generator on a buoy on the river surface. After successfully testing a 40 kW pilot plant on the Fraser River in British Columbia, HydroRun suspended operations in 2015 due to some changes in the economics of the energy industry in Canada.

A Dutch company, SeaQurrent, has developed the TidalKite which consists of several wings tethered to the seabed. Forces generated by the high velocity wings drive pressurized fluid through a hydraulic motor to generate power. A scaled prototype of the TidalKite has recently been tested at the Marin Research Institute in the Netherlands.

Only a few companies and schools have worked on underwater kites, a relatively new concept compared to airborne wind energy, which has benefited from the work of researchers at dozens of institutions worldwide. We expect more researchers to begin working on this emerging technology in the coming years. What will likely drive this future interest is the realization that tethered undersea kites have the potential to provide cheap electricity without producing pollution.

Ongoing work has begun to fulfill the promise of underwater kites, but more development is needed in the next decade to fully realize this potential. Improved methods for controlling underwater kites for optimal power production are needed, materials that will extend system life must be developed, and more accurate simulations of system performance will aid future design improvements. Prototypes are undergoing sea trials, and power plants that will electrify the grid are on the horizon. At the same time, research and development also continues at universities to further refine and optimize the technology.

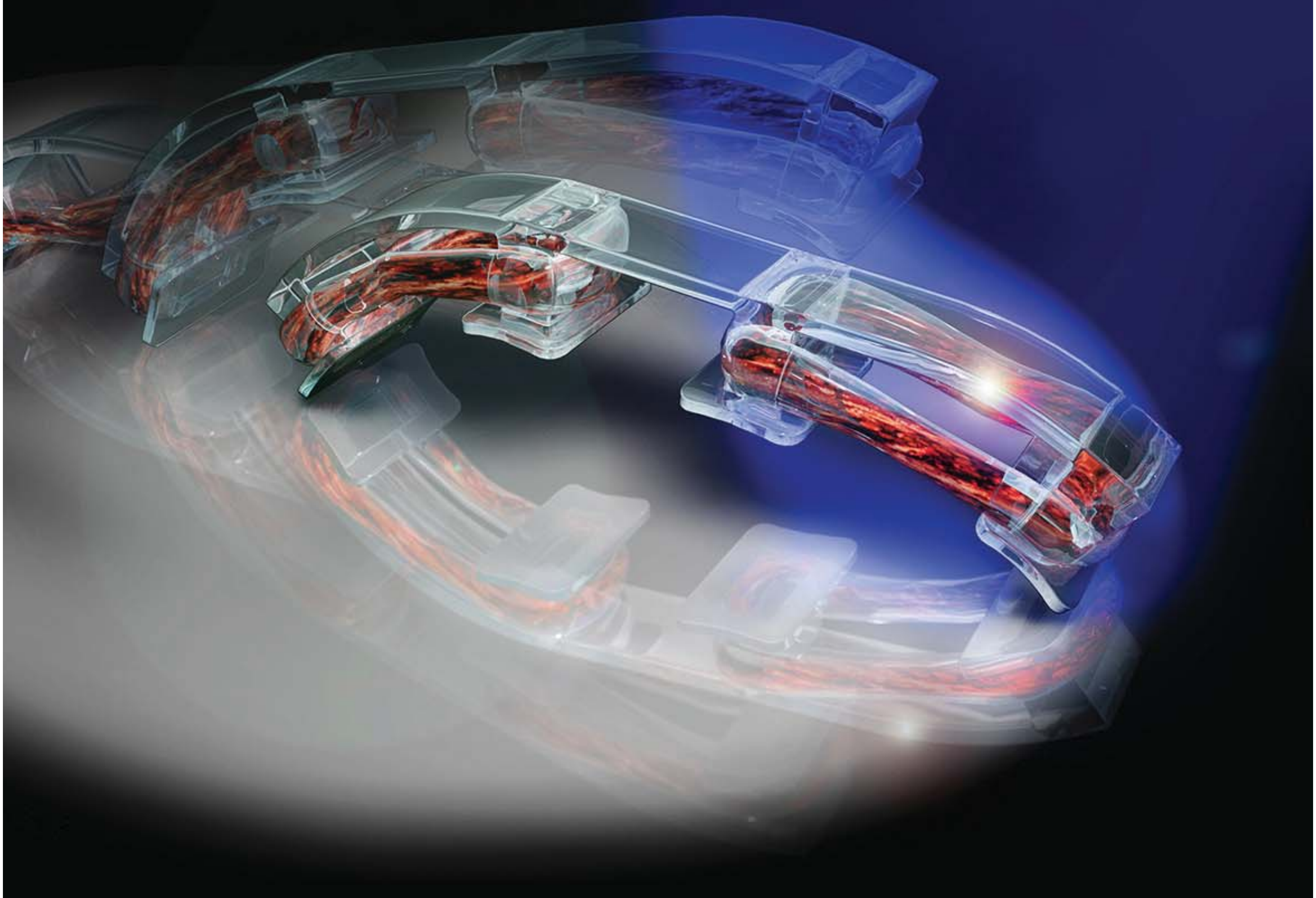
At WPI we have started to study one such refinement where the wing and turbine are suspended under a tethered, floating hull. A similar idea has been patented by HydroRun. This winged hull should be easier to control than a fully submerged kite, since it only needs to move along the surface. This set-up also moves the tether between the hull and buoy out of the water and into the air, where it experiences far less drag. As a result, we expect that the hull and turbine will slalom at higher speeds, much like our water skier. So far, we have designed and built a test apparatus for this concept, and completed a first test in our water flume.

Studies like this, we believe, will continue to advance this exciting new technology. **ME**

DAVID J. OLINGER is an associate professor in the mechanical engineering department at the Worcester Polytechnic Institute in Massachusetts. His article is based, in part, on papers presented at the ASME Power & Energy Conference & Exhibition in 2015 and 2016. The author thanks the National Science Foundation's Energy for Sustainability Program for support.

LIVING MACHINES

BY MONIQUE BROUILLETTE



The muscle-powered biobot shown in this artist's rendition walks on command when exposed to light.
Image: Rashid Bashir, University of Illinois, Urbana-Champaign.

A large NSF-funded research team is building working machines out of living human cells.

Blood vessels don't pump blood, for example, but imagine ones that could. A blood vessel that supplies the heart could be engineered to sense rising pressure from a blood clot in a clogged artery, and start pumping to disperse the clot. A swimming, sperm-like robot powered by muscle cells could swim in a patient's bloodstream, seek out hidden tumors inside her body and deliver targeted doses of life-saving drugs.

The first such biological machines are just now being built. Funded by the National Science Foundation, a consortium of researchers at major engineering schools have developed a handful of biological machines that can sense input, move, or both.

So far their devices are rudimentary, but the scientists are aiming for cellular machines that not only behave as simplified organs, but also improve upon their design.

Unlike today's tissue-engineered organ replacements, which seek to replace or repair damaged organs, these new machines harness the building blocks of life-like muscle and nerve cells and, put them together in ways nature never has. The goal is to build living, multicellular machines that sense, move, and solve real-world health problems.

Part Animal, Part Machine

"When we put these building blocks together, we can capitalize on their individual functionalities and make something new to serve whatever purpose we want," said Caroline Cvetkovic, a bioengineer from the University of Illinois, Urbana-Champaign, one of the 10 research institutions on a national Science Foundation-funded project called Emergent Behaviors of Integrated Cellular Systems (EBICS).

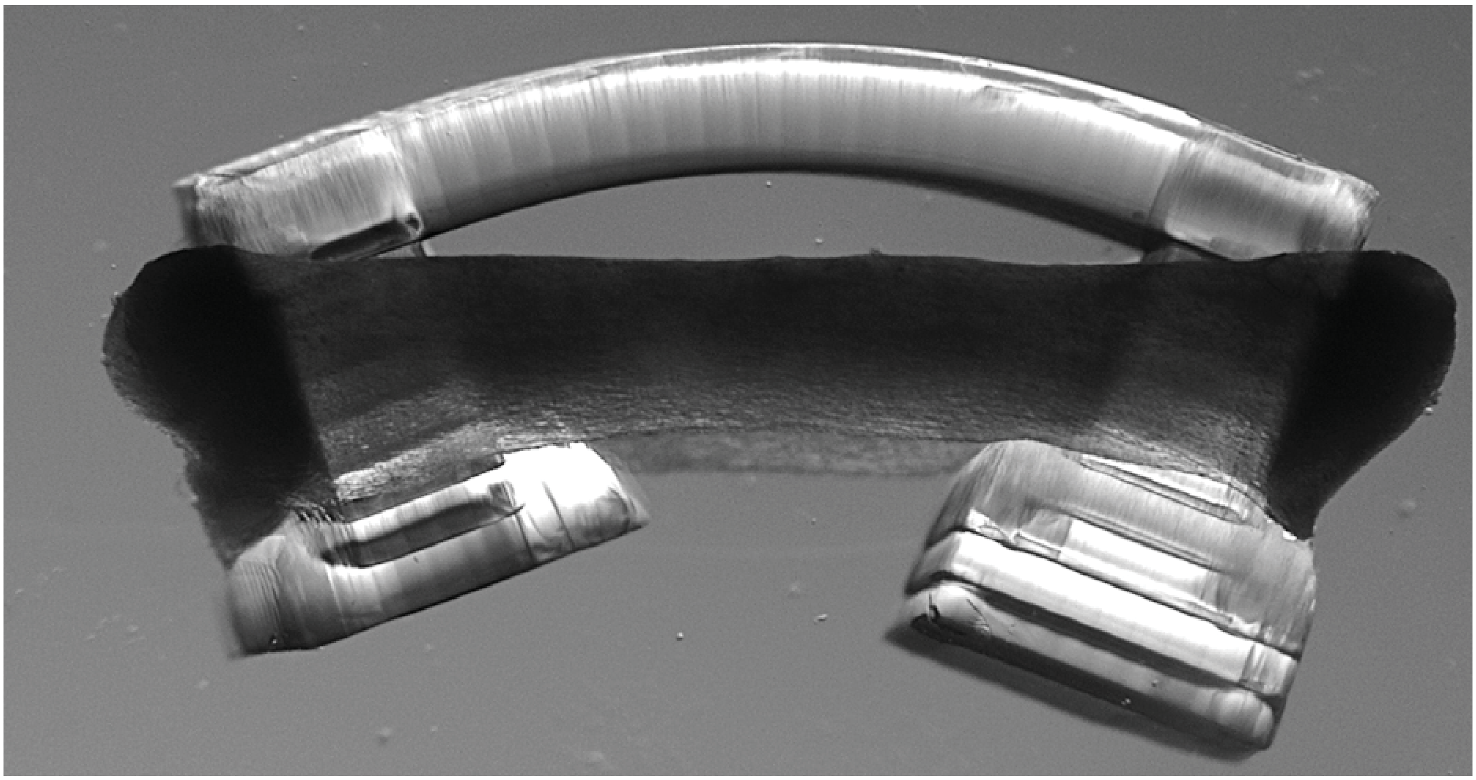
These new biological machine-building capabilities rely on recent advances in genetic engineering, bioinformatics, and stem cell engineering. Scientists can now genetically program cells to produce proteins that give cells prescribed functions, such as the ability to respond to light or pressure.

One of the first and most rudimentary biobots is the microswimmer, which is part animal, part machine and most closely resembles a sperm.

The microswimmer consists of a flexible microfilament string about the thickness of a human hair, with a bundle of cardiomyocytes—heart muscle cells—clustered at one end. As the cardiomyocytes beat in synchrony, they bend the string and propel the biobot forward.

"We used cardiomyocytes because they can self-organize, synchronize their beating and mimic a swimmer," said Taher Saif, the designer of the bot and bioengineer at University of Illinois at Urbana-Champaign.

One day this bot may be programmed to sense chemical signals emitted from cancer cells, seek them out, and deliver tumor-destroying chemicals, he said.



Skeletal muscle (dark band) contracts and extends on command, causes a hydrogel to flex repeatedly, which this biobot to walk. *Images: Rashid Bashir, University of Illinois, Urbana-Champaign*

A Walking Biobot

Another EBICS group has developed a biobot that walks. Inspired by the structure of human joints, this walker has two short, stubby legs connected by a bridge. The skeleton is constructed from a soft Jell-O-like 3D-printed skeleton called hydrogel, and surrounded by a band of skeletal muscle. Just as a muscle in the body contracts and moves a bone, these muscles contract to move the hydrogel skeleton.

In building the walker, Rashid Bashir's team at the University of Illinois, Urbana-Champaign used skeletal muscle cells instead of heart cells. That's because heart cells beat on their own, whereas a skeletal muscle needs a stimulus to contract, which allows the engineer to actuate it on command.

A skeletal muscle contracts naturally in response to electrical current, and at first Bashir and his colleagues used electricity as the stimulus. But now their latest biobot responds to light. The group genetically engineered the cells to produce a protein called channel rhodopsin, a sensory photorecepter that enables the muscle to contract in response to blue light. This provides an easy on-off switch to activate the muscle, spurring the bot to move its legs and walk.

As the cardiomyocytes beat in synchrony, they bend the string and propel the biobot forward.

Why use biological materials to construct machines at all, as opposed to building machines with more traditional materials like metal and plastic? There are many advantages, Saif said. To start, you don't need a motor. The heart cells that power the swimmer, for example, beat in synchrony and generate enough power to actuate the device.

Self-Assembling Cells

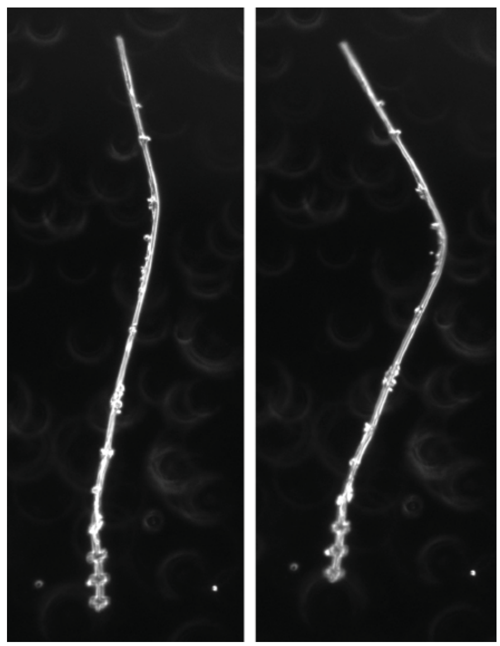
In addition, individual cells self-organize and condense into tissues without much prompting from a scientist, a phenomenon called emergence. To make muscle for the walker, Bashir's team simply combined 1.5 million muscle stem cells, extracellular matrix proteins like collagen and fibrin, and the 3D-printed skeleton in a small mold. Within a day, the muscle stem cells had linked to the proteins, condensed and aligned themselves into a band of solid muscle the length of a staple that could actuate the skeleton as a human muscle actuates bone.

Birds flying in a flock, fish swimming in a school, and even civilizations organizing themselves around major riverways like the Nile or Ganges are other examples of emergence. Cells, too, organize themselves. During development, they sense, process, and act on each other to form tissues and organ systems.

As biologists understand better how tissues develop, bioengineers will be able to reverse-engineer development to better program cells to self-assemble to create biological machines. In the case of Saif's microswimmer, "we didn't do much at all; we just put the cells in randomly," he explained. "They had the power within themselves and were cross-talking to one another."

Plans for future bots will include different cell types and many more functionalities. Bashir's team would like the walker to employ nerve cells, due to their built-in ability to sense and respond to chemical cues. Also in the works are artificial vascular systems that will be able to supply the interior of biological machines with oxygen

As biologists understand better how tissues develop, bioengineers will be able to reverse-engineer development... to create biological machines.

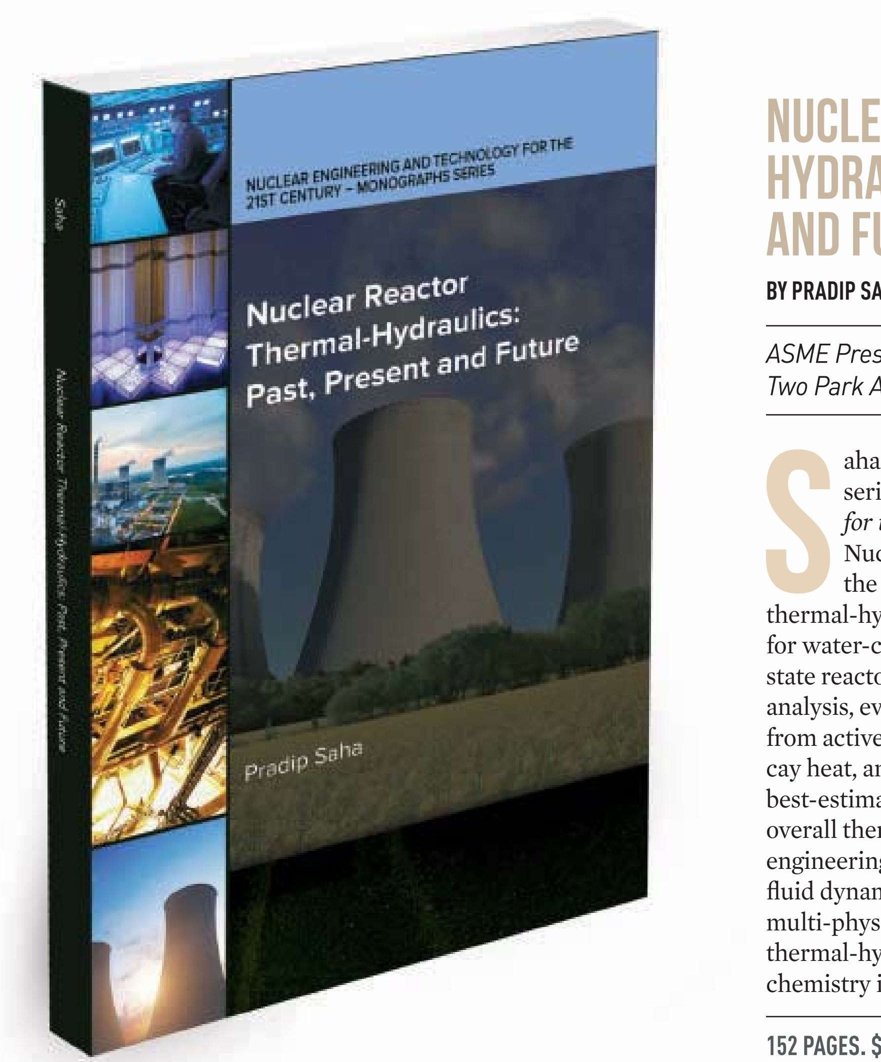


A biobot called the microswimmer moves when heart muscle cells beat in synchrony, causing a microfilament to flex and extend.

and nutrients. In the future, biological machines could also repair themselves.

For now, the next milestone will be a biological machine containing a functional neuromuscular junction. Saif said: "This will be the first biological machine with multiple cell types and potential intelligence."

MONIQUE BROUILLETTE is a science and technology writer in Cambridge, Mass. For more about biomedical engineering visit aabme.org.



FEATURED

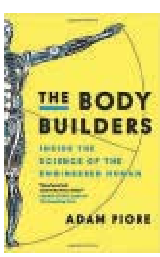
NUCLEAR REACTOR THERMAL-HYDRAULICS: PAST, PRESENT AND FUTURE

BY PRADIP SAHA

*ASME Press Books,
Two Park Avenue, New York, NY 10016-5990. 2017.*

Saha's monograph, the second volume of the series, *Nuclear Engineering and Technology for the 21st Century,* sponsored by the ASME Nuclear Engineering Division, summarizes the major developments on nuclear reactor thermal-hydraulics over the last 50 years, primarily for water-cooled reactors. Saha discusses the steady-state reactor thermal hydraulics including subchannel analysis, evolution of emergency core cooling systems from active to fully passive systems to remove the decay heat, and the development and consolidation of the best-estimate safety analysis methodology. One of the overall themes is the influence in computer-assisted engineering software on these analyses. Computational fluid dynamics tools are obviously important, but multi-physics methodology encompassing neutronics, thermal-hydraulics, thermal-mechanical and coolant chemistry is also playing a larger role.

152 PAGES. $99; ASME MEMBERS, $79. ISBN: 978-0-7918-6128-8

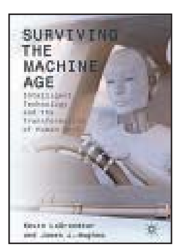


THE BODY BUILDERS: INSIDE THE SCIENCE OF THE ENGINEERED HUMAN

By Adam Piore
*Ecco, an imprint of HarperCollins,
195 Broadway, New York, NY 10007. 2017.*

"New technologies are allowing scientists to reverse-engineer the human body with unprecedented precision," writes Piore, a New York-based science journalist. His book is an exploration of that, and of the people pushing the ethical and engineering boundaries to go beyond repair and prostheses to augmentation and enhancement. He digs into the story of Hugh Herr, a mechanical engineer who designed his own replacement legs after an accident, as well as researchers looking to tap—and add to—the full potential of the human mind. Piore weighs the concerns over some of these advances, but comes down firmly on the side of optimism.

400 PAGES. $26.99. ISBN: 978-0-0623-4714-5



SURVIVING THE MACHINE AGE: INTELLIGENT TECHNOLOGY AND THE TRANSFORMATION OF HUMAN WORK

By Kevin LaGrandeur and James J. Hughes, eds.
*Palmgrave Macmillan,
175 Fifth Avenue, New York, NY 10010. 2017.*

How essential is human labor in a world where robotic dexterity and artificial intelligence far outstrip our own? LaGrandeur and Hughes collect essays that plumb the limits of that question, including the technological, economic, and moral implications. Some policy choices might well lead to mass unemployment, displacement, and poverty, but that isn't inevitable. Several near-term solutions are proposed, and in the more distant future, some of the essays contend, widely deployed automation and AI could lead to a world of material abundance and leisure. The problem is getting there, and while basic income guarantees might be the road to utopia, the roadblocks seem insurmountable.

166 PAGES. $99.99. ISBN: 978-3-3195-1164-1

A forum for emerging systems and control technologies.

DYNAMIC SYSTEMS & CONTROL

JUNE 2017 VOL. 5 NO. 2

HUMAN MACHINE INTERACTION:

BRINGING HUMANS IN THE LOOP

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Tentative future issues of *Dynamic Systems & Control Magazine*

September 2017
Powertrain Optimization for Connected Vehicles

December 2017
Smart Cities

Human-Machine Systems

In July 2013, an aircraft stalled during landing and crashed at San Francisco International Airport. It was reported that human factors contributed to this crash. The pilot had over-relied on the auto-landing system, instructions provided from the air traffic control caused mental overload on the pilot, and the pilot later stated that landing the aircraft was "very stressful, very difficult" in the absence of a specific sensor. While experienced in operating the aircraft, the pilot was challenged handling the situation.

Humans face many challenges when interfaced with machines. Applications to this end encompass driving in traffic, operating heavy machinery, using a new prosthesis, coordinating a swarm of robots, and making key decisions in airport control towers. Although sophisticated and agile decision making capabilities of humans are key for task performance, we also realize that interactions between humans and machines are always bidirectional, and understanding this complex interaction has the strong potential to advance the state of the art in human-machine systems. We are now at a point where machines are no longer just passive devices but embody intelligence and adaptation skills, with which they can interact with humans in order to optimize human performance as well as the outcomes of human-machine systems.

Looking at human-machine interactions as a closed-loop system, control theory is well positioned to advance human-machine systems. This calls for multidisciplinary collaborations with experts in human-factors engineering, operational psychology, machine learning, game design, and network science.

To this end, we have four articles in this issue, reflecting this truly multi-disciplinary field. The first article, authored by Yingzi Lin, covers design principles toward intelligent vehicles interacting with human drivers. The second article, lead authored by James C. Christensen, focuses on the complex interactions that arise between humans and machines, and how–and in what contexts–such interactions can be effectively communicated to both humans and machines. The next article, lead authored by Takeshi Hatanaka, demonstrates the coordination principle of a robotic swarm system in interaction with a human operator and under various network configurations. The issue concludes with an article coauthored by Rahul Warrier and Santosh Devasia on "How to Train your Robot?" which presents a control design scheme for achieving human-in-the-loop robot training.

We greatly appreciate all the authors and their contributions for this issue of *ASME Dynamic Systems and Control Magazine*. If you have any feedback on this issue, or any ideas for future issues of this magazine, please contact the Editor, Peter Meckl at **meckl@purdue.edu**.

Rifat Sipahi, PhD
Northeastern University
Guest Editor, *DSC Magazine*

COVER IMAGE: TOKYO INSTITUTE OF TECHNOLOGY

Remembering J. Karl Hedrick

J. KARL HEDRICK, professor of mechanical engineering at University of California at Berkeley and long-time member of the Dynamic Systems and Control Division, passed away on February 22, 2017 at the age of 72. He is survived by his wife, three daughters, their husbands, and two grandchildren. He was well known in the academic community as an outstanding researcher, lecturer and mentor. He was also a recognized great colleague and leader in the institutions and professional societies in which he participated.

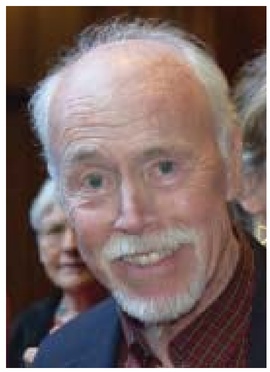

PHOTO: ANDREW ALLEYNE

Professor Hedrick was well known for his contributions and leadership on transportation research, including dynamics and control of coordinated aerial, ocean and ground vehicle systems, intelligent transportation systems, engine and powertrain controls, active suspension systems, embedded software design, and rail vehicle dynamics and control. His research spanned the full spectrum from experimental applied research to basic theoretical control, including many contributions in nonlinear control and estimation.

Professor Hedrick received his bachelor's degree in engineering mechanics from the University of Michigan in 1966, and his masters and doctoral degrees in aeronautical and astronautical engineering from Stanford University in 1970 and 1971. His career began as an Assistant Professor at Arizona State University (1971-1974), followed by tenure at the Department of Mechanical Engineering at the Massachusetts Institute of Technology (MIT) (1974-1988) and the Department of Mechanical Engineering at the University of California at Berkeley (Cal) from (1988-2017). He was the Chair of the Department of Mechanical Engineering at Cal from 1999 to 2004, and Director of the University of California's Partners for Advanced Transit and Highway Research Center from 1997 to 2003. He also directed the Vehicle Dynamics Laboratory at MIT and Berkeley's Vehicle Dynamics Laboratory, as well as serving as a co-director of the Hyundai Center of Excellence in Active Safety and Autonomous Systems at Cal.

He was a member of the National Academy of Engineering, Fellow of the American Society of Mechanical Engineers (ASME), past division chair and chair of the Honors Committee of the Dynamic Systems and Control Division (DSCD) of ASME. He was also the editor of the ASME's *Journal of Dynamic Systems, Measurement and Control* (JDSMC). He was member of the Society of Automotive Engineers, and the American Institute of Aeronautics and Astronautics. He received ASME's Rufus Oldenburger Medal in 2006 and was the ASME Nyquist Lecturer in 2009. He received many additional awards, including the ASME DSCD's Outstanding Investigator Award in 2002, the ASME JDSMC Best Paper award in 1983 and 2002, the Outstanding Paper Award from the Institute of Electrical and Electronics Engineers in 1998 and the American Automatic Control Council's O. Hugo Schuck Best Paper Award in 2003. He authored two books and published more than 140 peer-reviewed archival publications.

Throughout his career, he graduated more than 70 Ph.D. students, in addition to graduating M.S. students and mentoring post-doctoral fellows and visiting scholars. Professor Hedrick always dedicated personal attention to each mentee, providing them guidance and space to grow at both technical and individual levels, and provided the appropriate support to enable individual and group achievements. He was a role model for everyone, and his easygoing style is recognizable in all that he influenced. He gave a special meaning to the spirit of "academic siblings" among his students: they all felt like he was a second father beyond the role of an academic advisor.

Professor Hedrick's research focus was on real-life problems and real-life solutions supported by rigorous theoretical research. He led pioneering research efforts across a range of topics, including early work in the late 1980s on autonomous vehicles. This led to the first large-scale tests of real automated cars on the highway in San Diego, California, in the early 1990s. His approach to real-life problems led to many contributions to stability, dynamics, estimation, and control for coordinated groups of autonomous vehicles as well as fundamental contributions in control and estimation for systems described by discontinuous differential equations.

In addition to his research prowess, Professor Hedrick was an accomplished instructor. Many students that had the opportunity to be his advisees, or took his courses, would recall his ability to explain complicated concepts in ways that were accessible to them. He had the ability to move from simple to complex topics in a lucid and insightful manner, always keeping the student connected to the topics.

Karl Hedrick was dedicated to his family and was an accomplished athlete. His real family always took priority and he spoke very fondly of time spent tutoring his daughters, coaching their tennis and soccer teams, and riding bicycles together. He was a competitive tennis player, having been a Big Ten champion at Michigan, and he competed at major U.S. and European Open tournaments. He used to joke that "he was good enough to lose to some very good players in three U.S. Open tournaments." He decided as a young man to dedicate himself to engineering instead of becoming a professional tennis player, but he continued to play tennis competitively in the master's category until just before his death.

Many of his Ph.D. students, faculty colleagues from Cal, and his family had an opportunity to spend a day of celebration of his life during the summer of 2016. He also had an occasion to meet with his students in Asia a few years earlier, and he and a small group did a short visit to MIT during the summer of 2016. We were all fortunate that we could listen to his wisdom, and share his laughter one last time before he moved on to his next big project. He will be greatly missed. ■

– Andrew Alleyne, Joseph Beaman, Anouck Girard, Peter Meckl, Eduardo Misawa.

TOWARD INTELLIGENT HUMAN MACHINE INTERACTIONS

HUMAN ASSISTANCE SYSTEMS (HAS)

BY YINGZI LIN
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Humans create devices, which include structures, machines, etc., to help humans in coping with nearly all kinds of socio-technical systems (e.g., manufacturing, servicing, etc.). In fact, devices have never left humans alone; that is, a full automation has never taken place. Therefore, humans ubiquitously interact with devices to make sure that jobs are effectively carried out. Particularly, humans serve as masters while devices serve as slaves. In this context, devices are identified, inherently, as human assistance systems **(HAS)**. There are naturally two issues on constructing HAS. The first issue is about how to design the interface of HAS. The second issue is about how humans and HAS collaborate with each other during such interactions.

With regard to the first issue, interfaces are of two types: (i) devices used by humans to communicate with machines, e.g., keyboard, mouse, and (ii) devices used by machines to communicate with humans, e.g., display screens, audio systems. Type (i) devices are called human-to-machine interfaces and Type (ii) devices are called machine-to-human interfaces. Both types of interfaces are responsible for effective and efficient operation of HAS. Interfaces are of *soft* and *hard* parts. The *soft* part refers to "*What, Where, When (WWW)*" the right information and/or action are communicated to humans from HAS, and the *hard* part refers to how the information and/or action are realized with devices.

With regard to the second issue, humans may make errors or act improperly in human-machine interactions. HAS are expected to detect and compensate for human errors. In a case that a machine is a part of the team to complete an operation, it is highly desired that HAS collaborate with humans effectively. Indeed, HAS possess a certain level of human intelligence as described below.

HAS INTELLIGENCE LEVELS AND PROBLEM DIMENSIONS

There are several levels of intelligence with HAS:

Level 1: *HAS that can follow a pre-defined procedure of a human's operations.* Many displays in process plants, flight displays, and vehicles fall into this level of intelligence with HAS. In essence, this level of intelligence is such that system intelligence is built in by interface designers. The HAS with this level of intelligence may also be called *passive intelligence.*

Level 2: *HAS that can understand human action, cognition, and/or emotion.* One example is the smart steering wheel where an array of sensors (including heart rate, Galvanic skin responses, etc.) were constructed on the surface of the steering wheel to measure driver states [1]. HAS at this level do not change a machine's behavior and so, they still fall into the category of passive intelligence.

Level 3: *HAS that possess Level 2 of intelligence and can perform cognitive tasks and change machines to respond to a new situation that happens at the human side.* HAS at this level change machine's behavior, which could be in (physical) action, (non-physical) communication, and such intelligence may be called *active intelligence*.

Level 4: *HAS that possess Level 3 of intelligence and can further exhibit intelligence emotionally.* By emotionally, it is meant that emotion plays an important role in one's decision and action. For instance, HAS may take a more aggressive intervention to the braking operation when HAS detect that the driver is in an angry state [2]. That type of intelligence is also called *emotional intelligence*.

Level 5: *HAS that have Level 4 of intelligence and can express emotions known to humans.* For instance, driver assistance system (DAS) may use a particular soft voice to remind a particular driver of a hazard ahead.

Level 6: *HAS that have Level 5 of intelligence and can express emotions based on a machine's states in a physical and/or cognitive sense.* For instance, DAS in the braking operation would give an emotional message to a particular driver based on a state of the braking system.

Remark (1): Level 4, 5, 6 of intelligence with HAS all fall into the category of active intelligence, and can be further called *emotional intelligence I, II, and III;*

Remark (2): In the case of automation, machines are controlled by computers, and as such, human-machine interactions become human-computer interactions. However, the nature of human-machine interaction is not changed, as the computer in this case is a part of the machine and part of the machine-to-human interface;

Remark (3): In the situation when a machine is a part of computer software with no interest in the physically tireless machine behind, the software exhibits and operates intelligently, i.e., persuasive technology, which is a type of HAS at Level 5.

Basic problems of HAS may be described in the following dimensions:

Dimension 1: interface design and interaction (for all the levels of intelligence), particularly the problem of determining "*What, Where, When*" for a piece of information relayed to humans and how to exhibit this piece of information.

Dimension 2: development of human-to-machine interacting devices, e.g. joystick, keyboard, etc. (for all the levels of intelligence).

Dimension 3: development of machine-to-human interacting devices, e.g., audio, display screen, etc. (for all the levels).

Dimension 4: development of sensors that are built on or worn by machines for HAS to infer and predict human states (for Level 2 of intelligence and above).

Dimension 5: design of software for HAS to provide assistance, including soft message and/or hard intervention, to humans based on the analysis of information regarding a human's action and cognition (for Level 3 and above).

Dimension 6: design of software for HAS to provide assistance, including soft message and/or hard intervention, to humans based on analysis of information regarding human's action and cognition as well as emotion (for Level 4 and above).

Dimension 7: development of HAS that can exhibit human emotions on appearance (for Level 5 of intelligence).

Dimension 8: understanding of the relationship between machine's states and human's emotions (for Level 6).

HAS IN DRIVING APPLICATIONS

Advances on HAS have been made within application areas including vehicle driving, pilot flight interfaces, healthcare and rehabilitation, robotics, etc. In the following, research efforts in HAS for vehicle driving, which is also called DAS (driver assistance system), are described.

Advanced Driving Simulator

One important method for studying DAS is the availability of a powerful research tool (i.e., simulator), as the simulator is an effective means to generate real-world traffic scenarios without putting drivers in any real danger [3,4]. An advanced driving simulator has been in development for the past decade at the IHMS laboratory [5]. The purpose of the driving simulator is to facilitate the research and development of DAS with an eye on more generalized findings for HAS in other application areas and to facilitate the training and assessment of drivers in terms of essential skills in driving, e.g., reaction to hazards.

Specifically, there are two primary functions within driving simulators, see **Figure 1**. The first function is to test sensors with algorithms for the HAS to understand a driver's states in action, cognition and emotion. The second function is to test operation management systems (both hardware and software) for driver assistance. With these functions, the driving simulator can support research across all of the dimensions of problems, Dimensions 1-8, as previously mentioned.

The quality of the driving simulator lies in its fidelity. **Figures 2-3** show various road situations the driving simulator can simulate, and how the simulator facilitates the development of an operation management system for drivers' reactions to hazardous situations.

FIGURE 1 Sensors and Driver Interface.

The driving simulators are also developed into a networked platform (**Figure 4**), upon which scenarios can be constructed, where there are multiple drivers on the road [5,6,7]. Specifically, the networked simulator enables (a) the simulation of single- and multi-driver immersive driving, (b) the visualization of interactive surrounding traffic, (c) the specification and creation of reproducible traffic scenarios, (d) the capture of drivers'

FIGURE 2 *(Left)* **Virtual environments and driving scenarios.**

FIGURE 3 *(Above)* **Driving Simulation at IHMS Lab at Northeastern.**

behavioral and physiological data, and (e) real-time information communication between vehicles.

A variety of research projects have been performed, such as driver fatigue [8], distraction [9]. In the following, some selected projects are summarized.

Driver Hazard Perception

The primary goal of DAS in this case is first to assess hazards (including the driver's state of hazard perception, intent to react, and reaction) and then to take action (or no action) accordingly. Apparently, understanding the driver's hazard perception is most crucial. The behavior of hazard perception of a driver is found to be sensitive to the physiological state of a driver, especially Electroencephalography (EEG). This provides an avenue to develop a real-time marker or indicator of the driver's behavior of hazard perception. A project was carried out to develop such a real-time marker. The objective is to build a map between the physiological signal and the hazard perception behavior derived from a standard test available in the literature. In this pilot study, a total of about 50 participants were asked to see images of two categories: not hazardous situations, and hazardous situations (see **Figure 5**). The participants were required to respond to the situations in the images (Yes or No for hazardous situation identification). While driving, physiological signals of the participants are measured, which include EEG and skin conductance signals. **Figure 6** shows the experiment scene, in particular the display of hazardous images and the measurement of EEG signals and skin conductance (SC) of the participants. Data analysis establishes the mapping among the behavioral score, physiological signal, risk category or no-risk category. Data analysis also reveals that the physiological signal is more sensitive to the risk or no-risk category than the behavior score. Further, this strongly suggests that the driver's physiological responses are potentially reliable objective measures for driver licensing tests.

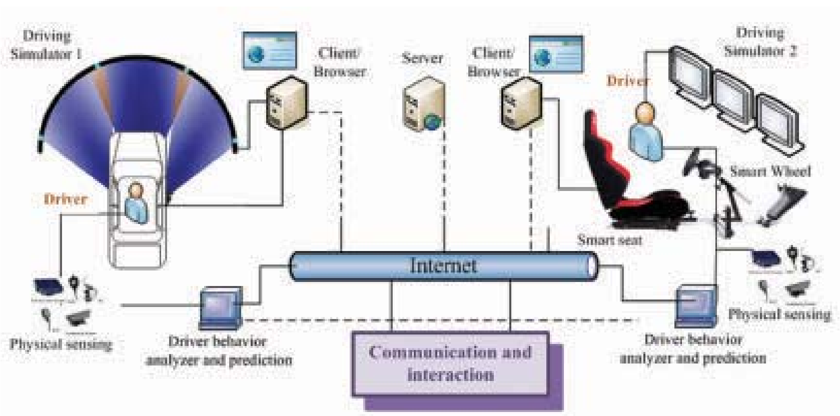

FIGURE 4 **Networked Multi-Driver Simulation Platform.**

Driver Road Rage

Driving anger, called "road rage", is a unique emotion caused by pressure or frustration from daily life or from bad traffic situations and the discourteous behavior of surrounding drivers. First, anger emotion was induced by elicitation events. Then, anger intensity was labeled in terms of the self-reported anger levels, and were associated with the EEG spectral features under different driving anger states. In particular, the relative energy spectrum of δ, θ, α and β bands of EEG signal among different anger levels were obtained, see **Figure 7**. As shown, the relative energy spectrum of β band (β%) in neutral state (anger level = 0) is the lowest, while β% at anger level 5 is the highest, and β% markedly increases with the increase of anger level. Meanwhile, the relative energy spectrum of θ band (θ%) markedly decreases with the increase of anger level. Additionally, the relative energy spectrum of δ band (δ%) in anger state (anger level = 1, 3, 5) is smaller than that in neutral state, and the relative energy spectrum of α band (α%) in anger state (anger level = 1, 3) is smaller than that in neutral state. However, the same consistent changing trends were not found for δ% and α%, respectively, with the increment of anger level [10,2].

Non-Intrusive Sensing

Sensors are a fundamental problem in human-machine systems; see the previous discussion on the dimension of problems (**Dimension 4**) and on the level of intelligence of human-machine systems (**Level 2** of intelligence and above). The sensor plays three roles: understanding of the scene, of the machine, and of the human. The sensors for the scene and the machine are not a focus of this paper; the sensor for the machine is the business of machine manufacturers. The IHMS laboratory focuses on the sensor for the human. Ample evidence shows that human physiological signals are sensitive to the human states. The essential criterion for sensors to measure human physiological signals is non-intrusiveness. We have focused on a so-called "natural contact sensor" [11]. The natural contact sensor makes a machine "wear" a wrapper or engineers a "skin" on a machine with such sensors embedded in the wrapper or the skin. The natural contact sensor paradigm for human physiological signals is complementary to the wearable sensor paradigm for human physiological signals. For the wearable sensor, humans need to "wear" sensors in order to measure their physiological signals.

There are two challenges with the natural contact sensor paradigm: (i) how to install this suite of sensors into a machine, and (ii) how to predict what point on the machine subjects will contact for operation. Therefore, the concept of flexible thin film sensing array was proposed [12], which can be easily wrapped and retrofitted to machine surfaces to address both of the challenges. Based on this, two such non-intrusive sensors have been developed. **(1) Skin Temperature Sensor.** Change of temperature and pressure from humans are the main factors that induce cross interference. In order to perform temperature compensation, the temperature sensors should be robust thermometers which have stable performance and suffer little from cross interference. Specific skin temperature sensors have been developed and their performance has been verified [13]; **(2) Heart Rate Sensor.** For Heart Rate Variability, heart rate can be measured by observing the amount of infrared light reflected by the skin from a light source, to measure Blood Volume Pulse. By combining quantum dots with conductive polymers used to make organic LEDs, a thin, flexible film that can measure Blood Volume Pulse can be developed [14].

Control Strategy Of HAS

A control strategy for HAS has been investigated, especially for DAS. The goal is to provide a warning message and/or intervention to the driver if necessary to avoid hitting objects on road (e.g., lead cars) while not frustrating the user. DAS make use of the program of assessing driver's hazard perception and assesses the risk level of driving per se. For the middle risk level and high risk level, one example is that it provides a warning and/or intervention based on a discrete PID control law. Intuitively, adjusting the operators' physical/mental states to achieve optimal performance is operators' own responsibility. In reality, the idea of having the operator as the only controller is not sufficient because human (controlling) behavior is inherently uncertain. An idea that deserves more exploration is to develop an intelligent system that collaborates with the human operator in controlling the machine's executive unit. This kind of HAS intelligent system is referred to as an operator assistance system (OAS) [15]. Subsequently, all human-machine cooperative systems can be simplified to a structure with operators, HAS or OAS, and peripheral executive mechanisms. In simpler terms, HAS become the brain of the machine, and the rest of the executive mechanisms are its actuators. The general function of HAS is to maintain the aforementioned nominal situation during human-machine cooperation. This general role is performed through three basic functions of HAS: (1) perceiving cues of human operators' states, (2) inferring human operators' mental state, and (3) making decisions and adjustments aimed at recovering or maintaining the nominal state. HAS leave the execution functions (e.g., steering wheel turning, gas pedal control, and brake pedal control in driving) to the actuators. From the viewpoint of HAS, the target system being dealt with is a human-in-the-loop system. From machine side, HAS collaborates with human operators to jointly control the actuators.

FIGURE 5 *(Above)* **Driver road hazard perception scene.**

FIGURE 6 *(Below)* **EEG Experiment set-up.**

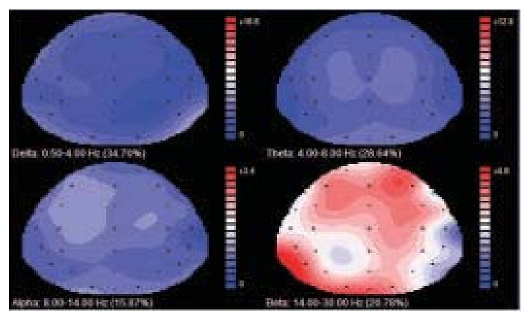

FIGURE 7 **EEG and driver state (Neutral vs. Angry).**

CONCLUSION, LIMITATIONS AND FUTURE DIRECTION

A technical system should be viewed as a human-machine system, as the premise of any technical system is that the human serves as a master while the machine is a slave. HAS are a generic notion as part of machine systems to improve the level of intelligence of machines and to ultimately improve the mission accomplishment of human-machine systems, and HAS are attachable and detachable to machines. This paper presented six levels of intelligence with HAS to improve machine intelligence in working with humans, and eight dimensions of problems in developing HAS with these levels of intelligence. A summary description about some related research projects have been described. However, there are a few limitations for our current work. Take driver hazards perception, for example. Further work is planned for having participants perform the test in more realistic situations, i.e., driving simulator or real road tests. Based on the above analysis, there is still a need for research on sensors (i.e., on Dimension 4 and below) to further improve the accuracy of inferring and predicting human cognitive and emotional state, especially human intent to take actions and emotions. This includes both research sensors and information fusion algorithms. Among these, human intent might be one of those most challenging research problems, but it is probably well worth it given the potential benefits it will bring to advance human-machine interactions. Second, research needs to be conducted to build emotional intelligence of HAS (i.e., on Dimension 6 and beyond). The key challenge is to develop associations between the machine's state (cognitive and physical) and the human emotion and the principle behind the association.

Despite its great technical and social significance, the modeling of human states and behaviors remains one of the greatest challenges in science and technology development. It is known that human states and behaviors are highly nonlinear, uncertain, and random, which challenge many scientific disciplines. This line of research truly calls for interdisciplinary and transdisciplinary collaborations from experts from all the related fields to lead to groundbreaking discoveries in the new era of human-machine interactions. ■

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TRUST BETWEEN HUMANS AND LEARNING MACHINES **DEVELOPING THE GRAY BOX**

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Current trends in learning systems have favored methods such as deep learning that have had high profile successes, including IBM's Watson and the Deepmind AlphaGo system. These systems are developed via extensive training rather than being explicitly designed, and as such many of the capabilities, behaviors, and limitations of learning systems are an emergent property of interaction/experience. Given appropriate training this can result in systems that are robust and meet or exceed human capabilities [e.g., 1]. However, this training process can have unpredictable results or produce apparently inexplicable behavior, which has been described as the "black box" problem of such systems. Indeed, the widely reported "Move 37" that AlphaGo selected in its second game against Lee Sedol was regarded as very unpredictable, a move that no human would have made, yet critical in the system's eventual win. This has resulted in a popular notion that without complete knowledge and predictability of a learning system, one cannot fully understand, and thus, partner with such technology.

There are at least three reasons why learning systems can create challenges for human interaction. First, a learning system may adopt behavior that is difficult to understand and challenging to condense to traditional if-then statements. Without a shared semantic space, the system will have little basis for communicating with the human. As a result, what a human may perceive as an error may be fully logical to the system. Second, an actual error on the part of the system may be difficult to detect by the human if the human does not understand the system's basis for the decision making and data/environmental state. Third, by definition, a learning system should evidence some degree of dynamic behavior which challenges the notion of predictability. This article adopts the perspective that learning systems may never be completely "knowable," much like humans; yet they very well may be trusted by providing the users with information to reduce uncertainty, increase understanding of rationale, and by sharing lessons learned through peer and informal networks. In this paper we explore the notion of the "Gray Box" to symbolize the idea of providing sufficient information about the learning technology to establish trust wherein, much like with humans, we trust based on the synthesis of predictability, feasibility, and inference of intent based on one's knowledge of the goals, values, and interaction with the system. The term system is used throughout this brief paper to represent an intelligent agent, robot, or other form of automation that possesses both decision initiative and authority to act.

RESERVISTS GO ACTIVE DUTY An MQ-9 Reaper pilot and sensor operator fly a training mission from a ground control station at Holloman Air Force Base, New Mexico. (U.S. Air Force photo by Airman 1st Class Michael Shoemaker).

TRUST AND TRANSPARENCY IN LEARNING SYSTEMS

Paramount in the notion of the Gray Box is the idea of reducing uncertainty. Predictability is an essential antecedent to trust of complex systems [2], and the same will hold true of learning systems–perhaps even more so. Yet, by their very nature, learning systems are believed to be unpredictable, due both to the fact that their future behavior is contingent on past experience and that many systems incorporate sources of randomness or random sampling in generating and selecting courses of action. While this is true, we contend that there are still ways to reduce uncertainty associated with such systems. In particular, we will discuss one method in detail–using transparency methods.

In general, transparency refers to a set of methods to establish shared awareness and shared intent between a human and a machine [3, 4]. This may include information about the current and future state of the system and information related to the system's intent in order to allow the human to develop a clear and efficient mental model of the system [5]. Chen and colleagues [5, 6] have proposed and tested the Situation Awareness-based Agent Transparency (SAT) Model which posits that users need to understand the system's perception, comprehension, and projection of a situation. Guided by the SAT model, Mercado and colleagues [6] found that added transparency increased user performance and trust, notably, without increasing workload. Lyons [3] offers a broader conceptualization of transparency to include features of the intent, environment, task, analytics, teamwork, human state, and social intent as it relates to the human. For learning systems, transparency will likely need to include some fusion of information from the SAT model and information from the various transparency facets discussed by Lyons [3].

Humans interacting with learning systems will need to understand how the system senses the environment, how it makes decisions and acts, how it teams with the human, and how this teaming strategy changes over time based on changing situational constraints or goals (i.e., the notable autonomy paradox of transfer of authority). To the first point, the human needs to understand how the system interacts with its environment. This may include understanding how the system ingests and perceives data, what kind of sensors it has and the limitations of those sensors, and where possible it

AIR FORCE CYBER COMMAND ONLINE FOR FUTURE OPERATIONS Capt. Jason Simmons and Staff Sgt. Clinton Tips update anti-virus software for Air Force units to assist in the prevention of cyberspace hackers July 12 at Barksdale Air Force Base, La. The Air Force is setting up the Air Force Cyberspace Command soon and these Airmen will be the operators on the ground floor. (U.S. Air Force photo/Tech. Sgt. Cecilio Ricardo).

should communicate its understanding of the environment to the human. This will help the human understand the mental model of the system in relation to the environment and notably how this mental model changes as the system adapts to novel situations. Second, the human should understand how the system makes decisions and how these decisions translate into actions. Research has shown that transparency methods in the form of decision rationale can increase trust for recommender systems in commercial aviation [7]. A replication of Lyons and colleagues [7] using a high-fidelity simulation found that added rationale increases user trust and reliance on the decision aid while reducing verification (i.e., second guessing) of the automation's recommendation [8]. Humans need to understand the logic behind any recommendations by a complex system. With a learning system, the human will need to understand if and how the decision logic of the system changes and why it changes (i.e., what conditions drive the strategy change, what are the thresholds for such changes, what are the underlying assumptions of the system?). Perhaps most importantly for a learning system, the human needs to understand how the system will team with the human and how this teaming strategy changes based on human states and situational constraints.

The teaming strategy of the system may include the division of labor between the human and the system, the intent of the system toward the human, and meaningful exposure of the human and system to events to jointly experience and react to novel stimuli. Future human-machine teaming paradigms will likely involve some division of labor between humans and intelligent machines. The human needs to understand both in real-time and future projections, how that division of labor is perceived by the system, how it will change, and what triggers the change. The system should visually represent the division of labor for a particular task or set of tasks. This will allow the human and system to develop shared awareness of the current and future teamwork context. Further, it is plausible that advances in physiological assessment and intelligent algorithms will allow systems to transfer authority between the human and the system as required by situational demands. For instance, the Air Force has fielded an advanced automated system called the Automatic Ground Collision Avoidance System (AGCAS) on the F-16 platform that will take control away from the pilot when it detects an imminent collision with the ground [9]. This system only activates at the last possible moment to avoid nuisance activations and interference with the pilot. It was this innovative design to consider the pilot's perceived nuisance threshold that drove much of its success–and it is this understanding that has positively influenced pilot's trust of the system [9].

INTENT AND CONSISTENCY

Humans must also understand the intent of the system in relation to the human. This will require that humans fully understand the goals of the system and how the system prioritizes multiple goals across a variety of situational constraints. Understanding this goal prioritization and how priorities fluctuate across situations will be an important antecedent of trust for learning systems. This forms the basis for understating what "motivates" the system's behavior. Humans can gain exposure to these nuances through systematic joint training sessions where the human and system jointly interact across a range of scenarios. These scenarios will comprise meaningful tests or stretches of the system's intent across the various situations that will be needed to foster appropriate trust of a learning system [10]. While the "values" of the system may be opaque, what we can do is to structure scenarios that test out the behavioral consistency of the system across a range of demanding constraints. Thus, while we can never test every possible scenario to achieve full understanding, much

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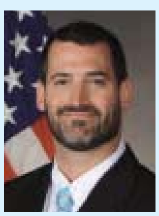

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like humans, we must infer behavioral consistency based on demonstrated consistency and predictability in a variety of challenging scenarios. I do not know how a close friend will react to positive or negative news with full certainty, but such outcomes are generally predictable based on prior experiences which we shared. The same will hold true for a learning system. Prior experiences should serve as information to guide future predictions of consistency. The value of such information will depend not on a factor of total time of interaction, but rather in the meaningfulness of the interactions that are jointly experienced. Ultimately, humans may not need to know in detail exactly how a learning system will react to a novel stimulus, however it would be effective to know that the system has reacted to other novel stimuli encountered in the past in ways that support their own goals. Understanding the rules that govern the behavior of the system and having experienced behavioral consistency that is in accordance with those rules should be a sufficient starting point for teaming with a learning system.

The rules or values that are encoded in a learning system are thus critical to overall success and especially successfully teaming with humans. Much like learning in humans, learning systems require explicit and implicit direction to instill those values. For example, in many implementations, explicit feedback in the form of negative rewards can be attached to behaviors (e.g., damaging a friendly asset), while implicit direction is provided by careful construction of training scenarios wherein violations of values lead to failure. This process then may be validated during a cooperative training process; as the human gains experience with the system's behavior they should have the opportunity to provide feedback to the system and reinforce those values.

SYSTEM UNDERSTANDING OF HUMAN STATE

In a human-machine team, transparency of the system is not the sole key for the human in understanding the learning system. The human partner must be transparent as well, in the sense that the system should monitor the state and inputs of the human partner in order to adapt and team most effectively–a concept that has been termed Robot-of-Human transparency [3] to refer to the bidirectional nature of transparency. Ideally, this monitoring is passive and nonintrusive so as to minimize additional workload burdens on the human partner. There are at least two potential ways in which data from human monitoring can be utilized by a learning system. One is error detection or expectation mismatch; signals such as verbal expressions of surprise or the P300 (an electroencephalographic waveform indicating that the human has perceived something as unexpected) can provide the system with evidence that its behavior has caused violated operator expectations, and trigger reevaluation, changes in behavior, and potentially queries to the human operator to clarify. This concept has been demonstrated in online control with no overt response from the operator [11].

A second way in which human data from physiology and behavior can be utilized is as a system input to adapt teaming behavior. This concept has been extensively discussed in the literature under adaptive automation and coadaptive aiding [12-15]. The key concept is that accurate real-time monitoring of human state (e.g., cognitive workload, stress, and fatigue) can become part of the total system environment and directly impact optimal function allocation and teaming strategies. This approach has the potential both to improve overall system performance due to optimizing utilization of human and system resources, and to improve the likelihood of user acceptance and adoption. Users have historically resisted adoption of aiding systems that can arbitrarily take control of tasks, however if the system only does so when the user is overloaded then the system can be framed and communicated as more of a partner and aid than an unpredictable, inflexible machine. There are a few key challenges to successful implementation of this approach. One is the limitation in accuracy of state assessment (generally on the order of 80-90% correct over time, [16]); confidence and error probability must be understood and quantified in the system's representation of the human partner and behavior selection. Another challenge is effective handoff or transfer of tasks; task set changes and sudden transitions in workload levels can have negative impacts on human performance [e.g. 17, 18].

In addition to providing transparency, we can reduce uncertainty of learning systems by facilitating knowledge sharing between peer groups. Stories related to both successful instances of interaction and failures can be a useful way to reduce uncertainty for a novel system. Stories shared among operators have been shown to influence trust of fielded automated systems in the Air Force [9]. These stories help to fill in the gaps of uncertainty as different users encounter disparate environmental constraints–and as a result a wider variety of experience with the system (under various conditions) is shared throughout the social network. A critical consideration, however, is to ensure that systems being considered are indeed the same, lest users share stories based on different versions of a system or a different system altogether. Designers should expect that users will transfer both optimistic and pessimistic expectations from one system to another when the users perceive the systems as similar.

RECOMMENDATIONS

In summary, we have three recommendations that will shed light on the function of learning systems, resulting in systems that can be described as gray boxes:

- Provide human operators with maximum transparency as to the inputs, process, and potential outputs of the learning system, as well as values encoded in that system.
- Train humans and learning systems together using challenging and realistic scenarios to increase mutual understanding, improve teaming, and enable human operators to gain experience and insight into system performance.
- Provide learning systems with transparency as to the state of the human operator, including their momentary capabilities and potential impact of changes in task allocation and teaming approach. ■

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A PASSIVITY-BASED SYSTEM DESIGN OF SEMI-AUTONOMOUS COOPERATIVE ROBOTIC SWARM

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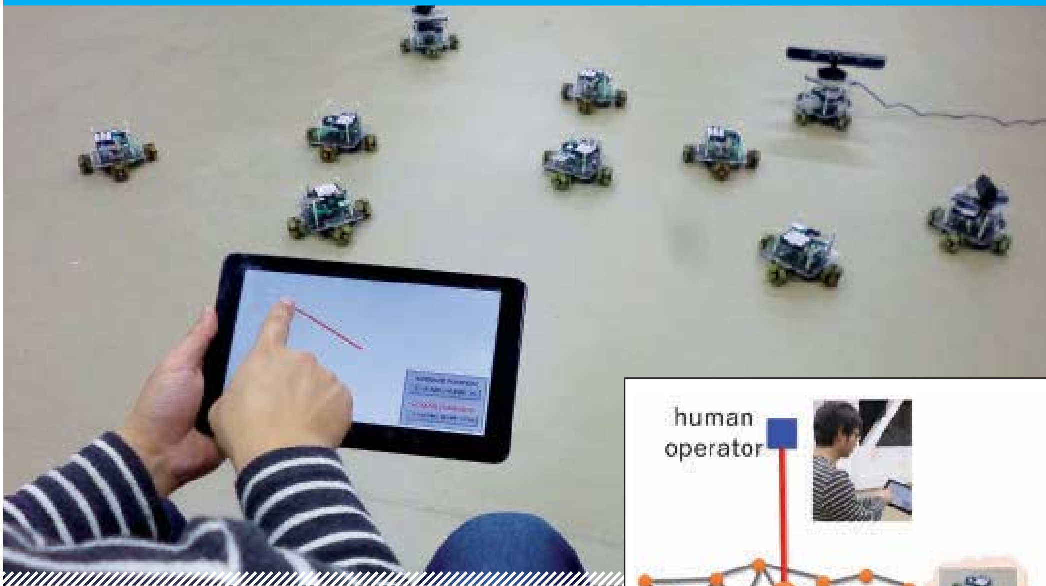
Over the past few decades, significant advancements have been accomplished in autonomous control of robotic systems. Nevertheless, in several critical applications, the inclusion of the human operator in the closed-loop system is necessary due to several reasons, the most compelling being that the autonomy of robotic systems has not advanced significantly to a level where they can be completely entrusted to operate autonomously in possibly unknown environments. Hence, complex robotic coordination tasks in highly uncertain environments require the system designer to take advantage of human operator's strengths like high-level decision-making and flexibility.

Motivated by these necessities, semi-autonomous operation of robots has gained increasing attention and has impacted several application areas. The human operator can receive various sensor feedback signals from the remote robot (termed the slave) contingent on the task at hand. For example, if the remote system is being used for manipulation tasks using single or multiple slave robots, then force or haptic feedback is useful [1]. On the other hand, if the objective is to control the center of mass of the remote robotic system via a tablet-like interface, then feedback may be based on the position or velocity mean of the robot ensemble [2,3].

Composability between heterogeneous human operators, multi-robot systems, and remote environments through unreliable communication links is an important desired characteristic of semi-autonomous robotic systems. Passivity emerged as such a property for bilateral teleoperation systems [1], where passivity of the teleoperator was guaranteed due to the passive interconnection of the master/slave robots, operator, environment, and the scattering/wave variable based communications. This paradigm has also been successfully utilized for bilateral control of networked robots where force feedback (using system states as proxies) was primarily transmitted back to the human operator through the master robot [4,5,6].

However, it is also important to study the human-robot-environment interconnection when system modalities apart from force feedback are utilized in coupling the operator to the remote environment. Recent work has been accomplished in this area [7,8]. Furthermore, it is important to couple the sensory feedback from an arbitrary ensemble of slave robots to the human operator without overwhelming the operator and while maintaining the desired stability and convergence goals [2,3]. In this article, based on the theoretical work in [2,3], and through remote experiments, a system and control architecture for achieving these goals is presented.



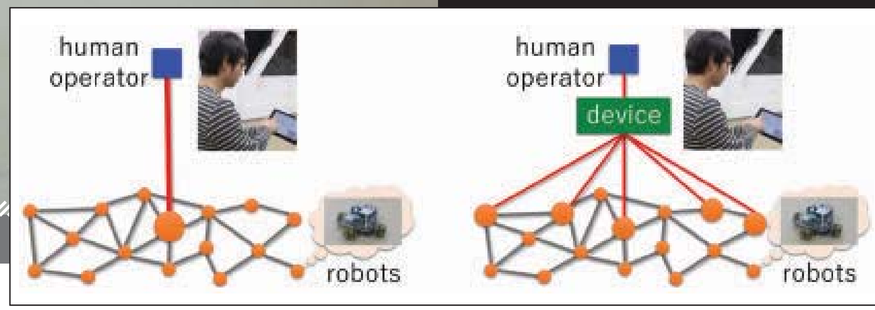


FIGURE 1 *(Left)* **Interaction between a robotic swarm and a human operator.**

FIGURE 2 *(Below)* **One-human-one-robot interaction (left) and one-human-multi-robots interaction (right).**

CONTROL ARCHITECTURE FOR HUMAN-ENABLED MOTION SYNCHRONIZATION

Imagine a scene in which a human operator maneuvers a robotic swarm toward a certain position or velocity based on visual feedback from the robots as in **Figure 1**.

In general, the operator can hardly determine more than one signal in real time, and hence a single signal from the operator needs to be utilized to supervise the robotic swarm. In addition, the information feedback to the operator also needs to be simplified so as to prevent operator fatigue and reduce errors.

Distributed motion synchronization schemes developed during the last decade have the potential to provide a solution to the above issues since they allow one to virtually view the robotic swarm as a single robot. For example, a trivial solution is to take the architecture detailed in **Figure 2** (left) [7,8], where only one robot interacts with the operator. However, this one-human-one-robot interaction is essentially fragile against communication failures. In this regard, the architecture in **Figure 2** (right) is preferable, wherein the information from multiple robots is fused before being presented to the human operator.

It is to be emphasized that the architecture in **Figure 2** is similar to those for the leader following or reference tracking studies that have been accomplished in the literature. The distinguishing feature of the proposed work is the presence of feedback from the robots to the operator. This feedback allows for flexible human decision-making and ensures the viability of global situation awareness.

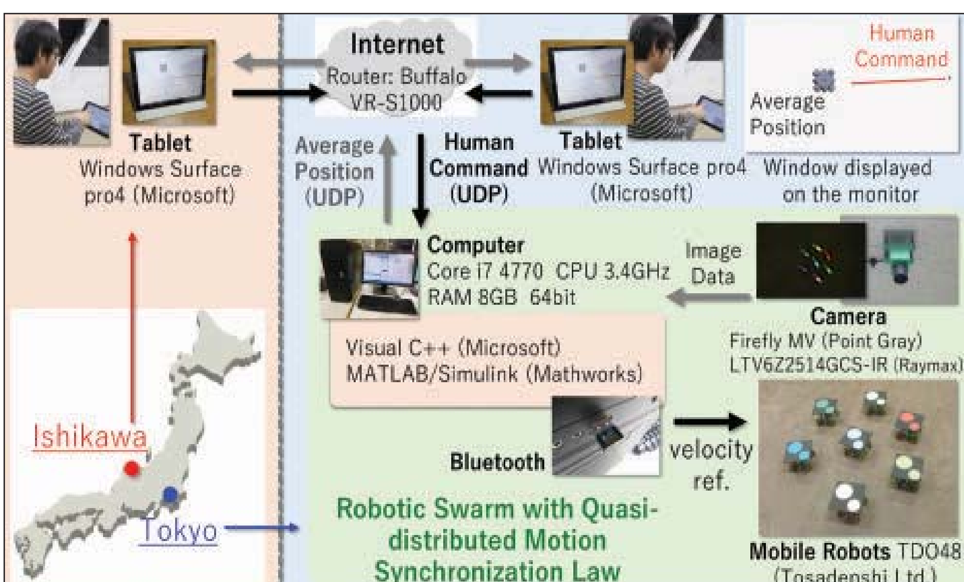
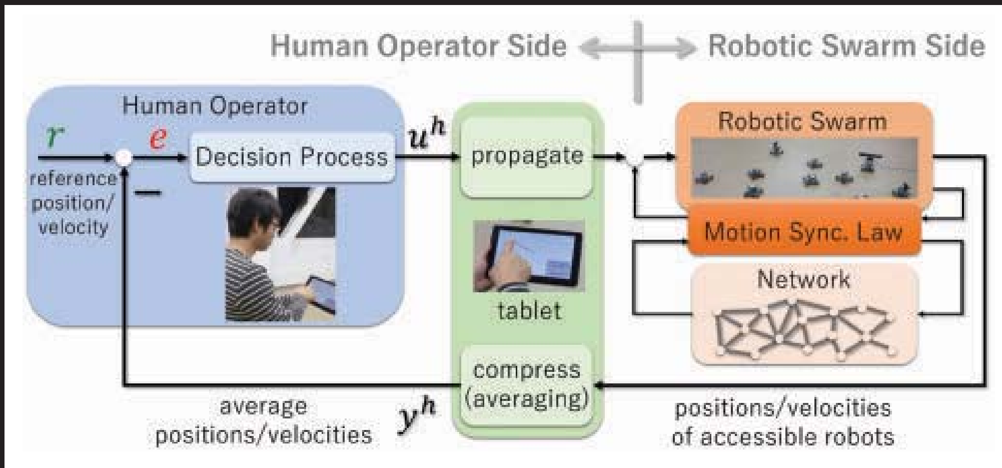


FIGURE 3 **Schematic of the present semi-autonomous multi-robot system.**

DESIGN OF SEMI-AUTONOMOUS ROBOTIC SWARM

As a solution to stable coordination via bilateral human-swarm interactions, the authors' group built the system in **Figure 3** consisting of multiple planar robots, an operator and a computer whose role is to implement the distributed motion synchronization law. In the system, the operator can choose either the position or velocity variable to be synchronized between the robots. A tablet is chosen as an interface to interact with the robots.

The computer first extracts the positions and velocities of the robots from the image data acquired by an overhead camera via image processing, and then computes the input for motion synchronization. Among a variety of potential synchronization laws, the present system employs the so-called PI consensus estimator [9] whose benefit is that both position and velocity synchronization are achieved by a single law and the robots are not required to share the selected variable to be synchronized. Simultaneously, the computer sends to a tablet the positions and velocities of accessible robots through the Internet. Accessible robots are a set of swarming robots that can receive input from the operator. The router is connected not only to a tablet in the room but also to a tablet at a



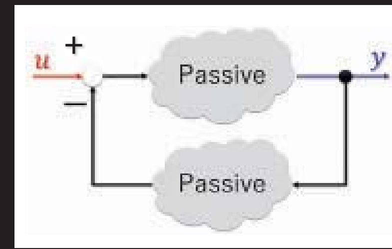
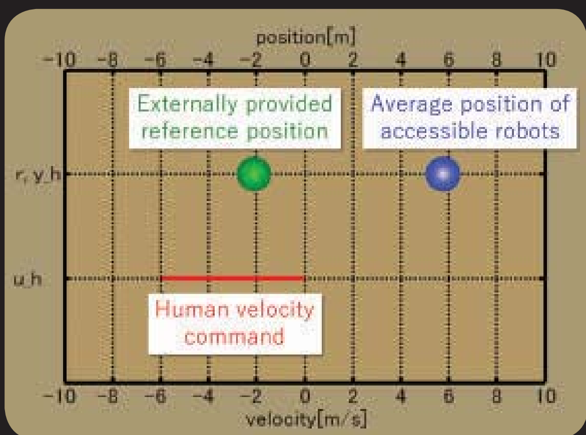


FIGURE 4 *(Left)* **Block diagram of the present control architecture.**

FIGURE 5 *(Above)* **Feedback interconnection of two passive systems, where the resulting closed-loop system is also passive from input *u* to output *y*.**



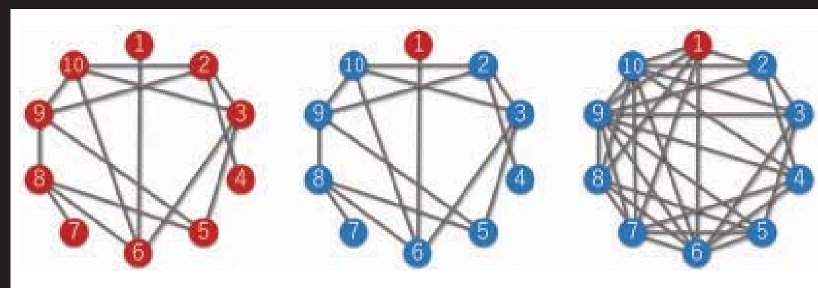


FIGURE 6 *(Left)* **Picture displayed on the tablet.**

FIGURE 7 *(Above)* **Network structures used for the human modeling, where the robots accessible from the human are colored red and the others blue. The left, middle, and right structures are called type 1, 2 and 3, respectively.**

distance of about 290km to simulate remote control.

Once the tablet receives the information from the computer, it displays the average position or velocity on its monitor depending on the variable to be synchronized. The operator then determines a velocity command, by the position of a finger tapping the monitor, so that the displayed information leads to a desirable position or velocity. In this case, the operator feels as if he is manipulating a single virtual robot with position (velocity) equal to the average position (velocity) of the accessible robots, thereby mitigating his cognitive load. The tablet then sends the human command to the computer.

Subsequently, the computer adds the received operator command to the computed synchronization input for the accessible robots, and communicates the resulting signal to each robot. The robots then regard the received signal as a velocity reference, and move so as to follow the reference velocity.

A condensed description of the signal flows is illustrated in **Figure 4**. It is to be noted that the error between the reference and the feedback information is internally computed in the operator brain.

WHY THIS ARCHITECTURE?

Consider a system from input $u \in R^p$ to output $y \in R^p$. The system is then said to be passive if the integral

$$\int_0^\tau y^T(t)\, u\,(t)\, dt$$

is lower bounded for any time τ and input signal u. This concept generalizes physical systems such that the internal energy never increases more than the energy supplied to the system [1]. Passivity is known to be preserved with respect to feedback interconnections in **Figure 5**, and stability of the closed-loop system is also ensured under additional assumptions [1].

A typical approach to stabilization of an interconnected system that includes a highly uncertain component like a human operator is to assume passivity of the component block. Specifically, modeling of the operator has been addressed in this manner for several studies in bilateral teleoperation [1]. If such a human model would also be acceptable in the present system, interconnecting the operator and robotic swarm in the form of **Figure 4** would guarantee closed-loop passivity as long as the robotic swarm is designed to be passive.

The above discussion inspires us to choose an appropriate y^h to be fed back to the operator so that the robotic swarm is passive with the input-output pair as (y^h, u^h), where u^h is the human operator input to the accessible robots. Fortunately, the property is guaranteed [2,3] if the output y^h is chosen to be the average position/velocity of the accessible robots under the assumption that the inter-robot communication is bidirectional and robots can directly determine their own velocities. This is why the operator feeds back the average information in the present system. In other words, it is passivity theory that provides critical insights into interconnecting the human operator and robotic swarm. Indeed, synchronization of the intended variable to the reference has been demonstrated [2,3].

HUMAN PASSIVITY ANALYSIS

Despite the above desirable result, an issue remains open, that is, validity of the key assumption on passivity of the human operator. To analyze the property, a human-in-the-loop simulator is developed, where the robot motion is restricted to one dimension in order to simplify the analysis.

The picture displayed on the tablet is shown in **Figure 6**. The blue dot is the average position of accessible robots, and the red bar is the human velocity command u^h to be sent to the accessible robots. The green dot is the externally-provided reference position, denoted by r, which is used as the input for system identification.

Since the human operator model needs to be identified through the process of the closed-loop system in **Figure 4**, a closed-loop system identification technique is employed. The detailed modeling procedure is described in [2,3] but, roughly speaking, two open-loop models from r to u^h and to $e=r-y^h$ are identified and then a model of the decision process is computed from these models.

Experiments for the human modeling are conducted for the three different network structures in **Figure 7**. For these networks, the human operator's models are identified using trial data for a subject. Please refer to [2,3] for more details on the trials.

Figure 8 illustrates the Bode diagrams of the identified human operator models for each network, where the dotted and solid curves describe the models before and after 10-min training, respectively. Ignoring the effects of nonlinearity, the operator is known to be passive if the phase diagram lies from -90° to 90°. In this regard, the models for type 3 provide an insight that the human approaches a passive system through training. However, for type 2, the subject does not attain passivity even after the training.

In previous work, the authors [2,3] experimentally demonstrated that a high-pass filter that modified the human command u^h is useful for overcoming the shortage of passivity. In this case, the cascade system of the operator and the filter can be viewed as a human. Bode diagrams of the cascade system identified using the data of additional trials after inserting the filter for the same subject are shown in **Figure 9**, where the dotted and solid curves describe the human models without and with the filter, respectively. It is seen that the cascade system attains passivity for all of the three network types.

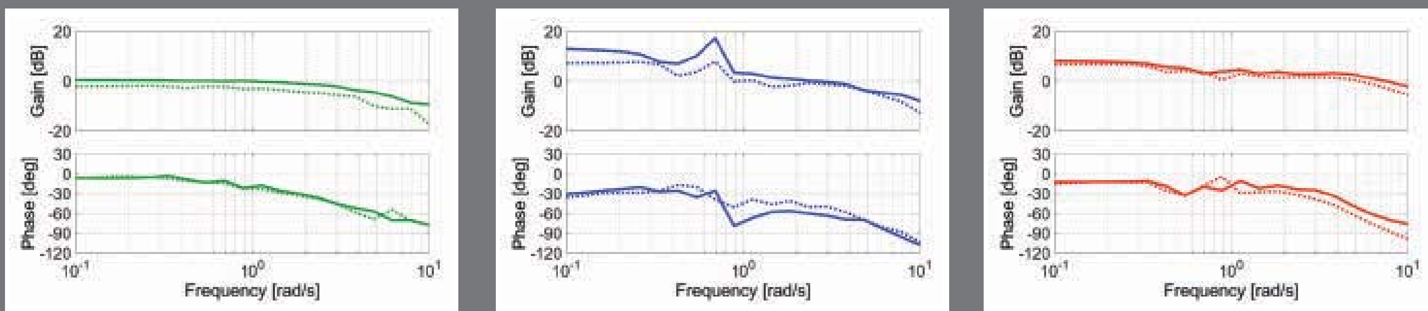
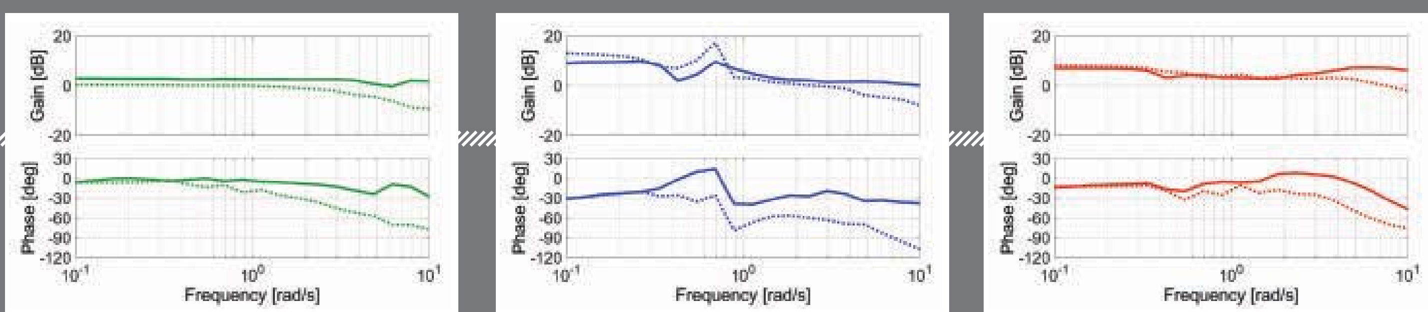


FIGURE 8 *(Above)* **and** FIGURE 9 *(Below)* **Bode diagrams of the identified human operator model without (Figure 8) and with the high-pass filter (Figure 9).**



REMOTE CONTROL EXPERIMENT

Experiments are finally conducted using the system in **Figure 3** with six mobile robots in Tokyo and a human operator with a tablet in Ishikawa. The inter-robot communication structure is illustrated in **Figure 10**, where robots 1, 3 and 4 are accessible from the operator. In order to avoid collisions, we aim at synchronizing, instead of the actual robot positions, virtual positions with biases, which are designed so that the robots eventually form a regular hexagon formation. In the experiments, the operator does not determine

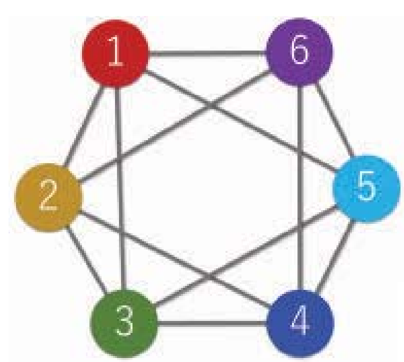


FIGURE 10 **Inter-robot communication network in the experiment.**

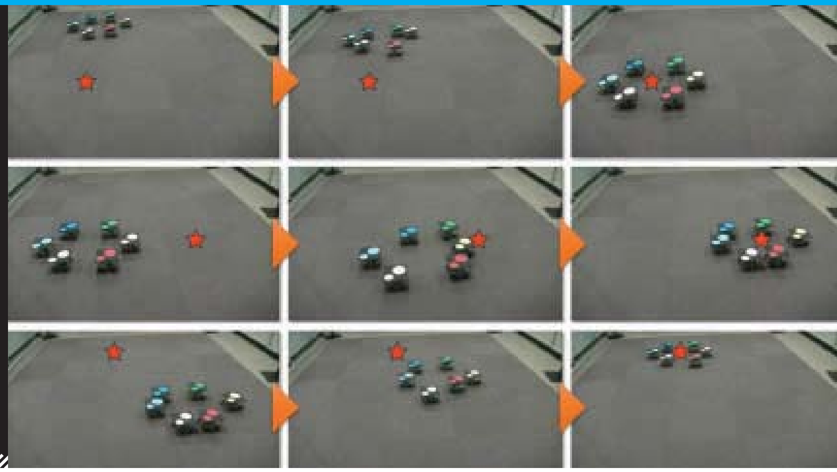


FIGURE 11 Snapshots of the experiments, where the red star describes the reference position shown to the operator. The figures in each row show the robots behavior for a common reference. The left figures are snapshots at the times of the reference switches, the right are those just before the switches and the middle show those at transient times.

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the reference position but it is determined by a computer to clearly observe the convergence. The reference is switched twice during the experiment.

Snapshots of the robots are presented in **Figure 11**. It is observed from the figures that the robots form and maintain the specified formation while they are maneuvered stably toward the desired references by the operator.

CONCLUSIONS

In this article, a novel semi-autonomous cooperative robotic system is presented. Information flows in the architecture are designed based on the passivity property. The human passivity needed to guarantee the control goal is demonstrated using a human-in-the-loop simulator and system identification techniques. Experimental results on remote control of the robots are finally demonstrated. ■

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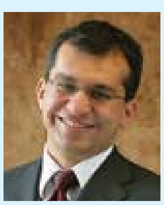

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HOW TO TRAIN YOUR ROBOT?

INFERRING INTENT DURING HUMAN-IN-THE-LOOP ROBOT LEARNING FOR OUTPUT-TRACKING

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Various studies over the years, focused on understanding the mechanisms of learning in humans, have agreed on the notion that primarily, new skills are learned by watching successful demonstrations by a teacher, followed by imitation and practice until the skill is mastered [4]. This is very commonly seen in infants and toddlers [1] as illustrated in **Figure 1**. Moreover, even in the animal world, such as in Capuchin monkeys, observations of a more proficient individual may benefit novices when subsequently acting on their own [2]. Formally, such a learning scheme is referred to as Learning from Demonstration (LfD) or Teaching by Demonstration (TbD) [5], [3], and is sometimes colloquially referred to by the endearing term, "monkey see; monkey do". Often the teacher might also physically hold the student's hand and demonstrate how to perform a task. For example, a tennis instructor might hold a student's hand and go through a tennis stroke as opposed to the instructor just displaying the stroke. This is referred to as kinesthetic teaching where the student's attention is directed to the effects of their movements while the learning is reinforced by real-time teacher feedback [7].

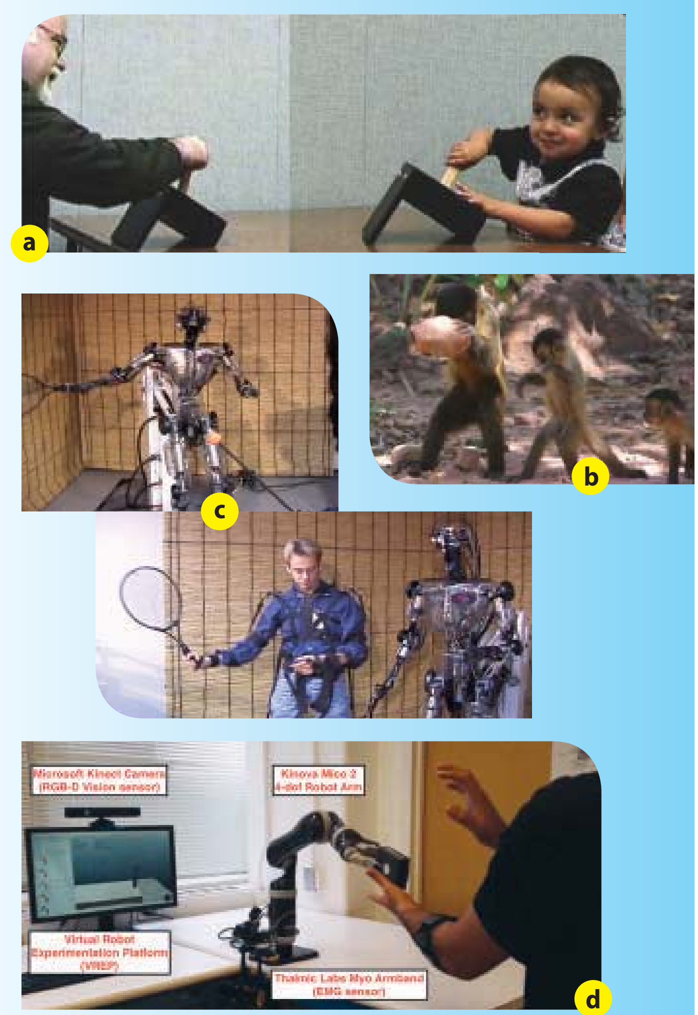

FIGURE 1 (a) Toddler learning to do the peg-in-the-hole task by observing and learning from demonstration, photo from [1], (b) Even in the animal world, such as in Capuchin monkeys, observations of a more proficient individual (e.g., using tools to crack hard fruit shells) may benefit novices when subsequently acting on their own [2], *photo by Barth Wright*. (c) Conventional imitation learning, photo from [3], (d) Human-in-the-loop robot learning.

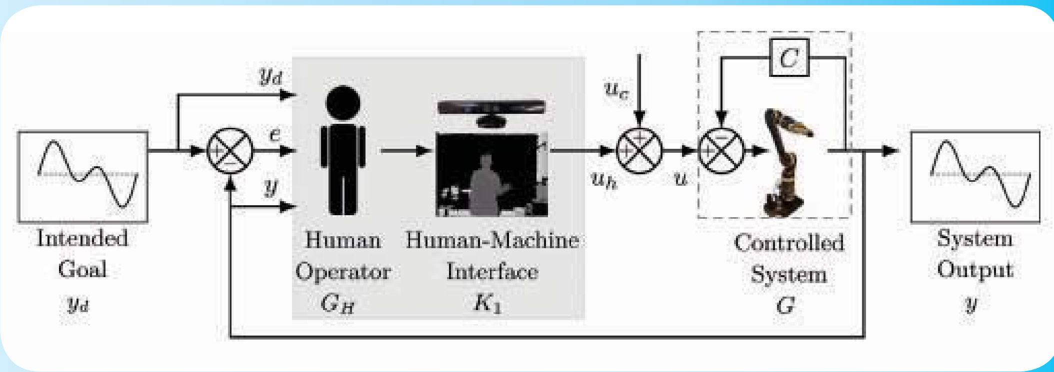

FIGURE 2 Human-in-the-loop trajectory tracking task, where the intended goal is to find the control input u_c to track a desired trajectory y_d with the output y of the controlled system G. G_H represents the human operator's feedback response dynamics. The challenge is that the human-intent y_d (i.e., the desired output) is not known to the controller when determining the input u_c.

Learning is also important as robots are being envisioned as social partners in a range of applications, as home caregivers to the elderly and as co-workers in manufacturing. In such scenarios, kinesthetic teaching of the robot partners may allow social robots to better adapt to their dynamic surroundings in response to the guidance from their human partners. Humans might also be tele-teaching robots, such as service robots [8], from afar to enable fewer operators to manage a fleet of service robots. However, high precision tele-operation tasks require human operators to undergo extensive training to achieve suitable levels of expertise to operate the robot, e.g., tele-operated precision surgery [9], tele-operation of equipment in confined spaces in manufacturing/assembly lines [10]. Nevertheless, such human-in-the-loop control exploits the ability of human operators to perform complex tasks (such as object detection in cluttered environments) while simultaneously ensuring safety and stability.

An advantage of the robot-learning framework is that it allows novice human operators, who may be experts in the task, but not in teaching a robot, to successfully achieve the task objectives, which can expand the usage and acceptability of robots in society. This is especially important in areas such as active prostheses/orthoses where the primary reason impeding widespread adoption is difficulty of use for first-time users [11]. Most often, problems in learning from the human arise not due to the complexity of controlling the robot per se, but due to the inherent limitations of the human response dynamics, which modify the intent of the human-in-the-loop so that the human actions are not sufficiently good reference trajectories that the robot should follow to achieve the intended goal. Therefore, inferring the intent behind the human operator's actions becomes important for human-in-the-loop robot learning, which is evident in human-robot collaborative tasks, e.g., when the human-robot team is collaboratively moving furniture [12]. Finally, model-based approaches have been studied to capture the human response dynamics [13], [14], in which case inverting such models results in estimating the human intent [15]. The estimated intent can then be used with conventional iterative learning control to achieve the desired task.

In the following, the effect of the human response dynamics on output-tracking performance is presented, followed by approaches to correct these effects. Issues in the human-response-model estimation when designing the iterative learning control are presented along with experimental results.

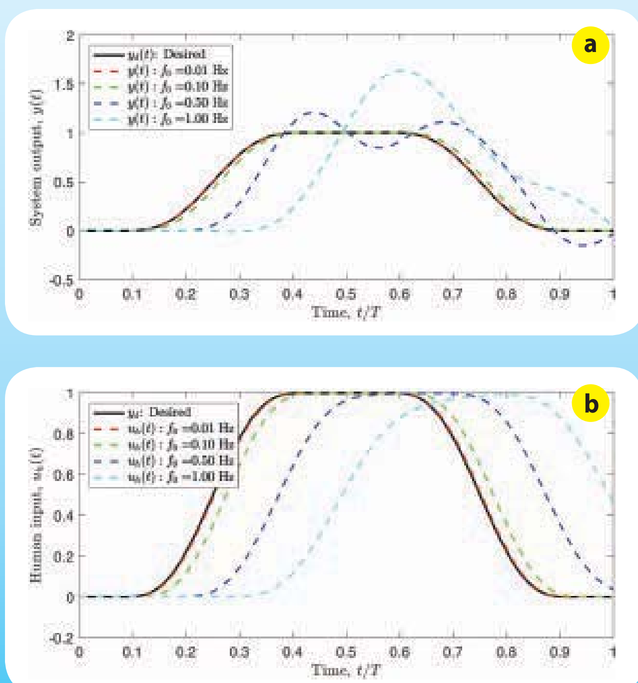

FIGURE 3 Simulation results when the controlled system is one, $G = 1$ in Figure 2, and desired output y_d defined as a reach-retract movement defined in Eq (4) with frequency $f_0 \in \{0.01, 0.1, 0.5, 1.0\}$ Hz for each trial. Human-in-the-loop output tracking using the Crossover pilot model to simulate human feedback response. (a) Tracking performance at higher frequencies is reduced mainly due to (b) phase errors between the desired output y_d and the human input u_h introduced by the human operator's dynamics G_h.

IMPACT OF HUMAN-RESPONSE DYNAMICS ON OUTPUT TRACKING

To understand the effect of the human response dynamics on robot learning, consider a human-in-the-loop trajectory-tracking task as shown in **Figure 2**, where the human operator performs the role of a feedback controller in operating a robotic-controlled system G to get the output y of the controlled system to match the intended goal y_d. This is a fairly typical human-in-the-loop configuration that is commonly observed, e.g., aircraft pilots, vehicular drivers, and heavy machinery operators. The human response dynamics (G_H in **Figure 2**) in such a scenario has been well studied in literature, and various empirical and analytical models exist that describe the human operator's feedback characteristics. For example, the Crossover Model, first introduced by McRuer et. al. [16], describes an analytical transfer function model where the parameter values and the specific model structure depend on both the specific human's characteristics as well as the controlled system G. It is sometimes referred to as an *analytical-verbal* model, where the *analytical* part of the model, G_H in **Figure 2,** is specified as,

$$G_H(s) = \frac{u_h(s)}{e(s)} = K_p \left(\frac{\tau_L s + 1}{\tau_I s + 1} \right) e^{-\tau_e s} \tag{1}$$

for $s = j\omega$ and $j = \sqrt{-1}$. The parameters in the model are: (1) K_p: operator static gain (including the human-machine interface gain K_1), (2) τ_e: effective time delay, (3) τ_L : lead-time constant, (4) τ_I: lag-time constant. The term inside the brackets is called the *equalization characteristic*, whose form depends on the type of controlled system G and the bandwidth of the reference signal y_d. The *verbal* part of the model refers to empirically validated adjust-

the situation when the output y of the controlled system G, such as a robot, is able to exactly track the commanded signal u, i.e., $y = u$. The desired output trajectory y_d is chosen to mimic a reach-retract movement with sinusoidal acceleration components of frequency f_0 as,

$$\frac{d^2 y_d}{dt^2}(t) = \begin{cases} A\sin(2\pi f_0(t-0.1T)), & \text{for } t \in [0.1T, 0.4T), \\ -A\sin(2\pi f_0(t-0.6T)), & \text{for } t \in [0.6T, 0.9T), \\ 0, & \text{otherwise.} \end{cases} \tag{4}$$

The plots in **Figure 3** show that at low frequencies, the tracking error is minimal and grows to be significant at high frequencies, mainly in terms of phase errors. Thus, imitation learning based on the human input (i.e., $u = u_h$) will not be sufficient and there is a need to infer the intended goal y_d from the human operator's actions u_h. The lack of access to the desired output y_d can be problematic for iterative learning control (ILC), since the input update in ILC depends on the tracking error, $y_d - y$. Thus, the primary challenge of robot learning with the human-in-the-loop is to overcome the limitation that the intended goal y_d is not directly available.

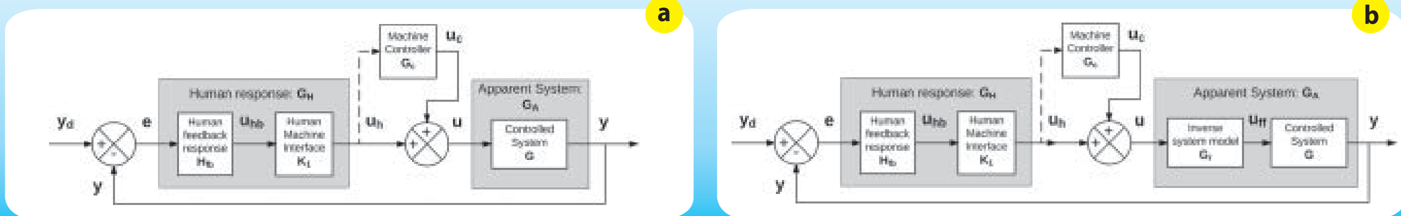

FIGURE 4 (a) Original system and (b) Modified system. Inverse control used to make the apparent controlled system, G_A seen by the human operator to be say a constant (or a first or second order system) for which typical parametric human models are available [18].

ment rules to determine the specific form of the equalization characteristic for different task conditions. As an example, consider a controlled system,

$$G(s) = K_c \tag{2}$$

where K_c is some constant, and suppose the reference trajectory y_d has a bandwidth f_{BW}=0.5 Hz (which is also the typical bandwidth of human visual smooth pursuit tracking [17]). The human-machine interface can be designed to set the operator static gain, $K_p \approx 1/K_c$. For a constant controlled system, $G = K_c$, the equalization characteristic has the form $1/(\tau_I s + 1)$. Then, the human-feedback transfer function model for the constant controlled system becomes,

$$G_H(s) = \frac{K_p}{\tau_I s + 1} e^{-\tau_e s} \tag{3}$$

with $K_p = 1/K_c$, τ_I = 0.2 s, τ_e=0.55 s, for a reference trajectory with bandwidth f_{BW}=0.5 Hz. Additional details of this human-response dynamics modeling procedure and experimental results using this model are available in [18].

A simulation shows the effect of the human operator on the closed-loop tracking performance is significant even when the controlled system in **Figure 2** is one, i.e., G = 1, and the control input is zero, i.e., u_c = 0. This represents

CORRECTING HUMAN-RESPONSE DYNAMICS

The human-response dynamics can affect the precision achieved by the human during human-in-the-loop operation. For example, during kinesthetic teaching of collaborative robots, the performance can be affected by the human operator's inability to achieve the required movements. Conventionally, the robot motion is taken to be the average of multiple demonstrations for a particular task. The averaged motion can still be affected by the human-response dynamics and can therefore be still different from the user's intent. Therefore, inferring the human intent is important and necessary in the context of human-robot shared control.

The main idea in the intent-inference scheme is that a known human model G_H may be inverted to obtain the intended goal y_d from the human input u_h and the measured output y as,

$$y_d(\cdot) = G_H^{-1}(\cdot) u_h(\cdot) + y(\cdot) \tag{5}$$

as shown in [15]. But, practical application of this model-inversion technique suffers from problems of modeling inaccuracies. In such situations, iterative learning control (ILC) [19] has been shown to result in improved tracking. Specifically, the proposed ILC update law for human-in-the-loop tracking is given point-wise at each frequency ω as,

$$u_{c,k+1}(\omega) = u_{c,k}(\omega) + \rho(\omega)\hat{G}_{fb}^{-1}(\omega)u_{h,k}(\omega) \quad (6)$$

for the k-th iteration step, where u_c is the learned control input, u_h is the human input, ρ is the iteration gain, and $\hat{G}_{fb}$ is the known model of the closed-loop system G_{fb}, given at each frequency ω as [15]

$$G_{fb}(\omega) = \frac{G(\omega)G_H(\omega)}{1 + G(\omega)G_H(\omega)} \quad (7)$$

where G is the controlled system, and G_H is the known human-response model in **Figure 2** considering only the compensatory feedback channel of the human response, i.e., $u_h(\cdot) = G_H(\cdot)e(\cdot) = G_H(\cdot)(y_d(\cdot) - y(\cdot))$. Briefly, the derivation of the update law in (6) follows from finding the control input $u_{c,k+1}$ that results in making the error small in the next iteration step, see [15] for details. The convergence of such ILC algorithms for human-in-the-loop trajectory tracking depends on the modeling error of the closed-loop system [15], [18].

MODEL SELECTION

As discussed earlier, the human-response model G_H depends on the type of system G being controlled.

1) When the system being controlled G is a constant, or a first or second order system, parameterized approaches such as the Crossover Pilot models are effective in developing iterative control approaches as shown in [15]. Nominal parameter models describe human feedback performance well up to a limited frequency range.

2) For more complex controlled systems G, typical parametric human models are not available. In this case, two options are available: (i) use more general human models that are valid for complex controlled systems [20], [13], [21], or (ii) modify the apparent controlled system G_A seen by the human operator to be of the type (such as a constant or a first or second order system) for which typical parametric human models are still available, as illustrated in **Figure 4**. The latter option can be achieved with conventional methods such as model-reference control, inverse

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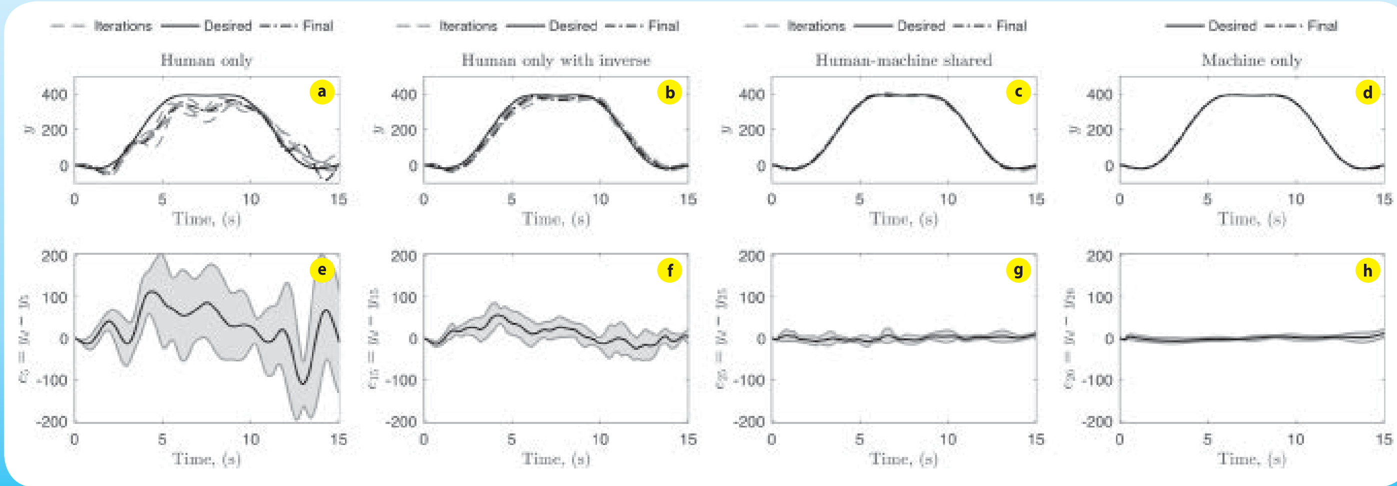

Figure 5 Adapted from [18]. Convergence of iterative inversion-based impedance matching control for target bandwidth frequency, f_{BW} = 0.2 Hz, and NMP controlled-system, G, with multiple human subjects. (a) System output, y_k, during human-only control with apparent system, $G_A = G\,(k \in [1, 5])$. (b) System output, y_k, during human-only control with apparent system, $G_A = G_r G\,(k \in [6, 15])$. (c) System output, y_k, during shared human-machine ILC with apparent system, $G_A = G_r G\,(k \in [16, 25])$. (d) System output, y_k, during machine-only control with apparent system, $G_A = G_r G\,(k = 26)$. (e) Tracking error, $e_5 = y_d - y_5$ at the end of human-only control ($k = 5$). (f) Tracking error, $e_{15} = y_d - y_{15}$, at the end of human-only control with inverse system included ($k = 15$). (g) Tracking error, $e_{25} = y_d - y_{25}$, at the end of shared control ($k = 25$). (h) Tracking error, $e_{26} = y_d - y_{26}$, during machine-only control ($k = 26$). Solid lines: mean trajectories over nine subjects. Shaded region: one standard deviation over nine subjects.

control, or even feedback control. Preview-based online inversion is a viable technique that allows for stable online inversion of complex linear controlled systems, even those for which stable causal inverses do not exist, such as non-minimum phase systems. Details of this system inversion technique for human-in-the-loop trajectory tracking is described in [18].

3) Parametric human models are restricted to a small range of frequencies, above which they deviate from actual human response. This limits the range of frequencies that can be tracked when using such models. Recent work has focused on extending the range of tracking frequencies, mainly by using online data-based modeling approaches, e.g., [22]. Additionally, such data-based approaches also make it possible to estimate more general human response models, i.e., involving all possible input channels shown in **Figure 2**, such as the feed-forward (y_d as input) and internal loop (y as input) channels in addition to the compensatory feedback channel ($e = y_d - y$ as input) [23]. Moreover, the estimated models can be improved when more data becomes available during the robot operations, allowing for improved personalization over time.

RESULTS FROM ITERATIVE LEARNING

The results of applying the inversion-based iterative learning scheme to the human-in-the-loop trajectory tracking task in **Figure 2** are presented next. **Figure 5** shows that the output tracking performance improves with respect to the manual tracking performance when inverse control is applied (about 70% reduction in tracking error). When the iterative learning control law is applied, further tracking improvement is achieved (about 20% additional reduction in tracking error). Thus, the learned control input can successfully emulate the human intent. ■

ABOUT THE AUTHORS

Rahul B. Warrier received the B.Tech degree in Mechanical Engineering from the Indian Institute of Technology, Madras, India, in 2011. He is currently working toward the Ph.D. degree in the Department of Mechanical Engineering at the University of Washington, Seattle, USA. His current research interests include human intent inference and skill transfer in human-in-the-loop learning tasks using a control theoretic approach.

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TENTH ASME DYNAMIC SYSTEMS AND CONTROL CONFERENCE 2017

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The DSC Conference, organized and led by the members of the ASME DSC Division, provides a focused and intimate setting for dissemination and discussion of the state of the art in the broad area of dynamic systems and control from theory to industrial applications and innovations in education.

In addition to regular sessions, the conference program will also include contributed sessions, invited sessions, tutorial sessions, special sessions, workshops, and exhibits.

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2018 AMERICAN CONTROL CONFERENCE

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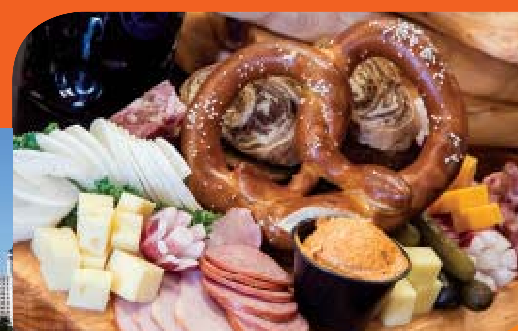

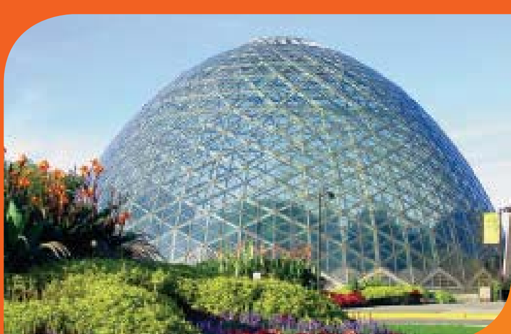

DETAILS CAN BE FOUND ON THE CONFERENCE WEB SITE AT HTTP://ACC2018.A2C2.ORG

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

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

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

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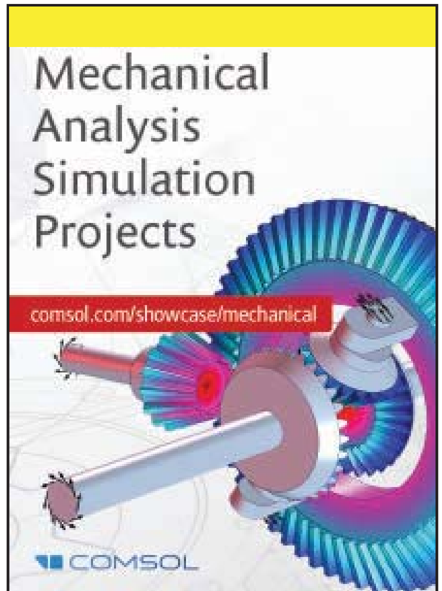

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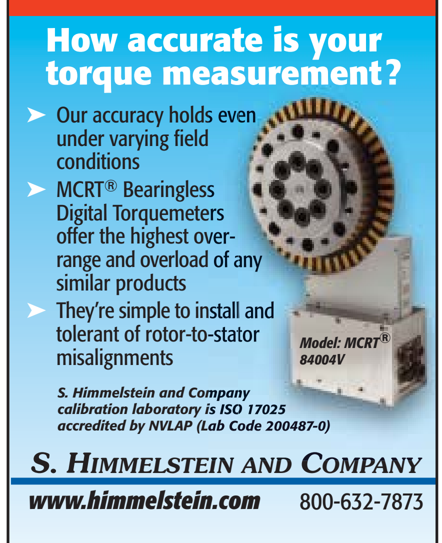

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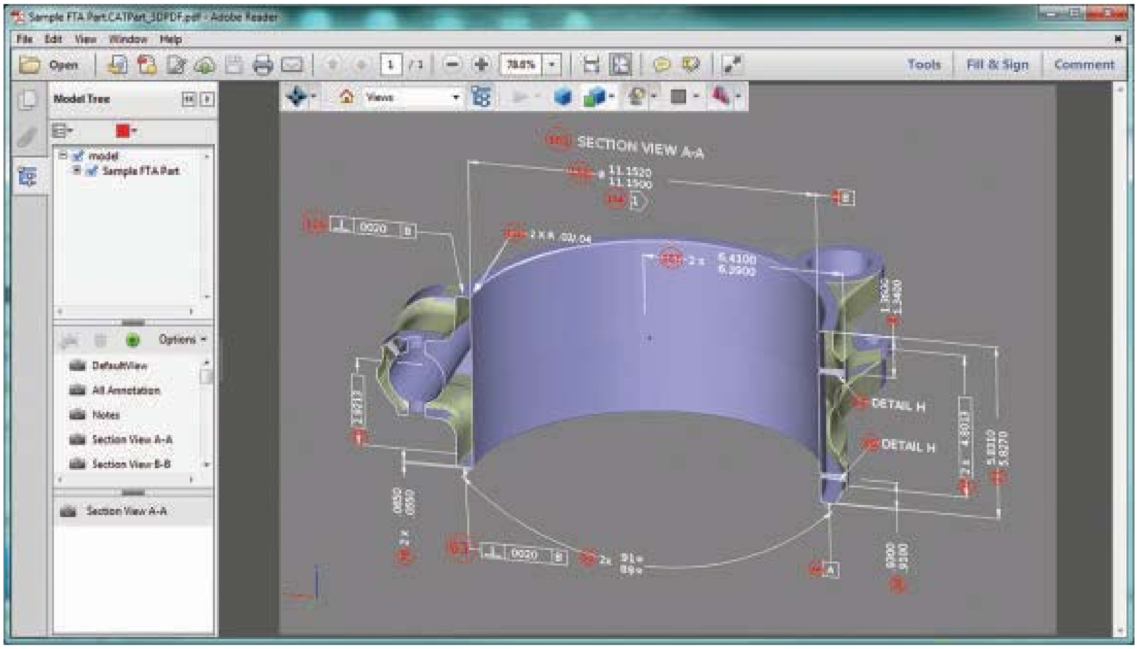


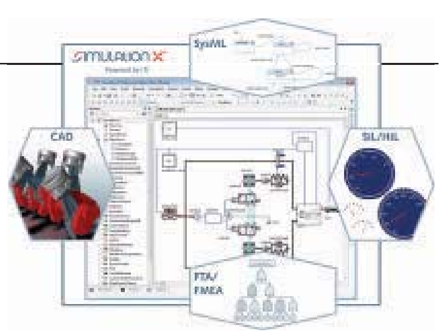
IDENTIFICATION AND REPORTING

INSPECTIONXPERT, APEX, N.C.

THE COMPANY HAS COMBINED InspectionXpert OnDemand and InspectionXpert OnDemand for CAD into a single product. Optical character recognition enables InspectionXpert OnDemand 2.0 to read product and manufacturing information from image-based PDF and TIFF files. Another feature allows users to extract PMI from multiple annotations in a single step, automatically identifying and creating individual characteristics in seconds. That feature, SmartExtract, is supported for a variety searchable text PDFs and native CAD file formats, including CATIA, AutoCAD, Pro|ENGINEER/Creo, and UG-NX to provide significant improvements in both speed and accuracy over manual methods.

SYSTEMS MODELING

ESI GROUP, PARIS.



ESI Group, an international provider of virtual prototyping software and services, released SimulationX, a platform for dynamic multi-physics system simulation that is tailored to the specific needs of various industries. With significant enhancements and added features, the application can simulate drive systems, electromechanics, hydraulics, and pneumatics for industries such as transportation, energy, industrial and mobile machinery, and mining. New functions will also help facilitate development of biomedical devices and prosthetics. The efficiency of energy systems for modern cities, including heat and combined grids, can now be optimized via ESI's update to SimulationX.

BATCH PROCESSING

JTB WORLD, STOCKHOLM.

SmartPurger 3.8 is a batch and script utility for processing multiple AutoCAD drawings with full control. The application handles crashes so the AutoCAD batch processing continues to the end and leaves bad drawings to be corrected manually. The latest release enables users to delete only certain "garbage" files without having to also run AutoCAD to purge and process custom scripts. It also provides quick access to the deleted files log file through new button on

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delete tab, and bugs related to usage with AutoCAD 2017 have been fixed. The upgrade is free to users who have purchased a license.

INTERNET OF THINGS

KEPWARE TECHNOLOGIES, PORTLAND, ME.

KEPServerEX version 5.21 extends the connectivity options available within KEPServerEX and expands interoperability with the ThingWorx Internet of Things platform by introducing a ThingWorx native client interface. That interface is built to provide rapid connection to industrial things—including PLCs, RTUs, PACs, DAQs, and controllers. The ThingWorx native client interface leverages Kepware's library of more than 150 communication drivers to provide real-time, bidirectional industrial controls data to the ThingWorx IoT platform. The update also enables users to connect and configure ThingWorx-developed applications to KEPServerEX. The update is provided free of charge with the KEPServerEX installation or through the ThingWorx Marketplace.

VISUAL ANALYSIS

KONINKLIJKE PHILIPS N.V., AMSTERDAM.

IntelliSpace Portal 9.0 is the latest version of Philips' advanced, quantification and visual analysis platform that provides 3-D printing and 3-D rendering for physicians. Clinicians can print detailed, high-resolution 3-D medical models with the STL export feature. The new version features expanded neurological tools to combat brain injuries and dementias and 3D models, so as to better understand patient anatomy, as the use of 3D printing technology has become more frequent in the medical world. IntelliSpace Portal 9.0 helps radiologists detect, diagnose, and follow up on treatment of diseases using longitudinal brain imaging (not yet approved in the U.S.) and NeuroQuant, which enables clinicians to quantify brain loss. The new version also includes key updates and tweaks to MR cardiac analysis and CT TAVI planning and can be accessed from any point in the hospital network.

CONSTRUCTION PLANNING

TEKLA, ESPOO, FINLAND.

Tekla Structures, the advanced BIM software, releases its new formwork placing tool set, streamlining the formwork planning process by automating drawing creation and material quantification. Enhanced visualization, coordination and communication is made possible by the constructible formwork models, so contractors can reduce risks when pouring concrete on site. The software allows effective management of pours thanks to advanced technology. Now available for download in Tekla Warehouse, the toolset enables intuitive and accurate placing of any wall formwork system quickly. Utilizing the pour and concrete geometry in Tekla models makes formwork system placing of such elements as wall panels, corners, ties, clamps, fillers, and shoring, more user friendly than before.

HARNESS PLANNING

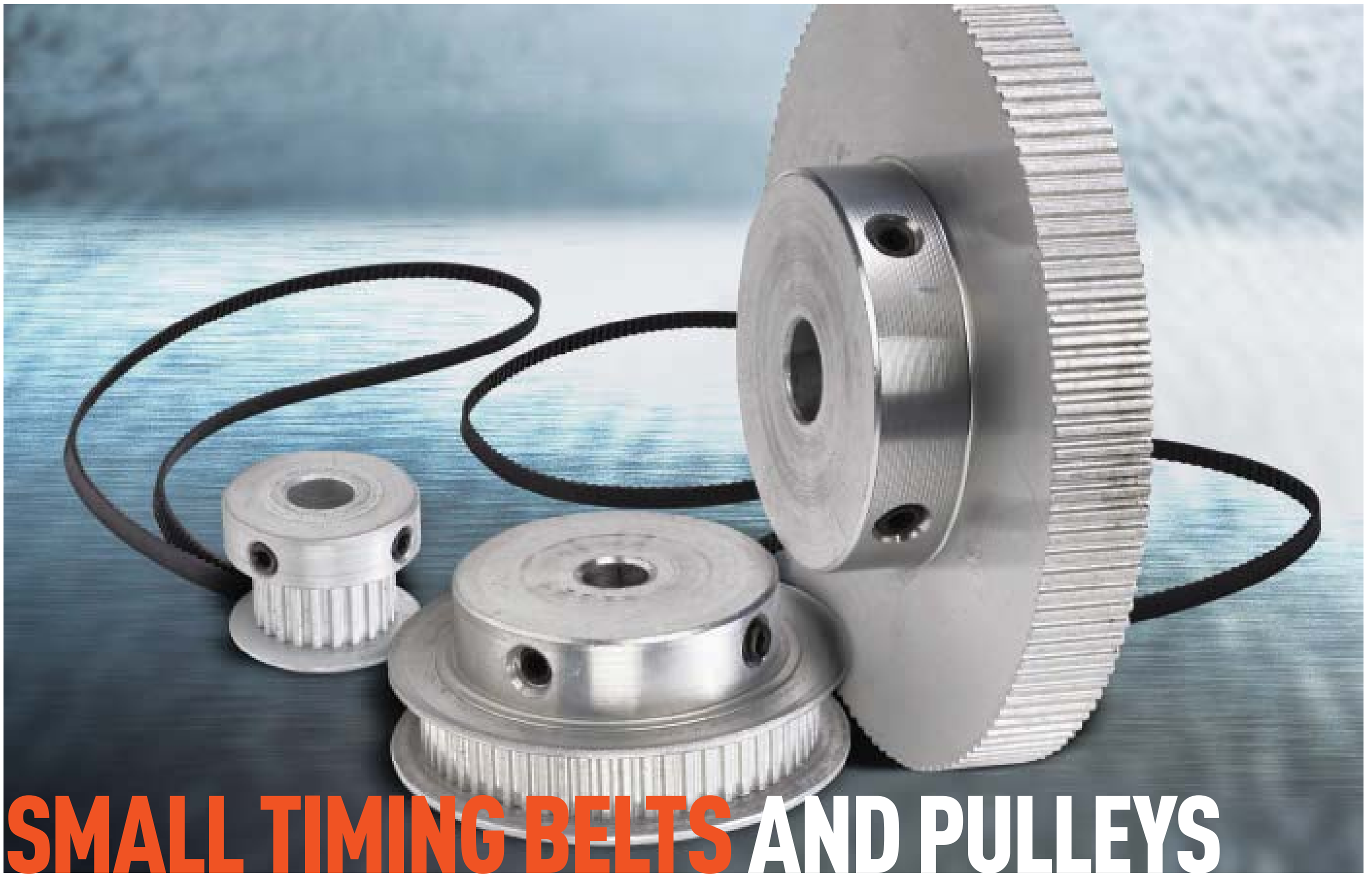
EPLAN, NUREMBERG, GERMANY.

EPLAN released its Harness proD version 2.6 application for cabling and wire harness engineering. EPLAN Harness proD 2.6 is based on the 3-D model of the mechanics and electrical schematics so the wire harness is designed in an intuitive manner. Major updates in the area of handing over the data to manufacturing, have been made. Integrating 2-D cable drawings allows for automatic dimensioning, saving valuable time and ensuring correct results. The design phase will now include defining stripping lengths and wire coatings, providing users with a comprehensive overview of their projects. Wires with predefined length can now easily be routed in an intuitive way and the current and targeted length are able to be depicted exactly so users can see how to optimally route the wires.

MACHINING DESIGN

GEOMETRIC AMERICAS, SCOTTSDALE, ARIZ.

Geometric Americas, Inc., has released CAMWorks 2017 featuring more than 60 customer-driven enhancements, including tolerance-based machining, which uses tolerances and non-geometric data in a 3-D CAD model to select optimal machining strategies and create toolpaths automatically. The update to the high-speed machining tool provides recommended feed and speed parameters to maximize the performance of VoluMill high-speed machining. 3-D interconnect in SolidWorks and CAMWorks Solids now provides a continuous path of associativity from 3-D model changes in all leading 3-D CAD formats, and the enhancement to SolidWorks integration ensures that design and manufacturing models are one and the same.



SMALL TIMING BELTS AND PULLEYS

AUTOMATIONDIRECT, CUMMING, GA.

THE COMPANY HAS ADDED to its SureMotion line of motion control products. The new addition includes synchronous timing belts and pulleys for small motor applications. Intended for various industrial applications, SureMotion MXL series timing belts are 1/4-inch wide, have a 0.080-inch pitch, and are available in neoprene with fiberglass reinforcement and urethane with polyester reinforcement styles. Neoprene belts are known for their excellent resilience and flame resistance. They are available in lengths from 36 to 500 teeth and start at $5.75 for a three-pack. Urethane belts, which have excellent wear resistance as well as oil and ozone resistance, are available in lengths from 36 to 400 teeth and start at $10.50 for a three-pack.

METAL CLAD CABLES FOR HEALTHCARE

AFC CABLE SYSTEMS, NEW BEDFORD, MASS.

Electrical product manufacturer AFC Cable Systems has released the MC Luminary HCF cables, a new addition to AFC's line of MC Luminary metal-clad cables. The cables combine electric lighting and control circuits under an interlocked armor and is approved for use in patient-care areas. A dual grounding path featuring a combined armor and full-sized aluminum ground/bonding conductor enhances safety. The new lighting control wire design responds to increasing use of solid state LED and fluorescent lighting fixtures in healthcare. MC Luminary HCF cables can be surface-mounted, fished, or embedded in plaster, while parallel bonding/grounding conductor enables faster termination.

HOLE FINISHING

WIDIA, LATROBE, PA.

Widia's new Top Ream design solution uses a single carbide disc and brazed joint. With a strong connection it is virtually immune to thermal effects during machining operations. As the use of additive manufacturing and other near net-shape processes continue to grow, so too will the need for accurate, cost-effective hole-finishing. Widia's WU05PR advanced reaming grade was developed specifically for the demanding tool wear and surface finish requirements encountered in most hole-reaming operations. The Top Ream features custom geometries, diameters, and edge preps, all available in three weeks or less. The Top Ream's design is geared towards anyone who needs fine hole finishes and high productivity rates, whether it's a Tier 1 automotive company or the small job shop down the street.

CONTRAST SENSORS

AUTOMATIONDIRECT, CUMMING, GA.

AutomationDirect has designed Datalogic print mark contrast sensors with 6-12 mm sensing distances that detect the difference in the wavelength of the reflected light between a target mark and background. The sensors use RGB light emission with automatic selection and sensitivity adjustments. They also feature selectable light on/dark on outputs and new TL Series contrast sensors with vertical or horizontal spot orientation, operating voltages ranging from 10 to 30 V dc, aluminum housings, and NPN/PNP logic outputs and are fitted with a 5-pin M12 quick-disconnect with adjustable exit angle. Datalogic print mark contrast sensors are CE, RoHs and Reach compliant.

BELLOWS COUPLING

R&W, BENSENVILLE, ILL.

The new SP3 couplings from R&W features an integral clamping ring system. The base hub components are held to a high level of concentricity between the two respective bores during the assembly process. An external clamping ring provides the advantage of symmetrical construction even when it comes to the small amounts of deformation during clamping compression onto the shafts, so inconsistencies in tightening the clamping system are contained to the ring itself, with the coupling straightness remaining highly accurate during installation. The couplings are available in sizes from 60 Nm to 500 Nm, with much higher torque capacities, custom flanges, and materials on request.

CERAMIC DIE

MORGAN ADVANCED MATERIALS, WINDSOR, U.K.

Morgan Advanced Materials has announced the release of a new ceramic extrusion die. Nilcra Zirconia TS Grade, a high performance, hot extrusion die, which is manufactured using advanced ceramic materials specially designed for use within copper and brass extrusion. This enables engineers to significantly reduce costs and issues associated with poor die life, dimensional control, inferior surface finish, and high scrap rates. An ultra-tough Mg-PSZ Zirconia, Nilcra Zirconia TS Grade has been proven by Morgan to provide up to a 30 times lifetime increase when compared to alternative metal dies.

ULTRA HIGH TORQUE BRUSHLESS SLOT-LESS MOTOR

PORTESCAP, WEST CHESTER, PA

Portescap has introduced the newest addition to their Ultra EC minimotor platform: the 22ECT brushless motor, designed specifically to deliver high torque in a compact size. With the unique coil technology and a patent pending multipolar rotor design, the 22ECT is specifically optimized for high, continuous torque at low to medium speeds, maximizing power between 10,000 and 20,000 rpm. Constructed with an enhanced high-efficiency magnetic circuit, the new 22ECT stays cooler and offers greater power density than many competing motors. A long-lasting and high-performance brushless motor with a low inertia design, the 22ECT is intended to be an option for applications requiring fast stopping, starting, and acceleration.

WELDING GUN

CENTERLINE, WINDSOR, ONT.

The FlexGun UL is a lightweight robotic welding gun now offered by CenterLine. Available in X, C, and pinch base designs, it is supplied in about 100 standard model configurations. The majority of the FlexGun UL models have total gun weights under 70 kg (155 lb.) which make for ideal use on 80 kg capacity robot models. They also may be suitable for high density welding cell designs and a range of spot welding applications. With an integrated robot mounting, superior strength-to-weight ratio construction, and symmetrical design, the FlexGun UL has an industry-leading life expectancy.

ATOMIZING NOZZLES

EXAIR, CINCINNATI, OHIO.

Exair's No Drip internal mix atomizing nozzles atomizes fluid and sprays at a right angle to the nozzle orientation. Working in the same way their standard atomizing nozzles do, liquid flow can be stopped when the compressed air supply is shut off, positively sealing off the flow of liquid. The nozzles are ideal where no post-spray drip is permissible. Available in five patterns—narrow angle round pattern, wide-angle round pattern, flat fan pattern, deflected flat fan pattern, and 360° hollow circular pattern—they are CE compliant and conflict mineral free.

SLIP RING

LEINE AND LINDE SYSTEMS, SCHAUMBURG, ILL.

Leine and Linde has introduced the new ADSR, the first diagnostic system for analyzing condition and predicting remaining service life within slip rings. Useful in onshore and offshore wind turbines, the centerpiece of the ADSR is the integrated sensors for measuring vibrations, the level of voltage and current, number of revolutions, internal and external humidity, and temperature. This systematic monitoring enables the expected remaining service life of the slip ring to be displayed, both in terms of time and revolutions. The ADSR's diagnostic system continuously monitors the contact systems and other key functions of the slip ring, enabling condition-based maintenance for optimized value. The ADSR slip ring is customized to meet specific individual design requirements and supplied from one single source.

SEALED ROTARY ENCODERS

HEIDENHAIN, SCHAUMBURG, ILL.

Heidenhain has introduced the ROD 620 and 630 models of the ROD 600 series. The design of these encoders enables the application in machine tools, plant construction, and position-feedback systems for controlling asynchronous motors. The ROD 600 encoders are now officially offered globally, after being sold in the Japanese market. Also, the newly integrated EMC design of the encoder series now complies with the requirements of the CE directives for European markets. The rotary encoders of the ROD 600 series are characterized primarily by an improved reinforced bearing with a high axial and radial-load capacity and a solid flange socket connection. Heidenhain also offers multiple couplings for interfacing the encoder with the rotating mechanism.

NON-CONTACT SAFETY SWITCHES

OMEGA, STAMFORD, CONN.

Omega is introducing coded non-contact safety switches with universal, slim, and European industry standard fittings. The Omega LPC/LMC, CPC/CMC, SPC/SMC series of coded non-contact safety switches high-quality constructed universal designs. With coded magnetic actuation, and a NEMA PW12 (IP69K) rating to fit a wide range of factory automation applications, they interlock to hinged, sliding, or removable machine guard doors in factory automation applications.

MILLING MACHINE

ROLAND DGA CORPORATION, IRVINE, CALIF.

Roland DGA Corporation, a manufacturer of 3-D milling machines, 3-D printers, and engraving machines, has announced the launch of the Modela MDX-50 benchtop CNC Mill. MDX-50 comes with easy-to-use CAM software and features a number of enhancements over Roland's popular MDX-40A mill, including a larger workspace, an automatic tool changer, and faster milling speed. The MDX-50 boasts many of the same features of the MDX-40A, plus a number of improvements that allow for greater productivity and an easier, safer user experience. The machining area is 60 percent larger, to accommodate larger models, and is equipped with a standard automatic tool changer that further enhances productivity by reducing the time and effort required to replace tools. An optional rotary axis unit can rotate work materials 360° for milling cylindrical objects and automating the fabrication of two-sided, four-sided, and custom-angled items. Together, these advanced features ensure trouble-free, uninterrupted production.

SUBMISSIONS

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ELECTRIC DRIVE

DANFOSS, NORDBORG, DENMARK

Danfoss has introduced the Vacon 20 ac drive. With its compact size and wide power range, combined with built-in, highly flexible PLC functionality, the Vacon 20 is one of the most adaptable, cost-efficient ac drives for packaging machine applications. Available in a range of common voltages and a power range up to 18.5 kW (25 hp), the Vacon 20 offers something for OEMs worldwide. Vacon 20 is intended to cut cycle times and provide maximized control for users. The built-in RS-485 interface offers a simple serial control interface for the drive. The Vacon 20 can be connected to almost any communication system including CANOpen, Fieldbus, DeviceNet, and Profibus DP. Easy-access terminals, built-in DIN rail mounting and the MCA parameter-copying tool, which can clone settings without main power in the drive, are all features that help reduce start-up time.

MILLING MACHINE

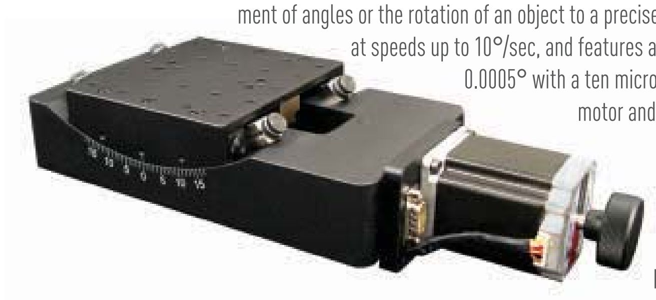
PEMA, LOIMAA, FINLAND.

Pema's new CM 55 milling machine is intended to improve welding quality and efficiency, while also providing ease-of-use to operators. Additionally, features included in the CM 55 are specifically designed to reduce defect rate. With the ability to mill efficiently and precisely, the design of the CM 55 is intended to produce quality circumferential seams while ensuring precise groove preparation and root opening even in the thick walls. The milling depth can be up to 140 mm while providing 55 kW spindle power. The depth control is equipped with high-accuracy servo slide and sensor feedback. Pema's CM 55 milling machine is equipped with lifting points that promote portability, and the main frame is supported and levelled with hydraulic legs.

GONIOMETER STAGE

OPTIMAL ENGINEERING SYSTEMS, VAN NUYS, CALIF.

Optimal Engineering Systems, Inc., has released the AK130-15 Goniometer Stage—a low-cost, low-profile solution for the precise measurement of angles or the rotation of an object to a precise angular position. The 120 mm-by-130 mm table has +/- 15° of rotation at speeds up to 10°/sec, and features a precision ground worm gear with a 304:1 ratio and a resolution of 0.0005° with a ten micro-step per step stepper motor drive. The stage is available with a servo motor and optical encoder and is ideal for microscopy, crystallography, measurements of surgical cutting blades, laser positioning, light measurement, and inspection applications. Mounting holes on the stage and in the base assure easy integration into applications, and a calibrated indicator displays the angle of rotation. The stage can be ordered plug-and-play with a fully compatible controller from OES.



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If you are looking for information regarding an ASME code or standard committee, conformity assessment program, training program, staff contact, or schedule of meetings:

PLEASE VISIT OUR WEBSITE: WWW.ASME.ORG/CODES

COMMITTEE LISTING: For a listing of ASME Codes and Standards Development Committees and their charters, visit the Standards and Certification website at http://cstools.asme.org/charters.cfm.

CONFORMITY ASSESSMENT: For a listing and description of ASME Conformity Assessment (accreditation, registration, and certification) programs, visit the Standards and Certification website at go.asme.org/certification.

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STAFF CONTACTS: To obtain the ASME staff contact information for a Codes and Standards Development Committee or a Conformity Assessment program, visit the Codes and Standards website at http://cstools.asme.org/staff.

SCHEDULE OF MEETINGS: Meetings of Codes and Standards Development Committees are held periodically to consider the development of new standards and the maintenance of existing standards. To search for scheduled meetings of Codes and Standards Development Committees, by date or by keyword, visit the Standards and Certification website at http://calendar.asme.org/home. cfm?CategoryID=1.

PUBLIC REVIEW DRAFTS

An important element of ASME's accredited standards development procedures is the requirement that all proposed standards actions (new codes and standards, revisions to existing codes and standards, and reaffirmations of existing codes and standards) be made available for public review and comment. The proposed standards actions currently available for public review are announced on ASME's website, located at http://cstools.asme.org/csconnect/PublicReviewpage.cfm.

The website announcements will provide information on the scope of the proposed standards action, the price of a standard when being proposed for reaffirmation or withdrawal, the deadline for submittal of comments, and the ASME staff contact to whom any comments should be provided. Some proposed standards actions may be available directly from the website; hard copies of any proposed standards action (excluding BPV) may be obtained from:

MAYRA SANTIAGO, Secretary A
ASME Standards & Certification
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ASME maintains approximately 500 codes and standards. A general categorization of the subject matter addressed by ASME codes and standards is as follows:

Authorized Inspections
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Bioprocessing Equipment
Boilers
Certification and Accreditation
Chains
Controls
Conveyors
Cranes and Hoists
Cutting, Hand, and Machine Tools
Dimensions
Drawings, Terminology, and Graphic Symbols
Elevators and Escalators
Energy Assessment
Fasteners
Fitness-For-Service
Gauges/Gaging
Geometric Dimensioning & Tolerancing (GD&T)
High-Pressure Vessels Systems
Keys and Keyseats
Limits & Fits
Materials
Measurement of Fluid Flow in Closed Conduits
Metal Products Sizes
Metric System
Metrology and Calibration of Instruments
Nondestructive Evaluation/ Examination-Nuclear
Operator Qualification and Certification
Performance Test Codes
Piping & Pipelines
Plumbing Materials and Equipment
Post Construction of Pressure Equipment and Piping
Powered Platforms
Pressure Vessels
Pumps
Rail Transportation
Reinforced Thermoset Plastic Corrosion Resistant Equipment
Risk Analysis
Screw Threads
Steel Stacks
Surface Quality
Turbines
Valves, Fittings, Flanges, Gaskets
Verification & Validation
Welding & Brazing

The ASME Standards & Certification section is published as submitted to Mechanical Engineering magazine by ASME's Standards & Certification Department.

POSITIONS OPEN

ASSISTANT, ASSOCIATE, OR FULL RESEARCH SCIENTIST IN STRUCTURAL ENGINEERING The University of California, San Diego, Department of Structural Engineering (http://structures.ucsd.edu/) seeks candidates for the position of Research Scientist to lead the research operations and implementation of innovative structural testing methods at the Englekirk Structural Engineering Center. The candidate is expected to contribute to and support the research mission of the laboratory as well as attract and mange experimental programs from industry. Research expertise in structural dynamics, experimental mechanics, and controls, particularly as related to structural and seismic testing is desired. The candidate must be well versed in the operation of servo-hydraulic control systems and data acquisition/instrumentation systems, and have knowledge of modern cloud computing for data exchange, storage, retrieval and post-processing; as well as dynamic scheduling and budgeting methods to allow smooth collaboration with national partners. The Center is home to the Large High Performance Shake Table (LHPOST), the largest shake table in the US, and the Blast Simulator Facility among other structural and geotechnical testing facilities. The mission of the Englekirk Center is to provide the structural engineering community with a world-class testing facility producing high quality experimental data as well as consultation on experimental design and training/education. The LHPOST is currently a national shared-use experimental facility as part of the National Science Foundation supported Natural Hazards Engineering Research Infrastructure (NHERI) program (http://nheri.ucsd.edu/).
An earned doctoral degree or advancement to candidacy in civil engineering, mechanical engineering, structural engineering, or a related field is required at the time of application. Entry-level candidates for a Research Scientist (non-instructional) will need to demonstrate that their research trajectories are likely to position them to become independent scientists within a few years after appointment, while mid-senior level candidates will be expected to have a track record of independent peer-review research. For consideration, please apply via https://apol-recruit.ucsd.edu/apply/JPF01399.
Applications must include a cover letter, curriculum vitae, a statement of scholarly interests and accomplishments especially as related to structural testing, the names and contact information of three to five referees, and a personal statement summarizing past or potential contributions to diversity. For further information about contributions to diversity statements, see: http://facultyequity.ucsd.edu/Faculty-Applicant-C2D-Info.asp. Candidates may also submit a statement of interest in or evidence of teaching effectiveness (e.g., teaching evaluations). Review of applications will begin on June 1, 2017, and will continue until the position is filled. The level of appointment is commensurate with qualifications and salary based on UC pay scales.
UC San Diego is an affirmative action/equal opportunity employer, and the Jacobs School of Engineering is committed to building an excellent, diverse, and inclusive faculty, staff, and student body (http://www.jacobsschool.ucsd.edu/diversity/). Candidates with experience with or willingness to engage in activities that contribute to diversity and inclusion are especially encouraged to apply.

Faculty Positions in Mechanical and Energy Engineering at the Southern University of Science and Technology (SUSTech), China

The Department of Mechanical and Energy Engineering at the Southern University of Science and Technology (SUSTech), China (http://www.sustc.edu.cn/en) invite applications for tenure-track or tenured faculty positions at all ranks (Assistant Professors, Associate Professors, Professors and Chair Professors). The Department is established with three broad subjects, i.e., Robotics and Automation, Innovative Design and Advanced Manufacturing, as well as Energy Engineering. There are extraordinary opportunities to develop own careers together with the rapid development of the Department in these three major subjects

Established in 2012, SUSTech is a public institution funded by the municipal of Shenzhen City, a special economic zone in southern China. Shenzhen is a major city located in Southern China, situated immediately north of Hong Kong. As one of China's major gateways to the world, Shenzhen is the country's fast-growing city in the past two decades. The city is the high-tech and manufacturing hub of southern China. As a state-level innovative city, Shenzhen has chosen independent innovation as the dominant strategy for its development.

SUSTech is a pioneer in higher education reform in China. The mission of the University is to become a globally recognized institution which emphasizes academic excellence and promotes innovation, creativity and entrepreneurship.

Successful candidates are expected to establish vigorous teaching and research programs in the three broad subjects and related interdisciplinary areas. Candidates should possess doctoral degrees in relevant subjects and demonstrate research accomplishment and/or potential. Senior candidates are expected to play leadership role of teaching and research. Globally competitive salaries and start-up packages will be provided. Those interested are invited to apply through the job website at http://talent.sustc.edu.cn/en/enindex.aspx, with submission of the following material electronically to rongym@sustc.edu.cn:

1) Curriculum Vitae (with a complete list of publications).

2) Statement of teaching philosophy.

3) Statement of research interests.

4) Selected reprints of three recent papers, to represent your research.

5) Names and contact details of five references.

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RECRUITMENT

CHINESE MECHANICAL ENGINEERING SOCIETY DELEGATES VISIT ASME HEADQUARTERS

On April 6, a delegation of leaders from the Chinese Mechanical Engineering Society (CMES), led by the society's Vice Chairman and Secretary General Lu Daming, visited ASME headquarters in New York City to meet with members of the ASME staff and discuss potential opportunities for future cooperation.

During the event in New York, Lu and his colleagues from CMES met with ASME Executive Director Thomas Loughlin as well as members of several ASME departments including Standards & Certification, Global Development, Engineering Education, and Marketing.

CMES has had a long and collaborative history with ASME spanning more than 30 years. One of the first major milestones in the relationship between the two societies took place in 1986, when ASME and CMES signed their first agreement of cooperation, which led to more active participation by CMES members in ASME activities, particularly in ASME conferences.

ASME Executive Director Thomas Loughlin (center left) and CMES Vice Chairman and Secretary General Lu Daming (center right) with ASME staff and the delegation from CMES.

In 2000, ASME and CMES jointly organized the International Congress of Mechanical Engineering Societies (ICOMES) and the International Conference on Mechanical Engineering.

More recent collaborative activities have included a 2015 visit by the ASME Board of Governors to China, during which members of the Board met with CMES, the China Academy of Engineering (CAE) and China's General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ).

Last year, ASME and CMES cooperated on the Sino-American Technology and Engineering Conference (SATEC) Forum on Innovation and Intelligent Manufacturing. **ME**

TWO STUDENTS TAKE TOP HONORS IN MARS MEDICAL CHALLENGE

Two pre-college students from the West Coast were recently selected as the winners of the Mars Medical Challenge—the latest in a series of Future Engineers competitions sponsored by the ASME Foundation with technical assistance provided by NASA.

To take part in the Mars Medical Challenge, which was the fifth Challenge offered through the program since its launch in 2014, k-12 students from across the U.S. were asked to create a digital 3-D model of a medical or dental object that could be used by astronauts to maintain their physical health during a three-year mission to Mars. Devices could address a variety of space medical needs, including diagnostic, preventative, first aid, emergency, surgical, or dental purposes.

Nearly 750 students from 34 states submitted entries for the latest Challenge in either the Teen Category, for students aged 13 to 19, or the Junior Category, for students aged 5 to 12.

The winner in the Teen Category was Lewis Greenstein, an 18-year-old student from Seattle, for his device, the Dual IV/Syringe Pump. The winner in the challenge's Junior Category was Lauren Lee of Cupertino, Calif., for her entry, the Drug Delivery Device. Each student winner will receive a trip to Houston where they will have the opportunity to tour NASA's Johnson Space Center.

Deanne Bell, the CEO and founder of Future Engineers, was impressed by the ingenuity and desire to learn that the students, especially Greenstein and Lee, demonstrated during this latest Challenge. "It is inspiring to see these two students use 3-D printing to innovate something truly unique in space travel," Bell said. "This ongoing collaboration between the ASME Foundation and NASA catapults our youth into another realm of science and engineering expertise. I am happy that our platform continues to challenge students to dream big and think off-planet." **ME**

ISHOW EVENTS HIGHLIGHT SOCIAL INNOVATION

In April, the organizers of the ASME Innovation Showcase (ISHOW) program selected the 28 finalists to take part in this year's ISHOW competitions, which offer developers of hardware-led innovations that benefit society the opportunity to win a share of $500,000 in prizes and receive an extensive design and engineering review of their products by a panel of industry experts.

Eight teams competed at the first of the three events, ISHOW India, which was held in Bengaluru on April 27 at Le Méridien Bangalore. Ten finalists competed at ISHOW Kenya which took place in Nairobi, Kenya, on May 25.

Ten more will compete at the third event, ISHOW USA, to be held in Washington, D.C., on June 22.

One of the finalists who participated at the ISHOW in India, Anjan Mukherjee, is the creator of the Taraltec Reactor, a low-cost device that eliminates water-borne diseases—including diarrhea, cholera and typhoid—by killing microbes in water from borewell hand pumps and motorized water lines.

Hive, a desktop structure for raising edible insects, is one entry that will be competing at ISHOW India.

The 10 finalists who were chosen to compete in ISHOW Kenya include Brian Gitta, the inventor of Matibabu, and Victor Shikoli, the creator of HydroIQ. Matibabu is a noninvasive device that tests patients for malaria and features hardware that can connect to a smart phone to facilitate easy diagnosis. HydroIQ is a GPS- and Internet-enabled device that automatically monitors water use in water supply systems and sends data to an online platform.

The smart home-gardening system VeggieNest is one of 10 products that will compete in ISHOW USA in Washington, D.C., later this month. ME

ASME PAST PRESIDENT HONORED AT BOOK LAUNCH LUNCHEON

ASME Past President Madiha El Mehelmy Kotb was one of nine prominent women recently honored at Egypt's Permanent Mission to the United Nations in New York City as part of a gala book launch for *Daughters of the Nile: Egyptian Women Changing Their World*. The luncheon celebration, held on March 14, included two panel sessions featuring Kotb and eight of the other accomplished "daughters of the Nile" whose stories comprise the new volume.

Kotb, a resident of Montreal, served as ASME's 132nd president from 2013-2014 and is the former head of the Pressure Vessels Technical Services Division for Régie du Bâtiment du Québec. In her panel, Kotb shared the story of her own distinguished career, including the pivotal moment she was inspired to pursue engineering, which took place at age 16 while watching Neil Armstrong walk on the moon. She also told the audience about her experiences as the very first female engineering student at Loyola University.

Kotb is an ASME Fellow.

She credited her work in ASME Codes and Standards, and the encouragement she received from legendary ASME Codes leaders Mel Green and June Ling, as the driving force behind her rise to the pinnacle of ASME leadership. ME

NUCLEAR POWER EXPERTS TO CONVENE AT PUMP & VALVE SYMPOSIUM

Registration is now open for the 13th Pump & Valve Symposium—an event that is widely regarded as the premier conference on nuclear power plant inservice testing. The symposium, which is co-sponsored by ASME and the U.S. Nuclear Regulatory Commission (NRC), will be held from July 16 to 19 at the DoubleTree by Hilton Washington D.C.-Silver Spring in Silver Spring, Md.

The four-day event will explore the latest issues, technology, developments and trends in preservice and inservice testing (IST) of nuclear power plants. The symposium will feature the field's leading experts—including prominent officials from the NRC and ASME code leaders—addressing a wide range of topics including NRC rulemaking, general ASME Operations and Maintenance Code scope, content and philosophy, and the pumps, valves, motor-operated valves, air-operated valves, snubbers, and risk insight activities that are vital to the safe and reliable operation and maintenance of nuclear power plants.

One highlight of the Pump & Valve Symposium is sure to be the keynote presentation, which will be given by Mary Jane Ross-Lee, acting Director for the Division of Operating Reactor Licensing in the NRC's Office of Nuclear Reactor Regulation. Since joining the NRC in 1997, Ross-Lee has served in a number of areas within the agency including the Office of Nuclear Reactor Regulation, the Office of New Reactors, and the Office of Administration. Appointed to the commission's Senior Executive Service in 2011, Ross-Lee currently serves as the Deputy Director for Division of Engineering. ME

NEW LIFE FOR OLD STEAM

Duke Energy engineer Richard Coutant, left, helped the Charlotte Fire Department certify a 1902 steam boiler. *Photo: Mark Hames*

Brass-era automobiles hold special fascination for car enthusiasts. But when Charlotte Fire Department Chief Jon Hannan wanted to find someone to help ensure that the steam boiler in a heritage fire engine met modern safety standards, he turned to power plant engineers.

For mechanical engineer Richard Coutant, who has been a boiler engineer at Duke Energy for 34 years, that meant hitting the books.

"I had no idea how to work on a 115-year-old boiler," Coutant said. "So I went to the national boiler inspection code to find out what the rules were for historic boilers and spoke to other owners of historic boilers."

The Charlotte Fire Department has maintained the Metropolitan steam fire engine since its purchase in 1902 and had planned to use Old Sue (as it is called) during the national conference of firefighters in July. The State Department of Labor, however, wanted proof that the steam boiler could meet the current safety standards.

Old Sue was built well before the first boiler and pressure vessel code was written. Coutant said the original design specs were no longer available.

Instead, Coutant and his team established the boiler's original design through reverse engineering.

"We used ultrasonic gauges to test the thickness of the boiler's metal shell and fiber-optic remote video to view the internal components," Coutant said. "We took all sorts of measurements such as surface area, shell diameter, staybolt spacing and so on to come up with a maximum allowable working pressure to be used going forward for any further inspection."

The team—Coutant, welding program manager Scott Bowes, and non-destructive evaluation program manager Tony Battaglia—set up an inspection and testing checklist for the fire department to go through and get the boiler recertified. Fire department battalion chief Robby Myers disassembled parts of the boiler for testing by engineers, reassembled the steamer, and prepared it for inspection.

The moment of truth for the engineers was when they reassembled the engine and conducted the first operational test, with North Carolina state inspectors there to verify that all the systems were working.

The fire department was ecstatic when Old Sue passed the inspection test.

"We saw the steam pistons pumping the engine. You got the smoke the smells and noise from this great piece of mechanical art and you were transported back to the era when the engine was horse-drawn with a guy on the back and the fire going in the pumper as they go through the streets," Coutant reminisced.

"It was a whole different world back then." ME

CHITRA SETHI

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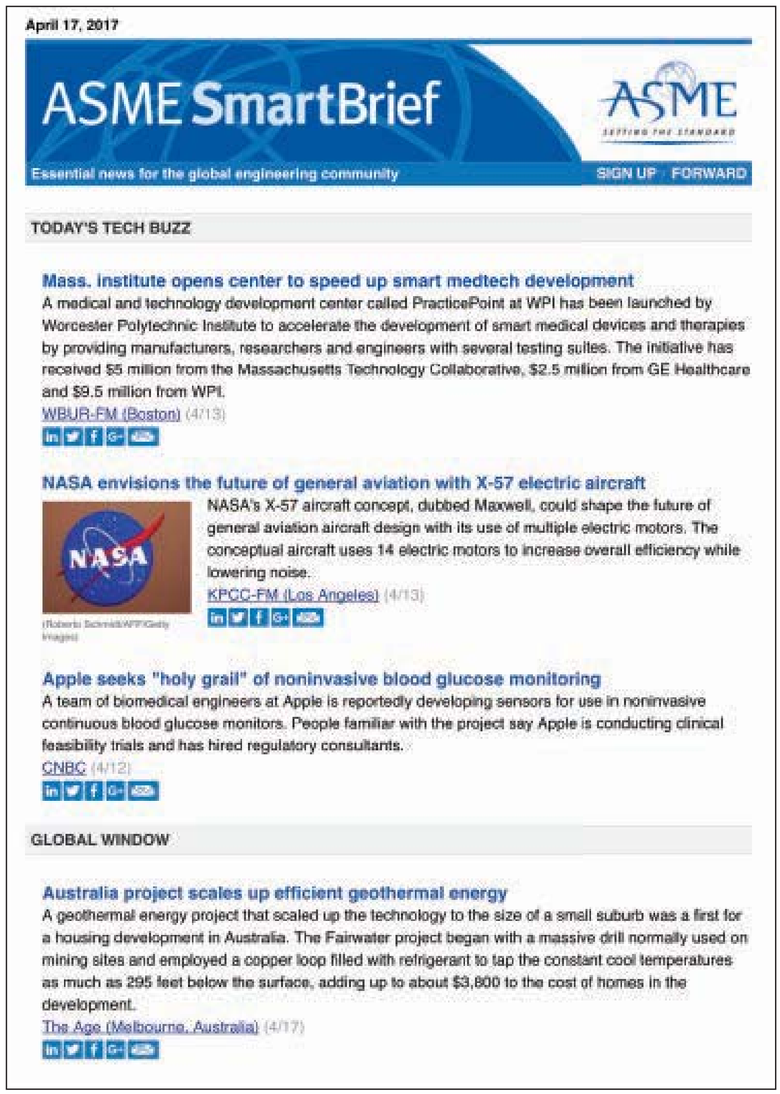
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TODAY'S TECH BUZZ

Mass. institute opens center to speed up smart medtech development

A medical and technology development center called PracticePoint at WPI has been launched by Worcester Polytechnic Institute to accelerate the development of smart medical devices and therapies by providing manufacturers, researchers and engineers with several testing suites. The initiative has received $5 million from the Massachusetts Technology Collaborative, $2.5 million from GE Healthcare and $9.5 million from WPI.

WBUR-FM (Boston) (4/13)

NASA envisions the future of general aviation with X-57 electric aircraft

NASA's X-57 aircraft concept, dubbed Maxwell, could shape the future of general aviation aircraft design with its use of multiple electric motors. The conceptual aircraft uses 14 electric motors to increase overall efficiency while lowering noise.

KPCC-FM (Los Angeles) (4/13)

(Roberto Schmidt/AFP/Getty Images)

Apple seeks "holy grail" of noninvasive blood glucose monitoring

A team of biomedical engineers at Apple is reportedly developing sensors for use in noninvasive continuous blood glucose monitors. People familiar with the project say Apple is conducting clinical feasibility trials and has hired regulatory consultants.

CNBC (4/12)

GLOBAL WINDOW

Australia project scales up efficient geothermal energy

A geothermal energy project that scaled up the technology to the size of a small suburb was a first for a housing development in Australia. The Fairwater project began with a massive drill normally used on mining sites and employed a copper loop filled with refrigerant to tap the constant cool temperatures as much as 295 feet below the surface, adding up to about $3,800 to the cost of homes in the development.

The Age (Melbourne, Australia) (4/17)

"It's about more than just awareness building. It has had a definite impact on how I do business. The information is so timely and far reaching that it helps me to think about innovation and development going forward."
— CEO

"This is one of the best tools ASME provides. Thank you for bringing this service to the membership."
— Engineer

"When I meet with clients I am better informed. I know things that [they] haven't heard yet, and it allows me to speak knowledgeably about a wide range of topics. It is a great confidence builder."
— President & CEO

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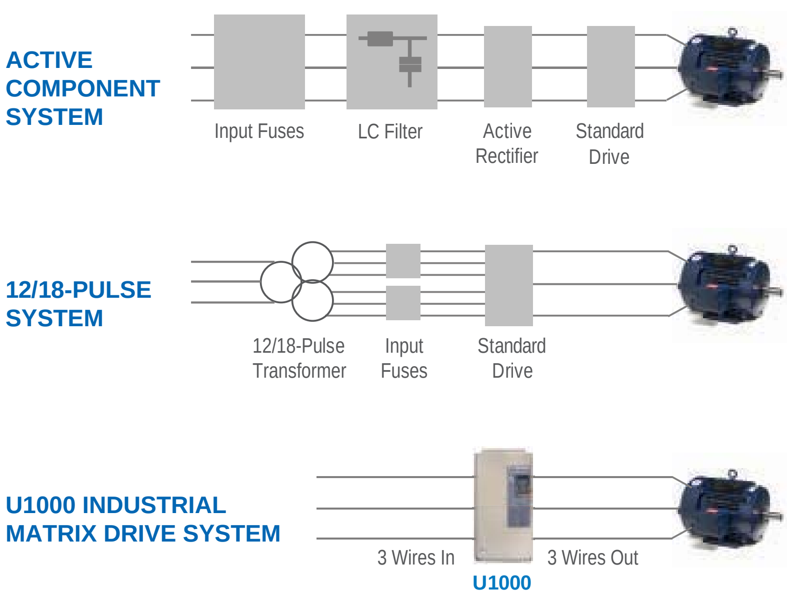

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