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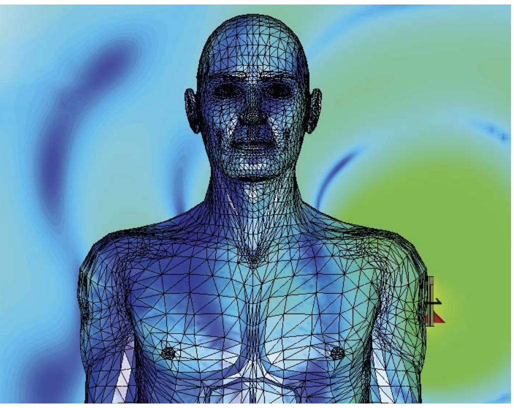

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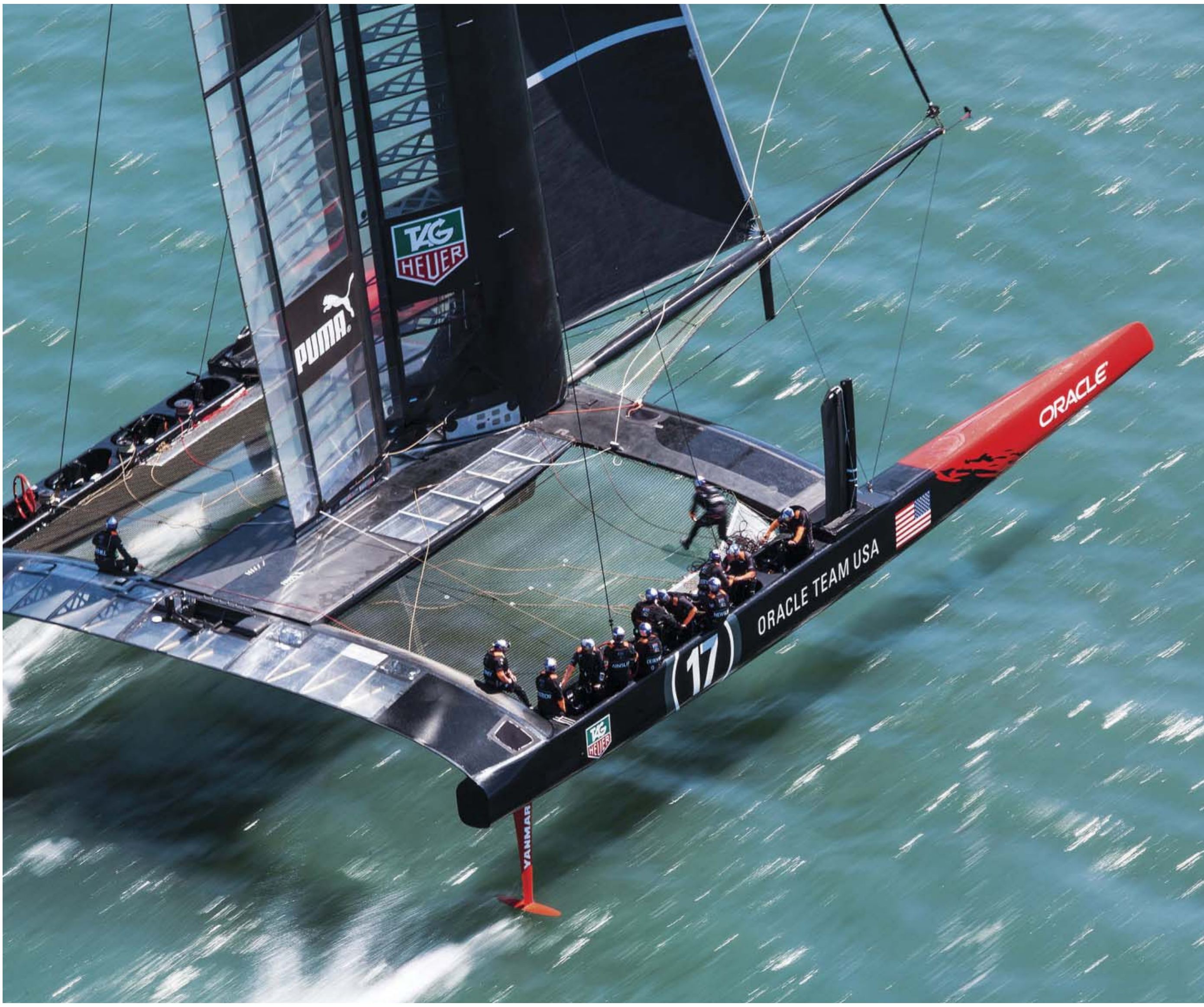

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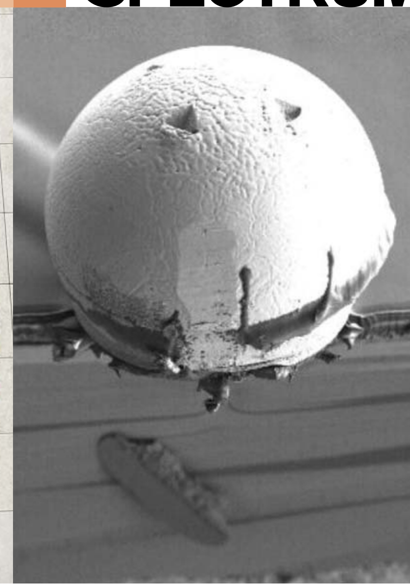

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MINIMIZING DAMAGE FROM NATURAL DISASTERS
This special issue of *The Institute* focuses on several IEEE members who are working on remote-sensing technologies that would help save lives and lessen the financial impact of earthquakes, sinkholes, and other catastrophic events.

IEEE ACCESS MAKES ITS DEBUT IEEE has launched its first free, online, open-access megajournal, featuring timely, original research in a range of disciplines.

PART-TIME PASSIONS One IEEE member builds ornate wooden furniture, while another choreographs English country dances.

FROM LEFT: T.A. RECTOR AND I.P. DELL'ANTONIO/NOAO/AURA/NSF; TOM MERTON/GETTY IMAGES; JOERG DREYBRODT AND PHILIPPE VON GUNTEN/EM MICROELECTRONICS

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BACK STORY_

Smooth Sailing

STAN HONEY has long had two passions: engineering and sailing. And by juggling intense development pushes at Silicon Valley start-ups with extended vacations and occasional leaves of absence, he's managed to pursue both endeavors professionally and at the highest level. As an engineer, he has collected 29 patents and six Emmy awards for technical innovation in broadcasting. If you're a fan of American football, you've seen one of his innovations: the yellow virtual first-down line, developed at Sportvision, the start-up he cofounded. As a professional sailor, he has been a member of teams that broke more than a dozen major records, including the fastest circumnavigation of the world, the fastest 24-hour run under sail, and the fastest transpacific and transatlantic passages–feats that earned him a spot in the National Sailing Hall of Fame.

Honey's sailing experiences started in high school, where he learned navigation using a sextant. At the time, navigation was more an art than a science. Over the years, as navigation got more technical, Honey rose to the top of the field. He has navigated for top sailing teams sponsored by Roy Disney, Steve Fossett, Richard Branson, and Larry Ellison, whose Oracle Team USA is hosting and defending this year's America's Cup races.

With the America's Cup, Honey's two careers have come together. In 2010, Honey navigated the *Groupama 3* on its record-breaking round-the-world trip. Shortly after *Groupama* finished its journey, Ellison's team approached Honey about developing tracking and augmented-reality technology for the 2013 America's Cup challenge, an effort described by Honey and coauthor Ken Milnes in "The Annotated America's Cup," in this issue.

The development effort has kept Honey on or at least close to shore, but after the races, it wouldn't be surprising to find him back on the open ocean. "I've sailed around the world twice now," he says. "I don't think anyone who hasn't traveled around the world on its surface has any idea of how big it really is. It is just enormous. And though we all are of course troubled by overfishing and environmental problems, it is amazing how beautiful and pristine so much of the planet still is. You can fly around the world looking out the window, but you don't get the sense as you do sailing around the world on its surface that wow, this place is *big*." ■

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Robert N. Charette

An *IEEE Spectrum* contributing editor, Charette is a self-described "risk ecologist" who investigates the impact of risk on technology and society. In this issue, he looks at recent claims of engineering shortages and finds them to be baseless ["The STEM Crisis Is a Myth," p. 40]. His interest is both professional and personal: He's a 33-year member of the IEEE Computer Society and has two daughters who are contemplating STEM careers. "Now I can give better career advice to my daughters," he says.

Mark Harris

Harris, a contributing editor, won a Grand Neal Award for his article "A Shocking Truth," which appeared in the March 2012 issue of *Spectrum*. As a freelance writer and Knight Science Journalism Fellow, he prides himself on sniffing out riveting stories. Recently, he learned that a tragic warehouse fire in a small Massachusetts town had ignited a race to build an indoor navigation system that could keep firefighters safe. He writes about the two front-runners in "The Way Through the Flames" [p. 26], in this issue.

Ken Milnes

Milnes is live graphics product manager for the America's Cup Event Authority, helping develop the broadcast wizardry behind the streaming "chalk talk" of this year's races ["The Annotated America's Cup," p. 32]. At Sportvision, he was lead engineer on RACEf/x, a tracking system for motor sports broadcasts. With coauthor Stan Honey [see Back Story], Milnes cofounded Etak, a pioneer in car navigation systems. An amateur sailor since childhood, Milnes recently built a very low-tech boat—a wooden kayak.

Alfred Poor

A speaker and author, Poor has written thousands of articles over the past 30 years. He is a senior member of the Society for Information Display, and he says he continues to be fascinated and amazed by new developments in screen technology. In this issue he writes about manufacturing problems faced by next-generation televisions [p. 22]: "I have seen many promising display technologies appear, only to drop out of sight again when they turn out to be too expensive or too difficult to build reliably in volume."

Takao Someya

Someya says that when he presents his research on electronic skins, the subject of his article "Building Bionic Skin" [p. 44], people sometimes get alarmed and raise questions about privacy. Because these e-skins can monitor vital signs and physical activity, they can offer insight into people's health conditions—and perhaps even their mental states. Someya's response? The technology could have many practical benefits, if it's employed responsibly. "This should not be nightmarish," he says.

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Is a Career in STEM Really for Me?

I JUST STARTED EIGHTH GRADE at a middle school in central Virginia. The school has an excellent reputation, particularly in math and science. Last year, it received national recognition for its STEM (science, technology, engineering, and math) program. I enjoy science and math, and I get straight As in those subjects. People tell me that future employers will be falling all over themselves to hire me if I pursue a career in STEM.

Well, for those future employers out there, I hate to tell you, but for me, and for my classmates who are also good STEM candidates, those subjects are far down on our list of career interests.

Why our apathy? First, while we hear science and math careers are fun, interesting, and well-paying, the actual scientists and engineers who visit our schools seem very one-dimensional. Working as an engineer for a utility company or as a biologist specializing in fungi may be fascinating to some people, but that's not how I want to spend my life. And to pursue and succeed in those one-dimensional jobs, you have to study very hard and get good grades in the most difficult subjects. I don't mind working hard, but I also want a career that allows me to pursue my full range of interests–like writing, art, and history, as well as STEM topics. I don't know what that career is yet, but I know what it isn't.

Another turnoff is the overemphasis on engineering. STEM is supposed to have four parts, each important in its own way. But engineering is presented to us as if it's the key and the other three areas are there only to support it as needed. For example, we're told that science may be responsible for important discoveries, but it's engineering that puts those discoveries to use.

Even as we're being pushed toward engineering, we aren't being told or shown what engineering really is. Instead, we're assigned simplistic exercises like building bridges out of drinking straws and marshmallows or telling a toy robot to turn left and right. Does anyone expect us to make future career decisions based on our ability to create a marshmallow bridge? And while I like solving math problems, what does finding the slope of a line using three different techniques have to do with anything I might do in the future? As I look to the next few years of math and science courses, I fear more of the same disconnect.

A third reason my friends and I discount STEM is the "teamwork" we are told is vital in such work. STEM may well be team oriented, but we aren't learning how to work in teams. In the marshmallow bridge exercise, the objective was to make the bridge as long as possible but still able to stand on its own. A few students found the assignment pointless and quickly lost interest. The rest argued over the best design. Instead of trying to work as a group to accomplish the goal, our "team" degenerated into mob rule. Our finished bridge consisted of a pathetic two straws connected by a single marshmallow. This distasteful ordeal was repeated in other team activities.

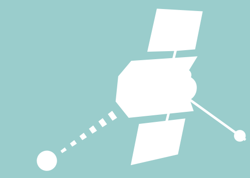
And lest anyone think my experience is somehow my school's or my teachers' fault, I've been told by friends and relatives attending other schools that they have had similarly negative STEM-related experiences.

So, future employers, take note: STEM is competing with other subjects that my classmates and I find more interesting and relevant. I may still get a STEM degree because I enjoy the subject matter, but don't count on my pursuing a STEM career. It just doesn't look very appealing. —MAURA E. CHARETTE

Maura E. Charette spent part of her summer vacation taking computer animation and theater courses. Her father, Robert N. Charette, wrote "The STEM Crisis Is a Myth," in this issue.

PHOTOGRAPH BY Robert N. Charette

NEWS



24 MILLION KILOMETERS: THE DISTANCE LASER PULSES TRAVELED TO AND FROM THE MESSENGER SPACECRAFT IN 2005

T.A. RECTOR AND I.P. DELL'ANTONIO/NOAO/AURA/NSF

SHINE BRIGHT: This image came from two telescopes. It'll take two more to test a new laser system this month.

MOONBEAMS BY THE MEGABYTE

A lunar orbiter will test the longest laser link yet

LAST MARCH, A LASER-RANGING system on the United States' East Coast beamed a tiny image of the *Mona Lisa* to NASA's Lunar Reconnaissance Orbiter. The transmission, which reached the spacecraft while it was in orbit around the moon, was just a trickle of data by Earth standards, topping out at 300 bits per second.

Soon, that modest demonstration could be trumped by a much faster, two-way link. On 6 September, the Lunar Laser Communication Demonstration (LLCD) is set to launch to the moon. Once in orbit, it is expected to be able to receive data from Earth via laser at a rate of 20 megabits per second and send data back at up to 620 Mb/s. If all goes well, researchers say, the experiment could someday enable spacecraft to send high-definition video from other planets and allow high-bandwidth communication with astronauts who venture beyond the moon.

Over the years, a number of Earth-orbiters have tested laser links with the ground and between spacecraft, and a few proof-of-principle laser pings have been sent to spacecraft en route to Mercury and Jupiter. But LLCD, which will orbit a good 10 times as far from Earth as the most distant geosynchronous satellite, "will be the longest laser communications link ever attempted," says Don Boroson, who led the design team for the instrument at MIT's Lincoln Laboratory. LLCD will attempt to receive data using an onboard 10-centimeter telescope and transmit it back with a half-watt laser.

DATA BYTE

6 KM The diameter of an LLCD laser beam by the time it reaches Earth's surface

The lunar component of the US $60 million experiment has been installed on NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) mission, a small orbiter that will study the thin lunar atmosphere. LLCD will boot up once the orbiter reaches the moon and will have a month to demonstrate communications during the orbiter's initial checkout period.

Boroson hopes that this will be enough time to prove the technology's utility to mission designers planning future spacecraft. Right now, all deep-space communication is done at radio frequencies, using antennas that may be bigger than the spacecraft themselves. But a laser-based system could be much smaller, and NASA estimates that it could be 10 to 100 times as fast. That's largely because the shorter-wavelength, near-infrared light doesn't spread out nearly as much as a radio wave does as it moves through space. A tighter beam translates to more power and higher transmission speeds. LADEE's radio signals will encompass an area larger than Earth by the time they reach home, Boroson says, while LLCD's laser beam will produce a spot just 6 kilometers across.

That creates some challenges when it comes to pointing. Minute vibrations from the reaction wheels that point the orbiter could easily knock LLCD's telescope and beam off target. LLCD will counteract this problem by fine-tuning its own orientation, using an inertial sensor to keep track of movement. On Earth, sensitive and compact detectors, based on arrays of superconducting nanowires, will be used to pick up individual photons sent by LLCD, pinning their arrival times within a few tens of picoseconds.

"Laser communications are key to removing a communications bottleneck that limits the amount we can learn from our deployed space probes," says Steve Hranilovic of McMaster University, in Hamilton, Ont., Canada, who works on free-space optical communications. "LLCD is a wonderful first step to demonstrating deep-space laser communications."

Hranilovic notes that LLCD's data is encoded only in brightness—in the presence or absence of light. But information can also be encoded in the phase or timing of a wave. Earth-orbiting missions such as Alphasat, operated by the European Space Agency (ESA), which launched in July, can transmit data using phase. This approach can lead to higher speeds, Boroson says, but it requires larger telescopes on Earth. It also presents an extra challenge for weaker signals sent to and from deep space, because phase information is difficult to recover after a beam has been distorted by atmospheric turbulence.

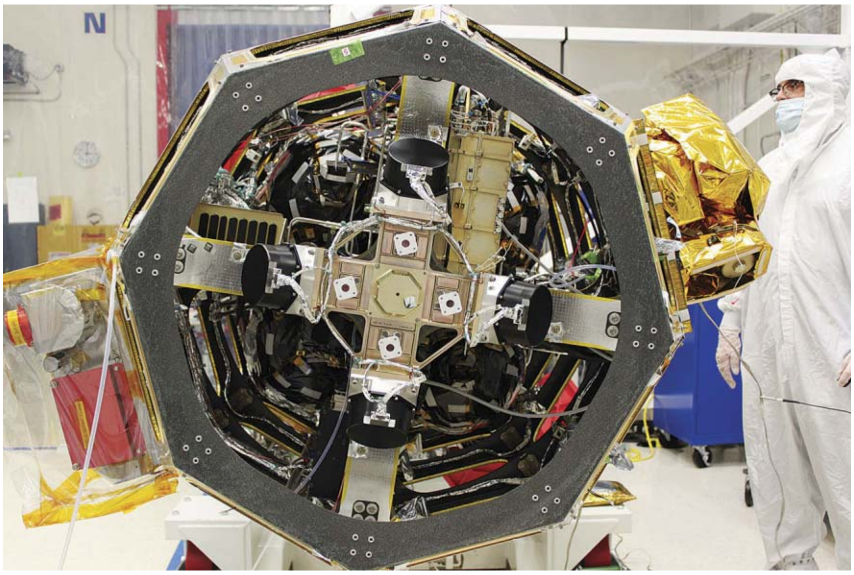
Weather in general is a limitation. Although optical signals can be received during the day, they can't penetrate clouds. As a result, LLCD's three receivers have all been installed in sunny settings: White Sands, near Las Cruces, N.M.; a mountain facility near Wrightwood, Calif., run by NASA's Jet Propulsion Laboratory; and an ESA site on Tenerife, in the Canary Islands.

If one site is cloudy, another will likely have a view of the moon. More sites could be added to boost coverage. "We're actually trying to slowly build ourselves a network infrastructure for optical communications," says Don Cornwell, mission manager for LLCD at NASA's Goddard Space Flight Center, in Greenbelt, Md.

Even so, future deep-space missions will likely carry some radio equipment to guarantee they can communicate with Earth. "We will see [lasers] more and more, but we'll have a hybrid system," says Manfred Wittig, a retired satellite communications project manager with ESA. "With radio, we can ensure there is always a link."

—RACHEL COURTLAND

TO THE MOON! Components of the Lunar Laser Communication Demonstration are installed on the Lunar Atmosphere and Dust Environment Explorer.



NASA

ENTER: Students, human and robotic, must pass an exam to get through the gates of the University of Tokyo.

JOHN S. LANDER/LIGHTROCKET/GETTY IMAGES

CAN AN AI GET INTO THE UNIVERSITY OF TOKYO?

The school's notorious entrance exam could be the perfect test for artificial intelligence

For the thousands of secondary school students who take Japan's university entrance exams each year, test days are long-dreaded nightmares of jitters and sweaty palms. But the newest test taker can be counted on to keep its cool: AIs don't sweat.

At Japan's National Institute of Informatics (NII), in Tokyo, a research team is trying to create an artificial intelligence program that has enough smarts to pass Japan's most rigorous entrance exams. The AI will start by taking the standardized test administered to all secondary school students; once it masters that test, it will move on to the more difficult University of Tokyo exam.

"Passing the exam is not really an important research issue, but setting a concrete goal is useful," says Noriko Arai, the team leader and a professor at NII. And by having the AI answer real questions from the exams, "we can compare the current state-of-the-art AI technology with 18-year-old students," she says. The latest results show that her protégé is coming along well in subjects like history and reading comprehension.

The project began in 2011, when the director of NII challenged his professors to come up with a problem that was "stupendously big and stupendously difficult," as Arai describes it, but could be easily understood by the general public. The University of Tokyo, known locally as Todai, has a legendarily difficult entrance exam, and the problem came to Arai in an elevator: "Could a robot get into the Todai?" she wondered. Thus the Todai Robot was born.

By 2016, the team hopes its AI will achieve a high score on the national standardized test, which includes multiple-choice questions in subjects such as physics and world history and requires students to solve math problems. But the machine-learning and natural-language-processing tools Arai's team is developing for that test won't prepare it for the Todai exam, which includes written essays. The team hopes the AI will pass the Todai exam by 2021, although they don't yet know how it will accomplish that goal. "The generation of text from information has not been studied very much," says NII associate professor Yusuke Miyao, another member of the team.

Even in the standardized test, each subject poses distinct challenges. The math portion, where an AI might be expected to excel, is made more complicated because the questions are presented as word problems, which the Todai Robot must translate into equations that it can solve. Physics is difficult too, because it presumes that the robot understands the rules of the universe. When equipped with a set of rules, however, the AI can simulate the scenario posed in a

NEWS

given question—for example, the trajectory of a missile—to arrive at the correct answer.

Surprisingly, the Todai Robot turned out to be a star student in history, where its natural-language-processing skills really shine. Miyao, who leads the work on language processing, explains that the AI can find the answers to questions by searching a database that includes textbooks and Wikipedia. But it still needs to understand semantic language and make the correct inferences. For example, the bot could try to determine whether the sentence "The janissaries were standing troops in the Ottoman empire" is true or false. It might find the information in a textbook that janissaries were musketeers in the sultan's household, but it then has to determine the "semantic equivalence" of musketeers and troops, Miyao says.

The team has recently tested the robot at several competitions organized for language-processing conferences. One task was multiple choice, where the AIs had to determine which one of four sentences was true by determining which was semantically equivalent to another sentence provided. Such a task would be easy for a human, because the answer is essentially given. In that exercise, the Todai Robot performed relatively well, with 57 percent correct. "This is much better than the random baseline of 25 percent, but still much worse than average high school students," says Miyao.

A harder task came closer to mimicking a real entrance exam: Once again, the AI had to determine which of four sentences was true, but this time it had to search for the answer in its own databases. There, the Todai Robot got only 31 percent correct. The AI also has work to do on reading comprehension tasks, in which it has to analyze a story and answer questions about its plot and characters. New results from another recent competition showed that the Todai Robot did well at identifying the characters, but it had trouble determining which sentences would provide the correct answer to a question.

It's clear that the bot still has some cramming to do before it's ready to matriculate, but AI experts are nonetheless impressed with the NII effort. "I think it's quite an interesting project, and quite an ambitious project, because they're tackling so many subject areas," says IBM researcher Jennifer Chu-Carroll. She works on Watson, the AI that crushed the human competition in the game show "Jeopardy!" in 2011. If the NII researchers create a program that can apply its natural-language-processing tools to math problems and history questions alike, they will "advance the state of natural-language understanding," says Chu-Carroll. —ELIZA STRICKLAND

CAR SHARING COULD BE THE EV'S KILLER APP

Paris's Autolib maximizes the advantages of electric cars

Parisians have learned to love electric cars by sharing them. Since the late 2011 launch of the French capital's Autolib car-sharing program, Parisians have taken its fleet of 1800 electric vehicles (EVs) on more than 2 million trips using 4000 dedicated charging points. That makes Paris one of the world's EV meccas, with more battery-powered cars on the road and more charging points than nearly any other city.

Now Paris's EV car-sharing vision is spreading. Autolib's operator, Bolloré, expects to launch a program in Lyon, France, next month and is preparing further installations in Bordeaux, France; Indianapolis; and an as-yet-undisclosed Asian city. Competitors, including automakers such as Daimler and BMW, have launched their own EV car shares in more than a dozen European and North American cities [see table, "EV Car-Sharing Leaders"].

Mobility experts say these programs could accelerate EV deployment worldwide by expanding access and making EVs a normal part of the urban environment. "Car sharing is a good way for people to get experience with EVs and to demystify the whole process. It can help EVs prove themselves to the public," says Richard Jones, deputy executive director of the Paris-based International Energy Agency.

Car sharing may, in fact, be the EV's killer app. Short trips within a defined urban perimeter and regular charging enable them to perform well despite the EV's current 100- to 250-kilometer range. Car sharing's pay-per-trip business model also frees users

EV Car-Sharing Leaders

Program	Primary vehicle/range	Fleet size/location
Bolloré Autolib	Bluecar/200 km	1800/Paris
Daimler Car2Go	Smart For two EV/140 km	1000/six cities
Citroën Multicity	Mitsubishi i-MiEV*/150 km	350/Berlin
BMW-Sixt DriveNow	BMW ActiveE/140 km	130/three cities

* Rebranded as Citroën C-Zero

CHARGED AND READY: Autolib has charging stations for its shared EVs all around Paris. The company keeps track of vehicle locations and charge status from a control center in the suburbs [below].

from paying the steep up-front cost of the EV's battery. "You're not buying the car, so you don't worry about the cost of the battery," says Jones.

Shouldering the risk for Paris is French industrial conglomerate Bolloré, which used its metal-extrusion expertise to develop the lithium metal polymer (LMP) batteries that propel Autolib's Bluecar EVs. The batteries use a solid metal electrolyte in place of flammable liquids and pack more energy per kilogram than most lithium-ion batteries. Vincent Bolloré, CEO of the family-controlled firm, saw Autolib as a high-profile venture to show that the company had increased the short life span that had plagued LMP technology.

It cost more than €1.7 billion (US $2.3 billion) to develop the battery and deploy it through Autolib. "Bolloré is a true entrepreneur who takes daring risks to make things happen," says Nicolas Louvet, director of the Paris-based mobility research group 6T.

Bolloré teamed up with Italian car designer Pininfarina to develop the compact Bluecar, whose 30-kilowatt-hour LMP battery provides an average 200-km range in urban use. Bolloré subsidiary IER, a leader in automated systems, created Autolib's integrated user interfaces, charging stations, and network. The result is an easy-to-use system that staves off drivers' range anxiety.

Members swiping their Autolib RFID cards at one of 800 stations are automatically given the local car with the best charge. In any case, the system will not release cars with less than a 40 percent charge. While drivers run errands, Autolib's central control center in suburban Paris tracks each car's trajectory and battery status. Drive a car below 20 percent charge or venture beyond the last ring of charging stations in Paris's suburbs and an Autolib agent will contact you.

Autolib general director Morald Chibout predicts the program will start turning a profit sometime next year. And the 400 000-km battery warranty that comes with individually purchased Bluecars—2.5 times as long as the battery warranty Nissan offers for its comparably sized Leaf EV—suggests that Bolloré is confident in its LMP technology.

Car-sharing program membership grew fivefold worldwide between 2006 and 2012, according to the Transportation Sustainability Research Center at the University of California, Berkeley, so there's room for more programs like Autolib. Still, whether EVs actually benefit will likely depend on municipal support, according to Susan Shaheen, the center's codirector. Only a small percentage of the 43 544 vehicles used by last year's 1.8 million car-sharing members were EVs.

The problem is that buying and operating an EV costs about $400 more per month than a regular car, according to Carolin Reichert, head of mobility projects for the French automaker Peugeot Citroën Automobiles. Citroën's car-sharing program in Berlin uses 350 EVs, but she says that further expansion would require city subsidies.

Surprisingly, the sharpest critics of Autolib and its competitors are some of the staunchest believers in car sharing, who say that newer programs such as Autolib are unlikely to keep users from buying their own vehicles. Research shows that the first wave of car-sharing systems, which allow members to reserve cars days or weeks in advance, convince many to give up their own cars—or to never buy one. The result is lower total car use overall. Autolib, by contrast, can only be used on the spur of the moment, so car availability is thus less assured.

Louvet says he needs data to quantify the impact, but he is betting that Autolib members who make important trips that are inconvenient without a car may still feel that they need one of their own. In other words, he says that Autolib's stress on flexibility over dependability is squandering some of car sharing's "enormous potential to change behavior."

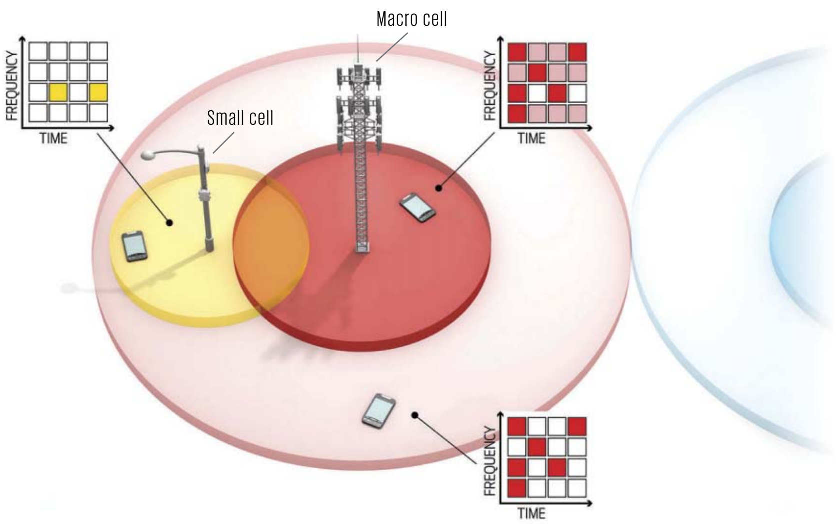
One fact, however, is undeniable: The air in Paris would be dirtier if its car-share vehicles ran on diesel or gasoline. Bolloré's shared Bluecars consumed 5746 megawatt-hours of electricity in 2012, about four-fifths of which came from France's low-carbon nuclear power plants. With the right power supply, the cities that follow Paris's lead will also give their residents swipe-and-go access to cleaner driving.

—PETER FAIRLEY

TOP: PIERRE CROM/REPORTERS/REDUX; BOTTOM: PETER FAIRLEY

KOREAN TELCOS ADVANCE TOWARD LTE-ADVANCED

"True 4G" wireless networks promise faster download speeds, fewer dropped calls, and cheaper data



WHAT'S NEXT: The next step in LTE-Advanced prevents interference in layered networks of different-size base stations by dynamically coordinating the time, frequency, and power of transmissions.

Long-term evolution (LTE), the wireless standard behind today's top-of-the-line smartphones and tablets, was never meant to be the end of the road for fourth-generation (4G) mobile networks.

And now, just a few years after the first LTE networks went live, operators are beginning to upgrade it to allow for more data capacity and more advanced applications, such as high-definition video.

In June, the South Korean operator SK Telecom Co. announced it had launched the "world's first LTE-Advanced service through smartphones." A month later, its competitor LG Uplus Corp. introduced its own LTE-A services. At least 13 other network operators, including AT&T, Japan's NTT DoCoMo, and Sweden's Telenor, have promised commercial LTE-A rollouts.

These networks will certainly beat regular old LTE. SK Telecom, for instance, claims peak download rates of 150 megabits per second–double the speed of its LTE network. "It's a major achievement," says Lingjia Liu, a wireless expert at the University of Kansas, who helped develop the LTE-A standard.

Technically, LTE-A encompasses a suite of technologies that the International Telecommunication Union has crowned "true 4G." When fully implemented, it can achieve download speeds of up to 1 gigabit per second for stationary devices, such as tablets in a café, and up to 100 Mb/s for real mobile broadband, such as for tablets in cars or trains.

And LTE-A is about more than just speed. It includes new transmission protocols and multiple-antenna schemes that will enable smoother handoffs between cells, reduce interference at their edges, and stuff more bits per second into a single hertz of spectrum. The result will be higher capacity, more consistent connections, and cheaper data.

But operators won't build out all of that at once. Rather, they'll order technologies from the menu as they're needed. Operators such as SK Telecom that now claim to have LTE-A networks or plans are really talking about a single menu item: carrier aggregation.

This core LTE-A feature stitches together frequency channels, or carriers, that reside in different parts of the radio spectrum. Previously, if an operator wanted to provide up to 20 megahertz of bandwidth to a smartphone, it needed a contiguous block of frequencies 20 MHz wide. Such wide swaths of spectrum, however, are hard to come by. Using LTE-A, SK Telecom combined two separate 10-MHz-wide carriers at 800 MHz and 1.8 gigahertz into one 20-MHz-wide carrier. Without LTE-A, those two carriers could have provided only up to 10 MHz to each customer.

One reason operators are starting with carrier aggregation in the iterative march toward LTE-A is that it provides the biggest performance gain, says Sang-min Lee, a senior manager at SK Telecom's R&D center in Seoul. LTE-A allows operators to combine up to five carriers as wide as 20 MHz each for a maximum bandwidth of 100 MHz–five times as much bandwidth as LTE can support.

One of the next LTE-A technologies operators plan to deploy will help alleviate network congestion. Like many operators, SK Telecom has begun rolling out small cells–compact base stations that can be overlaid on a traditional "macro" network to expand data capacity in congested urban centers. "In two years, small cells will be a major part of our network," Lee says. But as operators cram more and more cells into the same spaces, they will have to find ways to lessen interference.

One solution LTE-A offers is a transmission protocol called enhanced inter-cell interference coordination, or eICIC. It builds on the LTE protocol ICIC, which enables a macro cell to reduce transmission power at certain frequencies at certain times, thereby avoiding interference with its neighbors. Using eICIC, the macro cell can further reduce signal power at particular times, allowing small cells inside its coverage area to expand their transmission range [see illustration]. This dynamic coordination would let more customers link to the small cells while avoiding interference from the macro cell.

Lee says SK Telecom will begin using eICIC and other interference-reducing techniques next year. Other operators will surely follow. But now that they've already proclaimed the arrival of LTE-Advanced, what will they call these next advances? –ARIEL BLEICHER

ILLUSTRATION BY Emily Cooper

PHOTOGRAPH BY Pascal Rossignol/Reuters

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BATTERIES INCLUDED

Project Zero, pictured here at the Paris Air Show in June, is the world's first all-electric tilt-rotor vertical takeoff and landing aircraft. Its looks are breathtaking, and amazingly, it went from back-of-the-napkin sketch to unmanned aerial maneuvering in only 12 months. The craft is the brainchild of British helicopter maker AgustaWestland, and a veritable dream team of companies from several related industries contributed their expertise. For example, Stile Bertone, an Italian coachbuilder, is responsible for the aircraft's exotic look. And AnsaldoBreda, the Italian train maker, contributed the electric motor inverter and motor control algorithm. AgustaWestland has divulged few details about the aircraft. We do know, however, that the group is busy refining a hybrid diesel-electric model that will use the rotors as wind turbines to recharge its batteries when not in flight.

THE BIG PICTURE NEWS

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RESOURCES

278 000	360 000	450 000
2010	2011	2012

THE NUMBER OF PROCEDURES PERFORMED WITH THE DA VINCI SURGICAL ROBOT HAS BEEN RAPIDLY GROWING, WORLDWIDE.

RESOURCES_PROFILE

JUAN WACHS

SURGEONS COULD USE HIS HAND-GESTURE SYSTEM TO CONTROL ROBOTS

Three years ago, Juan Wachs was brainstorming engineering projects with his Ph.D. students when someone suggested a robotic nurse that could hand instruments to a surgeon during an operation.

"We started laughing," says Wachs, an assistant professor of industrial engineering at Purdue University, in West Lafayette, Ind. "In the beginning, it was more like a joke. But then one of the students came up with some algorithms that suggested it could actually be done. We said, 'If we don't try this, we'll never know.' "

Today, Wachs and his students are part of a multinational team developing a surgical robot, dubbed Gestonurse, designed to respond to hand gestures and verbal commands. The gestures and commands correspond to specific instruments used by surgeons. ▸

PHOTOGRAPH BY Greg Ruffing

The main goal is to reduce medical errors. "Most surgical mistakes are related to miscommunication between operating teams due to understaffing, high noise levels, long working hours, and changing operating room personnel," says Wachs. "Misunderstandings can result in handling the wrong instruments, delays, and items left inside patients. We found that experienced teams make almost no mistakes because their interactions with one another occur by multimodal communication: speech, gestures, and gaze."

"So far, the Gestonurse understands 10 commands issued through gestures and/or speech," says Wachs. "In the future, it will need to understand more verbal and nonverbal commands, such as body stance."

The Gestonurse takes the form of a robotic arm attached to a camera- and microphone-equipped computer, which translates hand gestures and verbal commands into commands that tell the arm which instrument to give the surgeon. Wachs's focus is on developing the speech and gestural recognition software for the Gestonurse project.

"The biggest challenge is incorporating human idiosyncrasies," he says. "People use gestures in different ways. The system has to be trained to recognize individuals. We have to look at the context of the task: how the gestures and body language respond to the procedure, where in the body the instrument is being inserted, and the difference between using hands to talk versus command gestures."

Wachs and the team are currently working toward building a version of Gestonurse to be tested in mock surgery scenarios, thanks to an anticipated three-year grant of more than US $1 million from the Qatar National Research Fund. The project will involve the collaboration of surgeons at the Hamad Medical Center in Qatar.

Crossing cultures is familiar to Wachs, who grew up in Argentina and received his higher education in Israel before moving to the United States. His fascination with robotics grew while earning a Ph.D. in industrial engineering at Ben-Gurion University of the Negev, in Israel, where he developed a system that used hand gestures to browse MRI images. After graduating in 2006, Wachs spent 18 months as a postdoc at the Naval Postgraduate School, in Monterey, Calif., applying his research toward naval training, before arriving at Purdue in 2009. A few months ago he received a U.S. Air Force Young Investigator award for interface research.

Wachs is also involved in a multidisciplinary team at Purdue collaborating with SRI International in Menlo Park, Calif., to reconfigure its Taurus military robot for medical purposes. The robot was initially designed to disassemble bombs, but it also can be a dexterous surgical assistant, and at 36 by 13 centimeters, it is easily transported between operating rooms.

"It takes a mixture of computing, engineering, and psychology to create man-machine interfaces that are able to read our body language," says Wachs. "We're having to invent a whole algorithmic system to understand context. It's very subjective. It's a new way of looking at context and understanding intent."
—SUSAN KARLIN

SOFTWARE-DEFINED RADIO, PART II

UPGRADING A CHEAP SOFTWARE RADIO FOR GLOBAL COMMUNICATIONS

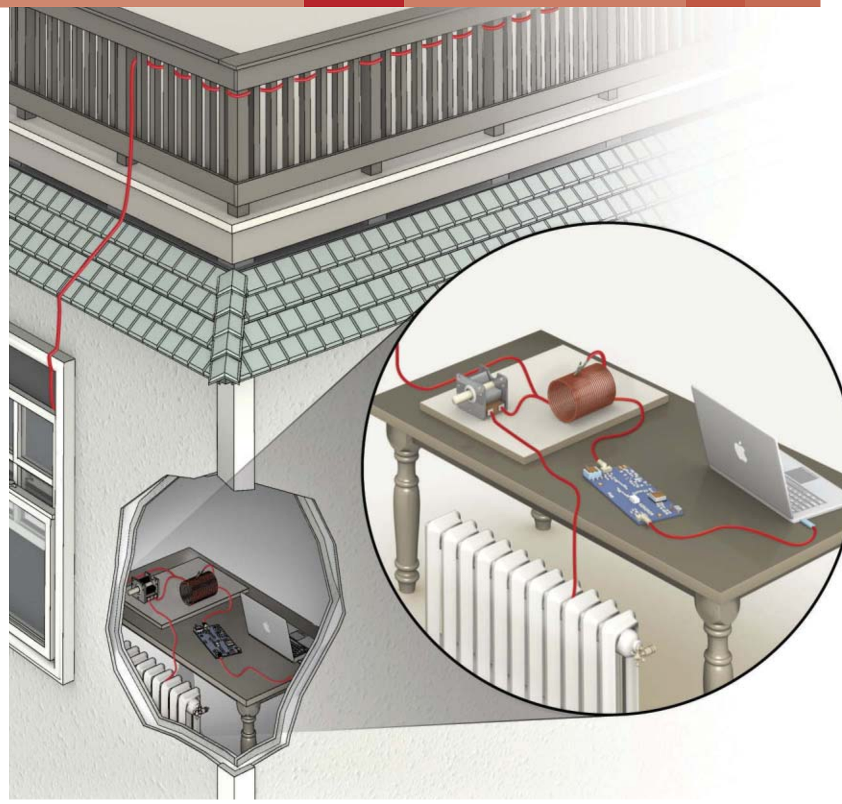
A COUPLE OF MONTHS AGO, I WROTE about how a cheap USB dongle designed to pick up digital television broadcasts could be hacked to act as a software-defined radio, or SDR. With this dongle and a TV antenna, I could decode an impressive range of analog and digital radio transmissions from about 50 megahertz up to a little over 2 gigahertz [see "A $40 Software-Defined Radio," *IEEE Spectrum*, July]. But I wanted more. I wanted to get below 50 MHz, into the shortwave bands where signals can be sent vast distances around the globe by commercial, government, and amateur broadcasters.

This required adding two components to my original setup: an upconverter and a better antenna. An upconverter shifts radio signals to higher frequencies, so a suitable upconverter would put even the lowest-frequency signals within the tuning range of the dongle. (It's also possible to crack open the dongle and solder an antenna line directly to the RTL2832U demodulator chip, which would allow it to operate on a wider frequency range without an upconverter. But this can put the chip at risk of being damaged by electrostatic discharge, and I wanted to preserve the form factor of the dongle for ease when traveling.)

For an upconverter, I purchased a Ham It Up v1.2 from NooElec for US $43 (about twice the cost of the TV tuner itself). The Ham It Up shifts transmissions below 50 MHz up 125 MHz. A bare-bones circuit board powered by a micro-USB connector, the Ham It Up is technically a kit. But assembly requires only the ability to push a 4-pin oscillator crystal into a socket the right way around. The board uses SMA connectors for attaching cables that connect to the dongle and to whatever antenna you're using. I lacked an appropriate cable, so I resorted to a somewhat Frankensteinian chain of adapters and cables I'd fished out of various drawers.

As Apple found out to its cost with the iPhone 4, the antenna is often the determining factor in the success of any radio-based system: All the digital design in the world can't abstract the physics away. In trying to pick up signals transmitted below 50 MHz, where the wavelengths of the various bands can vary from 10 to 160 meters long, I needed a much longer antenna than the set of TV rabbit ears I'd been using.

The commercially available antennas for these bands can easily run into the hun-



dreds of dollars, if not more. That was too steep for my budget, and in any event I didn't have anyplace to put one, living as I do in a third-floor rental.

So I went with a "random-wire antenna," which means you just run the longest length of wire you can, as high as you can, in whatever direction you can (bending it is okay). My building has a square roof deck and I've got tolerant neighbors, so I threaded about 20 meters of single-strand copper wire through the deck's perimeter fence and down to my home office.

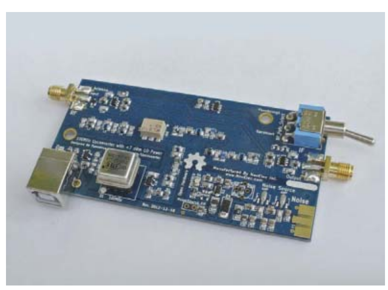
But I couldn't just plug this wire into the upconverter and expect great results: The impedance of the antenna had to be matched to the receiving circuitry for whatever band I was trying to pick up. Based on plans from the July 1986 issue of *QST* magazine, I built a very simple home-brew "matching network," consisting of an induction coil and a variable air-gap capacitor I had lying around. I made the induction coil by winding about 30 turns of wire around a cylindrical water bottle and scraping off the insulation at the top of each loop to create a tap point for an alligator clip. I used glue and a strip of wood to hold the coils in place after I removed the bottle. Then I mounted these parts on a board and grounded the capacitor to a radiator pipe.

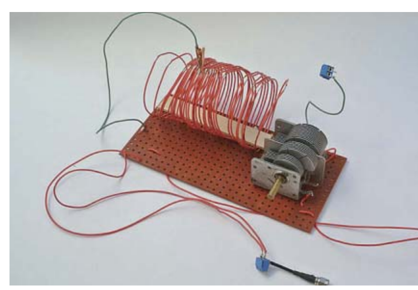
I connected the upconverter to the dongle I'd plugged into my MacBook Pro and launched the same graphical SDR interface—Gqrx—I'd used previously. Tuning to a band simply required a bit of addition: For the 80-meter band (3.5 to 4.0 MHz), for example, I set Gqrx to 3.5 + 125 = 128.5 MHz. I could immediately see some faint spikes on the display, indicating transmissions. As I moved the alligator clip from tap to tap along the matching network's induction coil, I watched the spikes rise from the background noise until I had the antenna matched as well as possible. I'd anticipated having to turn the variable capacitor for fine-tuning, but none of those adjustments seemed to make much difference.

The many shortwave radio stations below 25 MHz proved handy for making sure that the system was tuned correctly. I was also able to pick up voice and Morse code transmissions from amateur radio operators across North America and beyond. How well a band carries signals long distances depends on how the ionosphere is affected by factors such as the time of day and the amount of sunspot activity. So far I've had the best results with the 80- and 40-meter bands.

For Morse code transmissions—still popular with hams trying to communicate over long distances—I bought a decoder app (HotPaw's Morse Decoder, $10; available for iOS and Android devices). With the app, holding my smartphone to my speakers converts audible dots and dashes into a message written in hamspeak. For example, the software translated one Morse code transmission into "cq dx de ik2cio," which means "Call sign IK2CIO looking to talk with anyone far away." (Several lists of these ham abbreviations and their meanings are available online.) I was pleased to discover that the ham operator with that call sign was located in Italy.

Of course, I couldn't talk back, as my setup can't transmit. But there's still pleasure to be had in extracting these low-power, long-distance voices and messages from the air. The Internet has made international communication trivial, but with radio there's no gargantuan infrastructure: It's just you and your little collection of electronics, the other person with his, and the living, crackling planet in between. —STEPHEN CASS





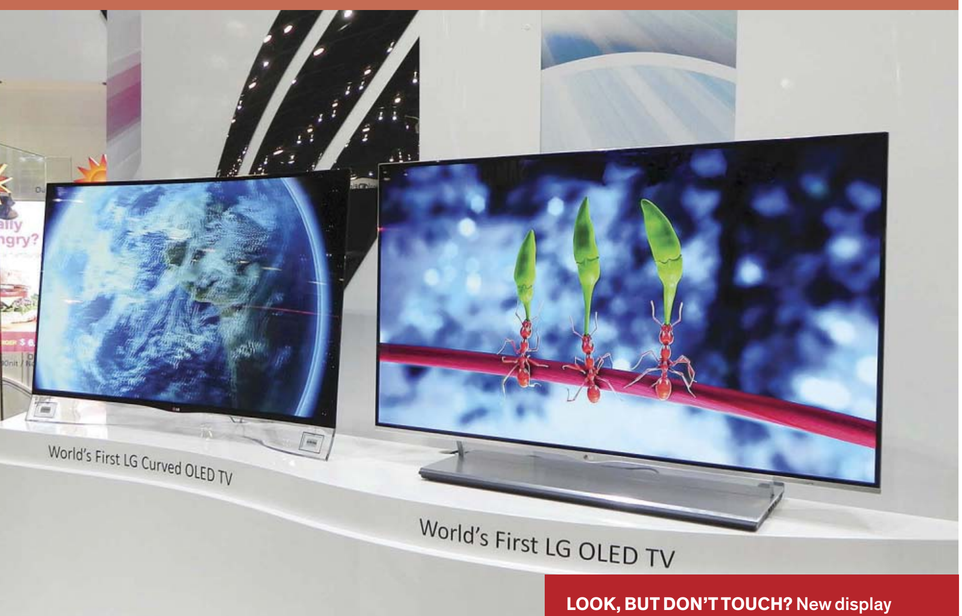
OLD AND NEW: Tuning in long-wavelength bands with my software-defined radio meant digging out old plans for a random-wire antenna and a matching network. I threaded the antenna wire through my building's roof deck [top] and connected it to a home-built matching network [bottom right] that I'd connected to an upconverter board [bottom left]. The board shifts wavelengths into the range that my USB tuner dongle can accept and digitize before passing signals on to my laptop.

STEPHEN CASS (2)

ILLUSTRATION BY Emily Cooper

NEXT-GENERATION DISPLAYS: REALITY SETS IN

OLED AND 4K TECHNOLOGY ARE FACING MANUFACTURING PROBLEMS



LOOK, BUT DON'T TOUCH? New display technologies, such as these OLED screens, provide amazing picture quality but have been troubled by manufacturing yield problems.

ALFRED POOR

As companies around the world showcased their latest developments, Display Week 2013 proved to be a good bellwether for how next-generation screen technologies were faring in the marketplace. As an extension of the trend toward higher-resolution displays, a lot of attention was focused on 4K displays, which have the same resolution as four standard 1080p HDTVs tiled together. And LG Electronics and Samsung both continued to tout their 55-inch organic light-emitting diode (OLED) television displays, which had been shown before but are now being offered for sale.

One of the themes of this year's show, run in Vancouver at the end of May by the Society for Information Display, was whether the industry can deliver these next-generation displays in large numbers. Manufacturers cannot yet produce enough units to have viable mass-market products, and they're spending a lot of time and money to achieve that goal.

Both 4K and large OLED displays suffer from the limitations of today's silicon-based backplanes. Backplanes serve as the substrates on which thin-film transistors are fabricated. (TFTs turn pixels on and off.) For a given screen size, a 4K display has four times as many pixels as a 1080p panel, so it requires TFTs one-quarter the size. You need a lot of electron mobility in the backplane to support TFT devices that small. Good electron mobility is also critical for OLED displays, even at 1080p resolutions, as the pixels must be driven by more current than with LCDs.

Electron mobility is measured in the somewhat awkward units of square centimeters per volt second (cm^2/Vs). Amorphous silicon, with an electron mobility of about 1 cm^2/Vs, served LCDs well for years but isn't suitable for the new displays. Laser annealing of amorphous silicon to turn it into a polycrystalline form, typically in the range of 50 to 150 cm^2/Vs, has been the mainstay for high-resolution mobile display manufacture. This process adds costs, however, and does not scale up well. Some manufacturers are making polycrystalline silicon with a so-called low-temperature process. Unfortunately, at large sizes the resulting polysilicon is not uniform, forcing makers to take complex quality control measures.

So manufacturers have been very interested in metal-oxide semiconductor backplanes; the most common type in production today uses a mix of indium, gallium, and zinc oxides. IGZO is a low-cost material that's easy to deposit on a glass substrate, and it scales up well. Its electron mobility is about 10 to 30 cm^2/Vs, sufficient for 4K or OLED displays.

Sharp has invested heavily in this technology and is now shipping LCDs with IGZO backplanes, such as the not-so-romantically named LQ315D1LG91, a 31.5-inch panel with 3840- by 2160-pixel resolution. LG Display is also using metal-oxide TFTs for its planned rollout of 55-inch OLED television sets.

It hasn't been all smooth sailing for metal oxides, however. Among other problems, the metal-oxide layer is often uneven. This can cause visible differences in performance from one spot to the next in OLED applications. In the worst case, a spike of material can pierce subsequent layers, potentially ruining the whole panel.

Researchers continue to work to counter these shortcomings. Increasing production to reduce prices and provide flawless performance will be essential if large 4K and OLED technologies are to find a place in consumers' living rooms.

Finally, of the few brand-new technologies shown at Display Week, perhaps the most notable was a flexible, self-organizing, transparent conductive layer that uses silver nanoparticles. A thin paste, made by Cima NanoTech, is applied to a surface, and silver particles within the paste are attracted to one another to form a random network of connections. The result has excellent electrical conductivity and is claimed to be 88 percent transparent. In addition to applications such as touch screens, the material can even be used as a transparent defrosting layer for car windows and is already shipping for some low-volume production items. —ALFRED POOR

Q&A: JASON OWEN-SMITH

A NEW STUDY FINDS THAT PROXIMITY SPURS COLLABORATION

MARISSA MAYER IGNITED A FIRESTORM WHEN SHE BANNED telecommuting throughout Yahoo. But there's little hard data about the value of working at an office versus at home. One researcher who has studied the problem is Jason Owen-Smith, an associate professor of sociology and organizational studies at the University of Michigan, and one of the four coauthors of a paper titled "Zone Overlap and Collaboration in Academic Biomedicine." He talked with Steven Cherry about it for *IEEE Spectrum*'s podcast series, "Techwise Conversations."

STEVEN CHERRY: You studied two different buildings in a medical center. What did you measure?

JASON OWEN-SMITH: We're interested in knowing how folks in [different] fields who haven't collaborated before come to collaborate, and when those collaborations are successful. We made a set of assumptions. The first was that most of us really occupy a fairly small component of our buildings. We then assumed that the zones people occupy are anchored by a set of basic spaces: the researcher's office and laboratory, the nearest relevant bathroom, and the nearest elevator. So for everyone in each of these buildings, we identified these four spaces and identified the shortest path among them, and we called that the person's "territory." For every pair of people, we then identified how much of that territory overlapped.

S.C.: What did you find?

J.O.-S.: In terms of forming new collaborations, we found that an increase of 100 feet in path overlap—so if the paths I walk every day overlap with yours by 200 feet rather than 100—all other things being equal, you and I are somewhere around 17 percent more likely in our models to form a new collaboration.

S.C.: What are some of the things that you think companies can do to encourage serendipitous interactions?

J.O.-S.: We're just beginning to do the research. I think the real challenge for an organization is to decide whether it wants to create a space that will facilitate greater contact *between* established groups, or whether it will try to create a space that will allow established groups to more efficiently go about their collaborative work. Those two things are likely to be trade-offs that come through the same physical arrangement of space.

S.C.: So do you think Mayer was right to ban telecommuting?

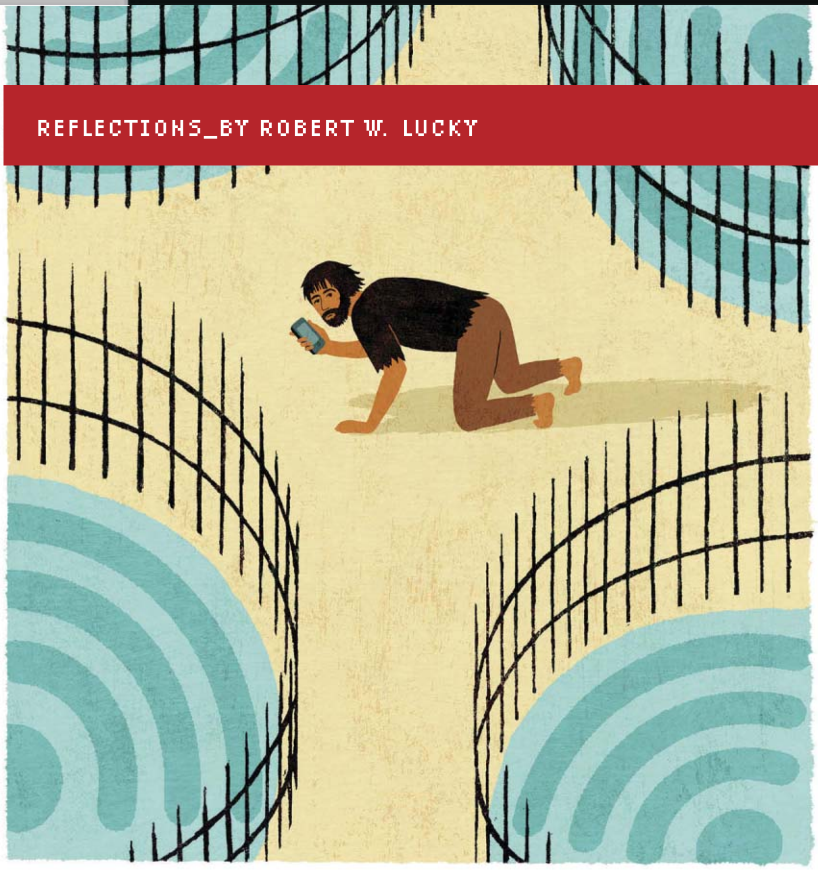
J.O.-S.: This is more an intuition than anything else, but to spur innovation that is unexpected, you need some form of physical proximity—because virtual work, to the best of my knowledge, does not yet have mechanisms that allow you to come to realize that someone you don't have a reason to talk to knows something you need to know.

So if you know and can articulate your needs, you might be able to use distance-enabled technology to search for potential collaborators who know what you need to know and might work with you. But if what the company is trying to bet on is unexpected, serendipitous discoveries that lead them in new directions, then, yes, it seems like a very smart decision.

These questions and answers have been edited and condensed. To read or listen to the full interview, visit http://spectrum.ieee.org/owen-smith0913

TOP: TOM MERTON/GETTY IMAGES

ILLUSTRATION BY GlueKit



WHITHER WIRELESS?

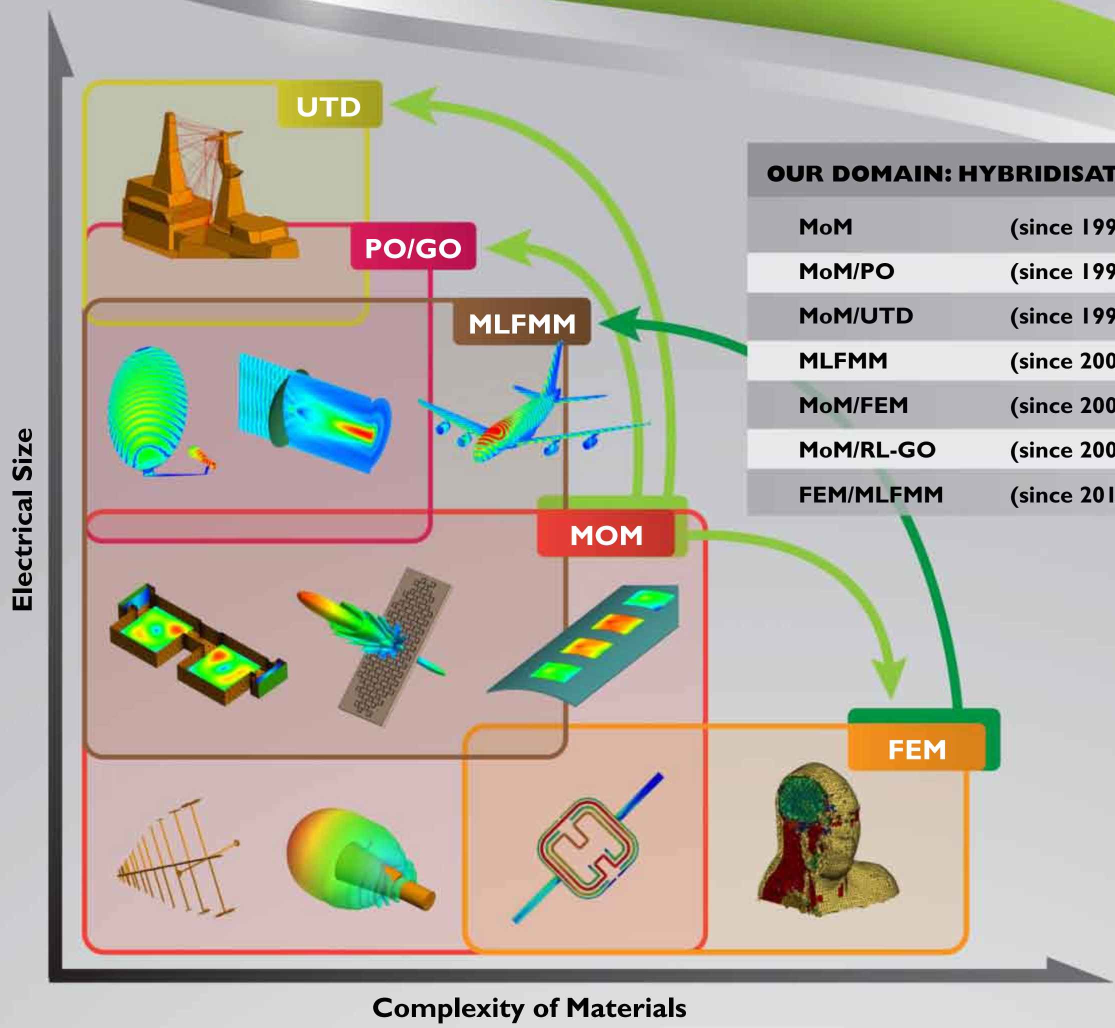
THE CELLULAR BANDS ARE NEARLY FILLED, NEW spectrum is hard to come by, and modulation techniques already use existing spectrum about as efficiently as possible. What's left to do? A recent report of the U.S. President's Council of Advisors on Science and Technology concludes that we must move to smaller and smaller cells. As the cell size shrinks, system capacity becomes virtually limitless. • I imagine a world filled with wireless picocells. But wait–don't we already have something approaching that with the spread of Wi-Fi hot spots? I consider the one I'm using right now, as I write this column in a coffee shop. The shop's little cell–where is it? behind the counter?–covers my fellow dozen customers. There's another cell next door, and next door to that, and so on, all the way down the street. In fact, when I drive through this little community, I'm never out of range of a Wi-Fi hot spot. • The website WiGLE.net lists about 100 million sites that have been discovered by contributors. When I zoom in on the map of hot spot locations, I see that in my little town there is a dense concentration of sites along all the main roads, and I know that the unmapped side roads are also dense with sites. Even my own house, so far from any road that a laptop in a passing car can't receive my home network's signal, shows up on Google Maps. Indeed, Google knows exactly where I am when I use my iPad at home. Just how does it do this? • Google says it uses crowd-sourced Wi-Fi hot spot data to triangulate the location of networks. I assume that it locates me by combining information from networks reported by several neighbors before it reaches a known street location. However Google does it, I'm impressed, and it says something to me about the density of Wi-Fi coverage and geographic usability of this data.

In spite of this density of coverage, when I walk out of this café, I will have to rely on my cellphone and the services of my cellular provider. Needless to say, this is expensive–in terms of both network resources and my provider's monthly bill–especially in comparison with the free coverage inside the café. But almost all those other networks outside this door are closed to me. WiGLE.net reports that only about 17 percent of the sites it lists are unencrypted and that this percentage has constantly decreased with time. I'm reminded of the old saying "Water, water everywhere, but not a drop to drink." The picocells are everywhere; I just can't use them.

I have this imaginary scenario where I convince everyone in my town to open up their Wi-Fi networks. We'd all use Skype for telephony, get rid of our cellphones, and get cheap, prepaid cellphones for travel and emergencies. Of course, there would be worries about privacy with open networks, although it could be maintained with encryption and other safeguards while leaving the network access open. Indeed, Apple's Wi-Fi routers–and many others–allow for the creation of a separate "guest" network.

I wonder how this scenario would evolve. Maybe open networks would spread throughout the country and the cellular providers would lose a lot of business. Investment in the cellular infrastructure might disappear. Wi-Fi locations might get overloaded and experience interference problems. Even today some experts are predicting the imminent collapse of Wi-Fi, but maybe, as with the old predictions of the collapse of the Internet, it will continue to thrive. In any event, what role it plays remains to be seen. Right now Wi-Fi is considered an adjunct to the cellular network, but it's conceivable that this paradigm could be reversed. ■

ILLUSTRATION BY James Steinberg



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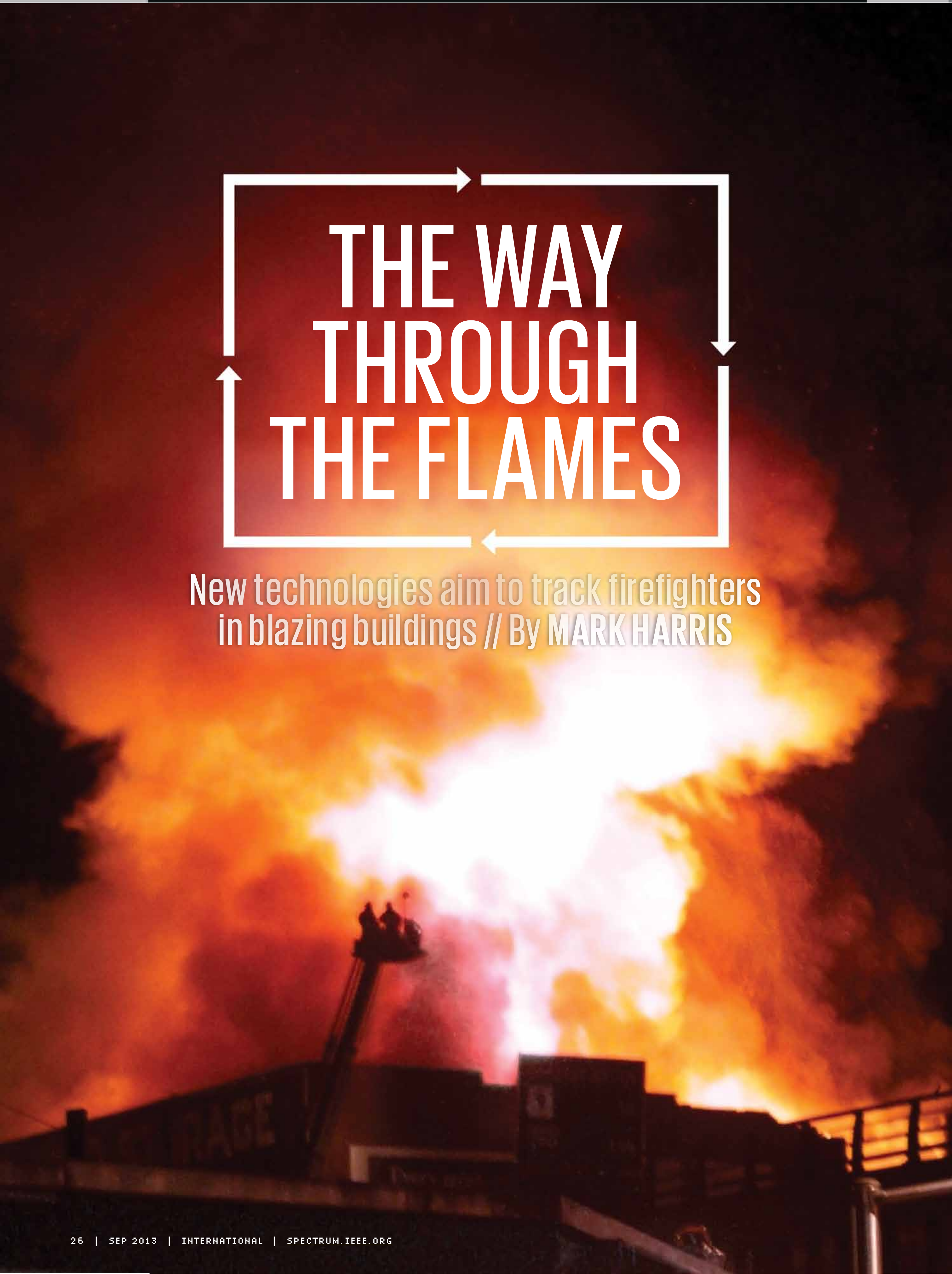
THE WAY THROUGH THE FLAMES

New technologies aim to track firefighters in blazing buildings // By MARK HARRIS



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LEFT: REUTERS; RIGHT: PAUL MARTINKA/AP PHOTO

DEADLY WORK: Firefighters battle conflagrations at an abandoned warehouse in Worcester, Mass. [opposite and next page] and at an apartment building in Brooklyn, N.Y. [this page].

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EARLY IN THE EVENING OF 3 DECEMBER 1999, two squatters in an abandoned cold-storage warehouse in Worcester, Mass., knocked a lit candle onto a pile of clothing. At 6:13 p.m., an off-duty police officer reported smoke billowing from the roof. Within minutes, dozens of firefighters arrived on the scene.

At 6:26, a message reached the on-site commander that homeless people lived there, and he ordered crews to search the building. As smoke spread through the six-story maze of corridors and meat lockers, visibility began dropping fast.

At 6:47, a firefighter who had entered from the roof sent a radio transmission: "Rescue to Command, I need help on the floor below the top floor of the building. We are lost..."

Firefighters are specifically trained to deal with disorientation. In near-black conditions, they often use hoses or search ropes to find their way back to safety. Without tethers, they follow the "right-hand rule," running the fingers of one hand along a wall until they reach a door or window through which they can escape.

The two lost firefighters didn't have ropes, and their right hands presumably led them only deeper into the warehouse's labyrinth. When they realized they were lost, they did what they'd been taught to do: They stopped moving, radioed for help, and activated the personal alert safety system (PASS) devices attached to their air tank harnesses. These battery-powered boxes emit a piercing alarm for rescuers to listen for.

None of the firefighters sent to find their colleagues heard the alarms. And because the warehouse was windowless, save for a few openings on the second floor, there was confusion about how many stories the building had. Not knowing which floor the lost men were on, rescuers wasted time searching the wrong ones.

As the fire raged, more firefighters were dispatched. At 7:10 p.m., a lieutenant made a distress call: "Chief, get a company up the stairwell to the fifth floor. We can't locate the stairwell. Or give us some sign as to which way to go. We are running low on air and we want to get out of here."

At 7:49, someone reported that the building might collapse. The heat and smoke were now nearly unbearable. When the commander finally called off the search at 8:00, six firefighters were missing.

GETTING LOST IS A HAZARD firefighters accept with the job. They know that most times, someone will rescue them before their air tanks run out or flames engulf them. But they also know there's a fair chance they will inhale smoke or get burned waiting. Each year in the United States, hundreds of firefighters suffer injuries, and a handful die because they can't get out of burning buildings.

You might think there's an easy tech fix. After all, satellite-based navigation systems do a fine job of maneuvering you through city streets or tracking down that laptop you left in a cab. But creating a system for navigating indoors, where satellite signals don't easily penetrate, is much tougher. Yes, consumer products already exist for airports, malls, and museums. But most of these require prior surveys of Wi-Fi signals, which aren't present everywhere, especially if access points or power sources go up in flames.

In the decade or so since the Worcester fire, dozens of engineers have joined the race to build an indoor navigation system that can track firefighters to within a meter. Now, two groups say they are close to succeeding. If they can clear just a few lingering technical hurdles, they may be able to get equipment in the hands of firefighters, paramedics, and other first responders within the next couple of years.

One of these groups was founded by John Orr, a professor of electrical and computer engineering at Worcester Polytechnic Institute (WPI). "I had the feeling that technology had to be able to solve this problem, where people were dying literally within 100 feet of safety," he says.

He recruited fellow professors David Cyganski and Jim Duckworth to brainstorm solutions. "We thought it was going to be a two- or three-year project," Duckworth says, flashing a rueful smile.

An early scheme the team devised called for three stationary radio transceivers that fire crews would set up outside a burning building. These would link wirelessly to one another and to a laptop-size base station, which would house an atomic clock and orient itself and the transceivers using GPS signals. The transceivers would listen for transmissions from small radios carried by the firefighters and pass those signals to the base station. By timing the signals' arrival from each portable radio, the base station could determine their ranges and then calculate their three-dimensional positions using basic geometry. This location data would stream wirelessly to the incident commander's computer display, which could be loaded with floor plans if any were available. Then if a

GETTY IMAGES

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firefighter got lost or injured, the commander could dictate an escape route or direct rescuers over voice radios. (No one expects firefighters in a crisis to deal with display screens themselves.)

The WPI team called its project the Precision Personnel Locator, or PPL. In theory, the system could achieve at least 1-meter precision. And indeed, early prototypes worked well in houses or small brick buildings. But they failed miserably in the presence of metal or concrete. Beams, joists, roofs, and rebar blocked or scrambled the radio waves, creating unmanageable multipath interference. "A commercial building is like a hall of mirrors," Cyganski says.

For nearly two years, the WPI team chipped away at the project with only its department's own funds. Then, on 11 September 2001, 412 firefighters and other emergency responders died in the aftermath of the attacks on the World Trade Center, in New York City. Suddenly, the ability to locate emergency workers became a national priority. So when the U.S. Department of Homeland Security formed its science and technology research arm in 2004, one of the new directorate's first tasks was figuring out how to track people inside buildings.

Leading this effort was Jalal Mapar, who at the time was a program manager at the Homeland Security Advanced Research Projects Agency and now directs its resilient systems division. He soon reached out to the WPI group and began sponsoring annual indoor navigation workshops at the university. Although he praised the WPI group's efforts, Mapar didn't think an ideal system should include fixed equipment that took precious time to set up. He began funding private companies to come up with alternative systems.

"My basic requirement was no infrastructure," says Mapar. "These things have to be self-contained and operate easily on their own." He favored using a gadget known as an inertial measurement unit. An IMU uses gyroscopes and accelerometers to track a wearer's movements in three dimensions. Modern microelectromechanical systems (MEMS) can squeeze these components into a matchbox-size package that firefighters can wear on their boots. Before a firefighter enters a building, this IMU-based locator would establish its initial position using a GPS receiver. It would then use a radio to beam position changes to the incident commander.

IMUs, however, are prone to drift. And because a unit determines its current position relative to its previous one, even tiny errors quickly add up. Just standing still can throw off many models, WPI's Duckworth claims. "Within 2 minutes, it'll look like you've drifted out of the building," he says.

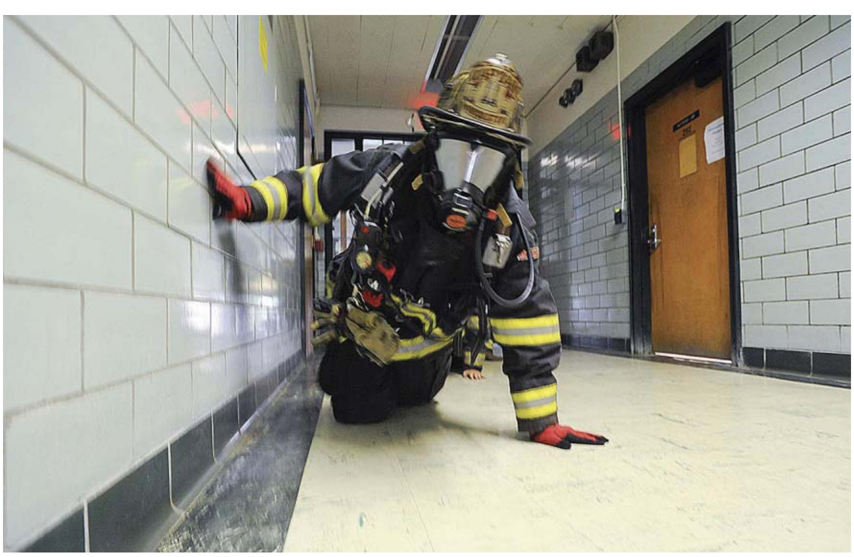
After several years of workshops at WPI, the experts all agreed that neither radio systems nor IMUs alone would work. By now, at least a dozen institutions and start-ups were trying to commercialize a product. Most of their prototypes used "fusion" algorithms to combine data from both radios and IMUs–and in some cases also magnetometers, pressure sensors, and digital compasses–to overcome the deficiencies of individual sensors. These systems performed well in the lab, and their inventors were itching to take them to the field.

IN APRIL 2009, Homeland Security hired the WPI group to assess six location systems that manufacturers thought were ready to market. (The department has kept the candidates' names confidential, though Mapar says the list didn't include the WPI team.)

At a police training academy in rural Massachusetts, more than 60 firefighters and police officers tested the systems in buildings they had never entered before. The firefighters blacked out their masks to simulate thick smoke, and the WPI engineers timed how long it took them to complete a series of rescues.

The results were abysmal. One system failed to detect sharp turns. Another directed a rescue team into the wrong building. Yet another worked when firefighters walked or ran but not when they crawled, which firefighters habitually do to avoid the worst of a fire's smoke and heat. "It's amazing how many [engineering] teams didn't comprehend how firefighters went about their business," Duckworth says.

None of the tech solutions helped firefighters complete missions faster than the old-school strategies, such as searching

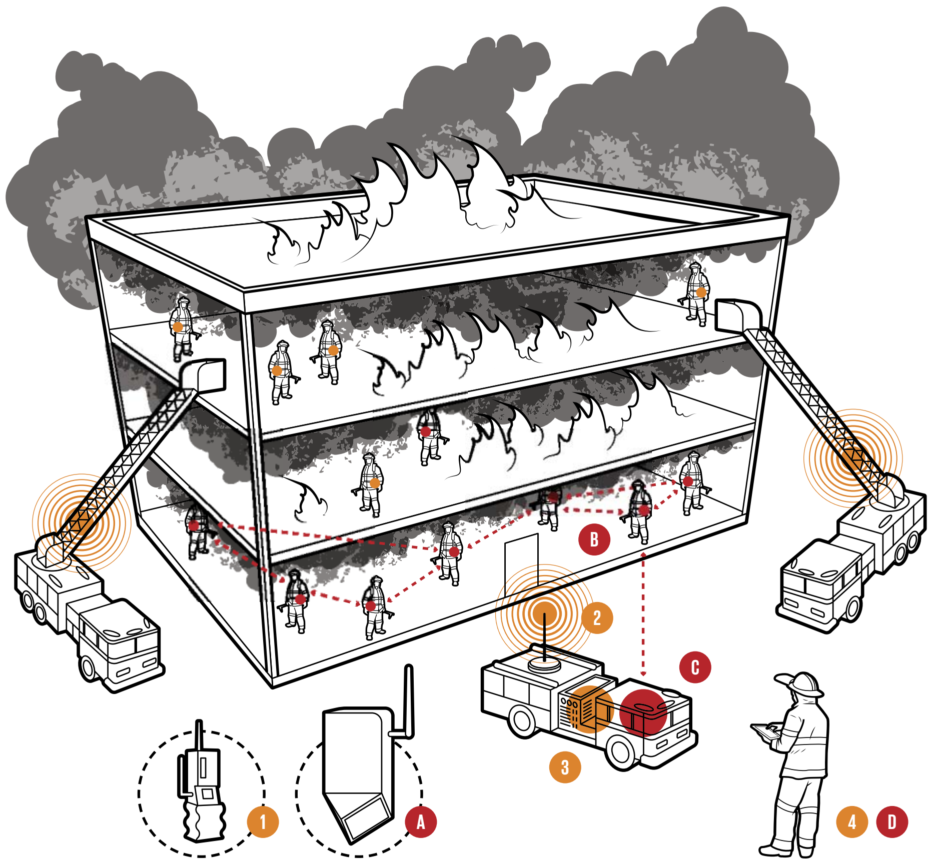


TRIALS BY FIRE: Wearing opaque masks to simulate blackout conditions, Worcester, Mass., firefighters perform test rescues using the GLANSER [above] and PPL [right top and bottom] indoor tracking systems.

WORCESTER POLYTECHNIC INSTITUTE (3)

How to Track Firefighters *INDOORS*

It's tough to navigate inside buildings, which can block satellite signals. But two promising tech solutions have emerged: the Precision Personnel Locator (PPL), developed at Massachusetts' Worcester Polytechnic Institute, and the Geospatial Location Accountability and Navigation System for Emergency Responders (GLANSER), a project of the U.S. Department of Homeland Security.



PPL

1 PORTABLE UNIT Each firefighter carries a radio transmitter that beams ranging signals and location data from a commercial-grade inertial measurement unit (IMU).

2 FIXED TRANSCEIVER Antennas built onto trucks or ladders act as reference points for finding the range of a portable unit.

3 BASE STATION One main station inside a fire truck crunches data from each portable unit to calculate its position. It improves accuracy by using a firefighter's movements to create a virtual antenna array.

4 WIRELESS TABLET The incident commander tracks the crew on a tablet display. He gives rescue instructions using a voice radio.

GLANSER

A PORTABLE UNIT This device latches onto a firefighter's gear harness. It houses a military-grade IMU, a GPS receiver, a radio, a barometer, and radars. Algorithms combine the data to pinpoint location.

B MESH NETWORK Nearby portable units can link to one another, letting them swap location data and relay weak or blocked signals.

C BASE STATION A fire truck carries a base station, which serves as a fixed reference point for radio ranging. This station links to the mesh network and to the commander's tablet.

D WIRELESS TABLET The incident commander tracks the crew on a tablet display. He gives rescue instructions using a voice radio.

methodically and listening for PASS sirens. In some trials, rescuers took nearly twice as long to reach victims; in others, they never found them at all. To the engineers' dismay, technology had made a bad problem worse.

With such disappointing commercial vendors, Mapar decided that Homeland Security would develop its own system, called Geospatial Location Accountability and Navigation System for Emergency Responders (GLANSER). In its current form, the system includes wearable units about the size of tissue boxes that attach to a firefighter's breathing gear. Each device packages a military IMU with a GPS receiver, Doppler radars to correct velocity, a pressure sensor to judge changes in altitude, and a radio to measure the range to a fixed base station and to other nearby units. This radio network uses short pulses to help get around the multipath problem. Inside each unit, powerful algorithms known as Kalman filters combine all these inputs to make a precise prediction of its position.

GLANSER also enables up to 11 neighboring wearable units to communicate with the base station and with one another, forming a "mesh network." Meshing lets the units swap location data, which improves individual accuracy even more. Two or three units working together can resolve their positions to at least 3 meters, Mapar says. In theory, adding more units would reduce that error, although Mapar will have to wait for the latest test results (due back this month) to know by how much.

Through meshing, units can also relay signals for one another. "If the signal from one unit can't reach the base station, it'll hop through the network to get out," Mapar explains. GLANSER can support more firefighters by adding more base stations and hence more mesh networks.

During tests at WPI in August 2012, GLANSER became the first system to show an advantage over traditional methods. Using the system, rescuers navigated to victims without making a single wrong turn and even completed one mission in only 6 minutes, as opposed to the

ILLUSTRATION BY MCKIBILLO

30 minutes or so typically needed to make similar rescues without the technology. Now, a handful of U.S. fire departments are testing early models manufactured by Honeywell International.

The technology still faces some obstacles. One of the toughest challenges will be reducing the size and weight of the portable units so that they don't impede firefighters' movements. Because the battery makes up much of a unit's bulk, power engineers at Homeland Security are working to develop a thin, flexible battery that could slip into the lining of a firefighter's jacket. Just 1 square meter of the 1-millimeter-thick material, Mapar says, would be "the equivalent of 100 AA batteries."

GLANSER's biggest drawback, though, is its cost: The components of a portable unit alone add up to between US $2000 and $3000, not counting the fancy battery. A commercial product would sell for many times that. According to the U.S. National Fire Protection Association, nearly three-fourths of the country's fire departments can't even afford spark-safe radios at less than $750 a pop. Mapar suggests that cash-strapped departments could set up lease deals with GLANSER distributors, but even then the price may be prohibitive.

THE WPI GROUP, meanwhile, is addressing the cost problem head-on. "Our approach is constrained by making something that can be mass-produced and literally cost a few hundred dollars," Duckworth says. To do this, he and his team aim to eliminate the need for expensive, power-hungry hardware by building better software.

In the group's latest vision for the PPL, firefighters would carry portable units the size of walkie-talkies. Each would contain a cheap MEMS IMU and a pulsed radio transmitter to reduce multipath error. As in the original design, a base station would calculate the units' positions using its atomic clock time and radio signals from three fixed transceivers. The WPI group envisions that the transceivers would be mounted on fire trucks or incorporated into ladders so that crews wouldn't have to waste time setting them up on the ground.

In addition to transmitting ranging signals, each portable unit would broadcast its IMU's internal position estimate. The base station would then fuse the two guesses into a more accurate one using a mathematical technique known as synthetic aperture imaging.

Military planes have long used this method to map ground terrain with radar. In traditional radar imaging, a physical antenna focuses an RF beam on a target and captures information from its reflections. Achieving higher resolutions requires narrower beams, which calls for larger antennas. To resolve fine details, such as tanks, a plane would need an antenna much longer than it could carry. Using synthetic aperture imaging, it can use a smaller antenna and simulate the larger version in software. In essence, the distance the physical antenna travels becomes the aperture of this virtual antenna.

From inside a fire truck, the PPL base station would do something similar using the transmissions from a firefighter's portable unit. Just as the plane's radar uses its flight path to virtually grow its antenna, custom-built algorithms at the base station would use the unit's movements to create virtual antenna arrays. By evaluating the multiple input signals, the algorithms would pinpoint the firefighter's location. Finally, the base station would feed these results back to the portable unit to help correct IMU drift.

The PPL has several advantages over GLANSER: The portable units are less cumbersome, they boast a 24-hour battery life, and they'll likely be much cheaper to manufacture. Over the past couple of years, the Worcester Fire Department has helped assess the equipment during mock rescues. Although these tests haven't been as rigorous as the evaluations of GLANSER, Duckworth says they've shown that the PPL can quickly locate victims, even in large steel or concrete buildings. The system is most accurate in residences, where errors are of no more than a meter, he says.

Still, the WPI group, like Mapar's team, must overcome a few technical obstacles before its system is ready to market. If fewer than three engines respond to a fire, crews will need one or two ground-based transceivers, and the WPI team will need to find a way for firefighters to deploy these without delaying their mission. The engineers also need to make the portable units more rugged and optimize the synthetic aperture imaging algorithms, which were developed on powerful PCs, to run on embedded processors in a base station.

"We're giving ourselves a difficult challenge," Duckworth admits. "You have to get firefighters within 1 to 2 meters, and it has to be 100 percent reliable or they'll never use it again." He estimates that the PPL system could be ready for fire departments to test in as little as 18 months, provided his team can find a manufacturer to license it.

REMEMBERING LIVES LOST: A Worcester, Mass., fire station [top] now stands on the very spot where a warehouse burned in 1999. A memorial [bottom] commemorates the six firefighters who died in the blaze.

BRITTON CROSBY (2)

IT TOOK EIGHT DAYS to uncover the bodies of the six firefighters lost during the Worcester warehouse blaze. Investigators later determined that the squatters probably escaped the building before the first engine even arrived.

Today a fire station stands where the warehouse burned down. A bronze sculpture of a kneeling firefighter, a plaque, and a portrait of six teammates carved in a granite wall commemorate the fallen men. If you drive by any day of the week, you will likely see crews cleaning trucks, testing gear, or running drills. These men and women willingly put themselves in harm's way to save others' lives. It's high time they had the tools to save their own. ■

POST YOUR COMMENTS online at http://spectrum.ieee.org/firesafety0913

THE ANNOTATED AMERICA'S CUP

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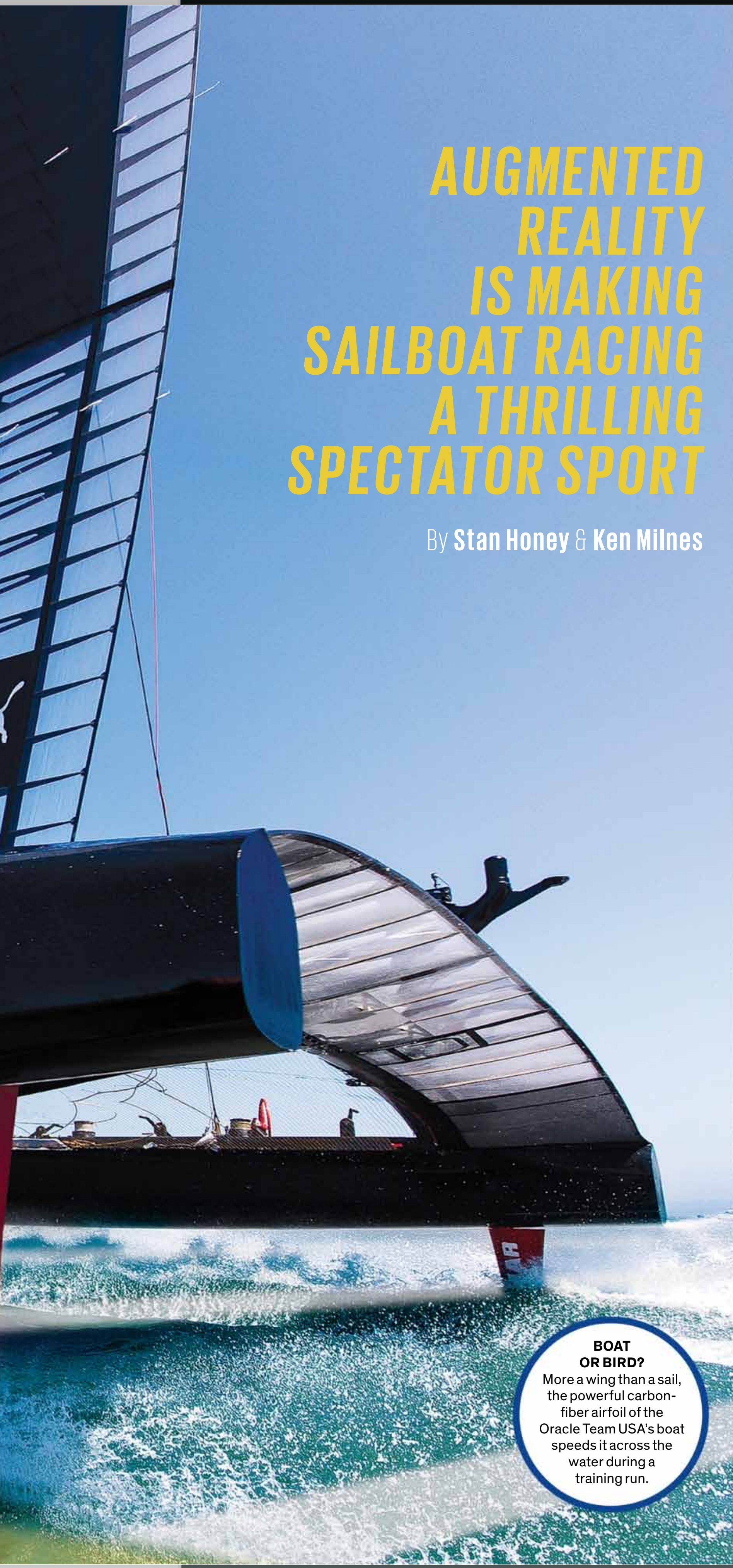
AUGMENTED REALITY IS MAKING SAILBOAT RACING A THRILLING SPECTATOR SPORT

By **Stan Honey** & **Ken Milnes**



BOAT OR BIRD?
More a wing than a sail, the powerful carbon-fiber airfoil of the Oracle Team USA's boat speeds it across the water during a training run.

AS A TV SPORT, SAILBOAT RACING is relegated to the same sorts of channels and time slots as bowling and poker: They're worse than those for fishing and golf. The problem is that even passionate sailing fans can find it hard to follow races on television, where producers cut back and forth between video of the boats and animated simulations of the action, attempting to show where the boats are in relation to one another. If you're channel surfing and you come upon a yacht race and have no idea which boat is in the lead, what would you do? Change the channel, probably. ● That's a shame, because sailboat racing is as thrilling, dynamic, and suspenseful as any sport around—if you're down there on the water with the boats, that is. And starting with the 2013 America's Cup, to be held this month in San Francisco, you *will* be there, virtually speaking. You'll be able to monitor the events live on TV and on your mobile devices. You'll see the spray flying off the bow of a big racing catamaran as its crew scrambles to make high-speed maneuvers in a stiff wind. You'll see the world's top sailors grappling to control powerful vessels driven by sail-like vertical wings, 12 stories high. You'll also see perspectives and information never before available to spectators: the tracks of the boats through the water, course boundaries, penalties issued, wind direction, speed, and other things that significantly affect the outcome of the race. ● Automatic tracking systems on each yacht will constantly feed position data to high-performance PCs on shore. Custom-built augmented-reality software will turn the position data into informative onscreen graphics in real time. ▸

The graphics will look as if they're painted on the water—essentially, a streaming "chalk talk" of race progress. Audio and video streams from the boats, virtual course marks "drawn" in real time on the televised water, and computer-controlled cameras on helicopters will all contribute to the viewing experience for those in front of televisions at home or standing near giant screens onshore.

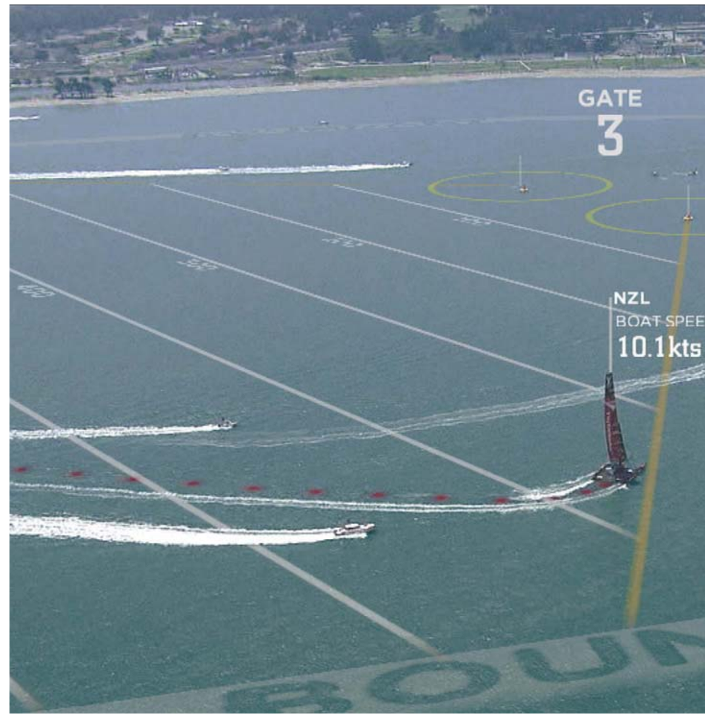
Whether or not the technology succeeds in its goal of bringing millions of new fans into the sport of elite sailing, it will change the race itself. For the first time, race umpires will be able to consult live computer-rendered diagrams showing boats and the location of different course markings before ruling on a possible rules violation, in much the same way that referees in American football now use instant replay—except America's Cup umpires will look at the images *before* making their calls.

THE AMERICA'S CUP tradition started in 1851, when a boat named *America* won a race around the Isle of Wight in England. The winning team named its trophy the America's Cup and donated it to the New York Yacht Club. The race has occurred every four to five years since, with a few longer and shorter intervals, and it is always between the current holder of the cup—the "defender"—and a single challenger. Since 1983, that challenger has been determined before each match in the Louis Vuitton Cup race series, in which national teams compete for the right to challenge.

Although it is among the oldest of sporting events, the America's Cup has embraced change far more quickly than other major sports, because each winning team takes over not just the trophy but the event itself. It can change the venue and type of boat, redefine the course, and completely rewrite the rules for the competition, with the agreement of the challenger. For example, racers used enormous and costly J-class yachts, typically about 38 meters in length, in the 1930s, then switched to the smaller and cheaper 12-meter class of boats, typically about 20 meters long, after World War II.

In this year's contest, Oracle Team USA, founded by software billionaire Larry Ellison, is the defender of the America's Cup. (As of mid-July, the challenge races among teams from Italy, New Zealand, and Sweden were under way.) A brash entrepreneur whose database company disrupted business computing in the 1980s and who is today the head of the world's third-largest software vendor (behind only Microsoft and IBM), Ellison isn't shy about betting big on new technologies. So it's no surprise that Ellison's America's Cup defense will introduce the most radical changes ever.

To begin with, consider the boats chosen for the competition: They are 22-meter (72-foot) catamarans, the highest-performance, most technology-laden, most innovative boats ever sailed in the America's Cup. They can reach speeds of about 45 knots, and each one costs about US $8 million—a price tag that has kept the field of challengers unusually small. The boats are built largely from carbon fiber, a material more common in aircraft than in yachts. The designers eschewed the usual fabric mainsails for "wing masts," which are stiff structures shaped like airplane wings. The controversy over these boats, which sacrifice some stability for speed, came to a head last May, when a veteran British sailor from Sweden's Artemis Racing team was killed after his boat "pitch-poled"—that is, it flipped end over end—and suffered a structural failure during a training run. The



accident followed another, nonfatal one in October 2012, when one of the Oracle team's boats pitch-poled, destroying its wing sail, not far from the Golden Gate Bridge. Not just the yachts but also the racecourse will be unusual. Instead of sailing well offshore, out of the view of spectators, the boats will sail on short courses in the San Francisco Bay, quite close to the shoreline.

IN JUNE 2010, THE ORACLE TEAM hired the two of us to develop the tracking, telemetry, and augmented-reality system for the races. We are both electrical engineers, and one of us (Honey) is a professional sailor who competes in elite races. We have a long history in applying augmented reality to broadcast sports. Our past projects include the yellow first-down line now ubiquitous in televised American football, the tracking system now used in NASCAR and other motor races, and the ESPN K Zone system used to track and show a baseball's path in the vicinity of the strike zone.

What these systems have in common is that they all highlight a location, path, or movement that is important to the sport and yet was previously invisible—or at least hard to see—on television. In American football, for example, the objective of most plays is to get (or prevent) a first down, which is achieved by moving the ball 10 yards down the field within four plays. Before we developed our system, the only indication of the down line was an official holding a pole at the edge of the field. If you were watching the event on TV and the TV camera happened to zoom in on the play, you could no longer see the man with the pole. To solve this problem, we inserted a yellow line into the live video; to TV viewers, the line appears to run across the width of the field, apparently underneath the athletes, making the distance to the first down obvious at all times.

But with sailing we were facing a much more difficult challenge. In sailing, almost everything that goes on is hard to see. Never mind the nuances of the sport; just telling who is in the lead is often difficult

PREVIOUS PAGES: GILLES MARTIN-RAGET/ACEA

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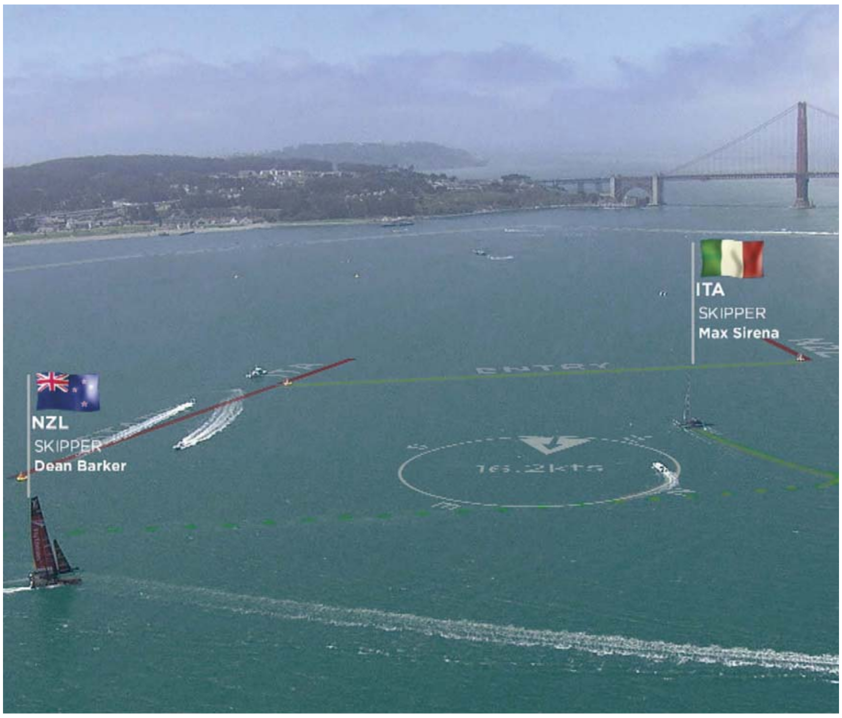


ON THE WATER The AC Liveline system inserts graphics into the live television feed of a sailing race, using video shot from helicopters and position data sent directly from the boats. **Lines 100 meters apart** [far left] span the course, creating a "ladder" that leads to the next gate or mark at which the boats must make a turn; this allows viewers to easily see which boat is ahead. **Yellow polygons** identify the area around the buoys that mark the required turns; for the sailing-savvy viewer, knowing this region is important because certain special race rules go into effect within it. **Yellow lines indicate laylines,** the places where the direction of the wind will allow a boat to sail in a straight line to the next gate. The **white text** that appears to hover in the sky calls out the gates through which boats must pass; it also identifies the boats, their speeds, and other information. Alternatively, **virtual flags** can quickly let viewers tell which boat is which, as shown in this image of the start of a race [near left]. The **virtual compass** on the water shows the wind direction and speed. **The start line, shown in red,** changes color the instant the race begins.

ACEA (2)

without onscreen graphics. Like a skier on a slalom course, a boat must pass through a series of gates or around "marks," which are designated with buoys. But that's about all that's visible. Take wind direction, a crucial piece of information for appreciating a sailing race. While spectators onshore can roughly tell the wind direction, those watching on TV can't do much more than guess.

Racecourses typically run parallel to the direction of the wind, but sailboats can't sail in a straight line directly into the wind, and sailing directly away from the wind is inefficient. So sailors must position the boat so the wind comes over the side of the boat at an angle and fills the sails to propel the boat forward. To do this, the crew follows a zigzag path, alternating between turning upwind (tacking) and downwind (jibing). In other words, when a boat is tacking, the sailors are turning it into and through the wind, which causes the sail to move from one side of the boat to the other. Confusing? For TV viewers, it is doubly so: Not knowing the wind's direction makes it tough to figure out where a boat is attempting to go or why it's doing what it's doing.

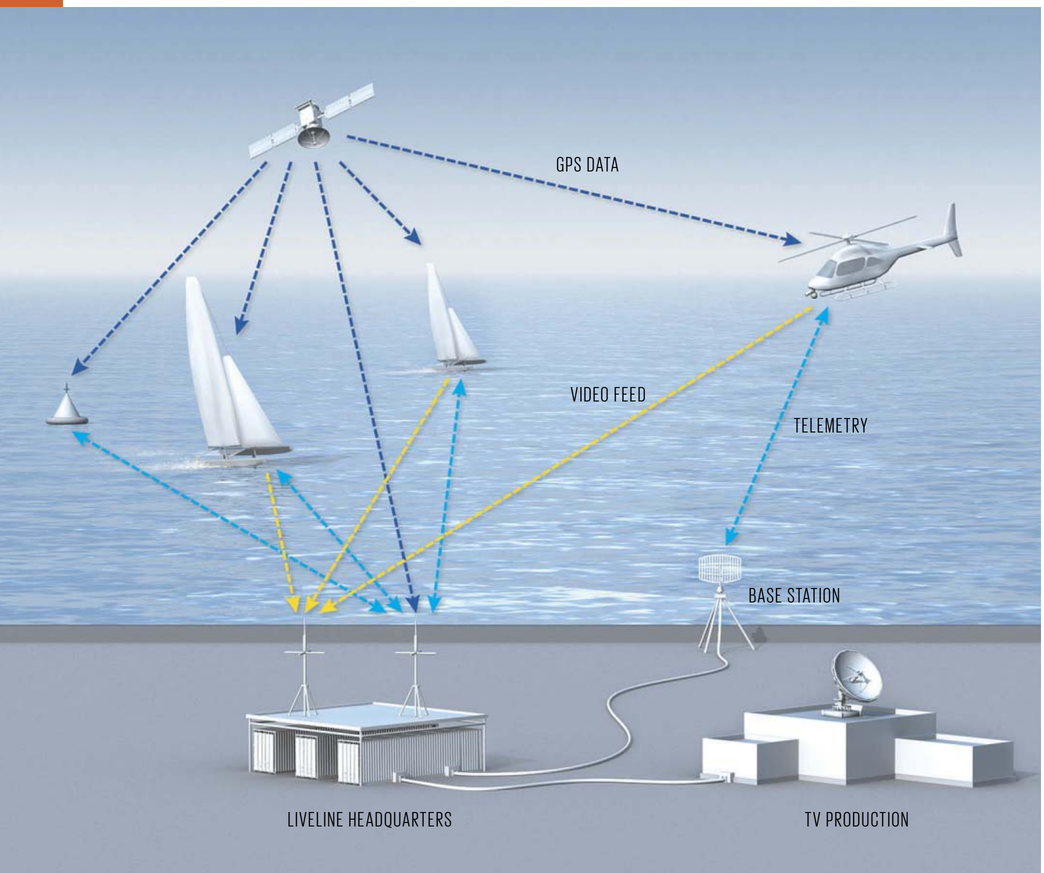
Other elements typically lost to viewers include the course's outer boundary and, crucially, the laylines. The laylines are imaginary lines that show the points from which the wind's angle allows a boat to set a straight-line course, without additional tacks or jibes, directly to the next gate—one of the many pairs of buoys that mark the twists and turns of the course. Knowing just the location of the gates doesn't tell a viewer much about race progress, because until a boat gets to a layline, it doesn't aim for the gate; instead it is tacking or jibing and may at times appear to be traveling perpendicular to a gate. For the 2013 America's Cup, all these lines, directions, and subtleties will be revealed to television viewers directly and in real time. In place of the graphical inserts or separate animations that were used to explain the action in the most recent broadcasts, the visual cues will be integrated right into the action.

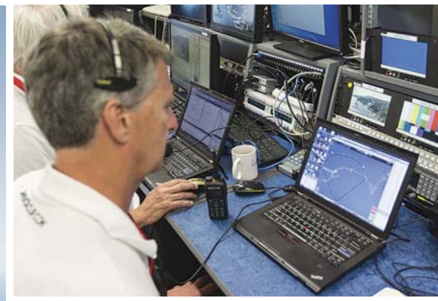
MAKING A SAILING RACE as easy to follow as a football game starts with defining the playing field. On the live video, we're superimposing lines that delineate the course boundaries along with a "ladder" of 100-meter lines. If two boats are on the same "rung" of the ladder, they have the same upwind or downwind distance to sail to the next buoy-marked gate or mark. With these lines as guidance, even a viewer new to sailing can quickly see which boat is in the lead. We're also marking an area extending three boat lengths out from each gate with a yellow polygon. When boats enter this yellow zone, race rules aimed at defining which boat has the right of way determine which boat can take the shorter, inside turn through a gate. That's why we're identifying the entire zone, not just the gate itself.

In addition to the ladder with numerical meter markings and the yellow gate zones, we're displaying laylines in yellow, boat tracks in a variety of colors, wind direction as an arrow on a compass, and text blocks that travel with the boats, spelling out such information as the boat's name and speed. At a glance, a viewer will be able to tell not only which boat is in the lead but also by how much, whether and how fast another boat is gaining on the lead boat, and whether competitors are taking similar or different approaches to the next gate.

Not all of these graphic elements are new. Starting with the 1992 America's Cup, broadcasts used virtual-reality graphics systems called SailTrack and Virtual Eye. These displayed laylines and other information as part of an animated rendering of the race action—but they were not superimposed on the live video of the race itself. As the TV broadcast toggled back and forth between the animation and the live video feed, commentators struggled to explain the similarities and differences to viewers. As a result, the race broadcasts were sometimes fragmented and confusing.

Augmented reality is far easier to interpret and vastly more interesting to watch than animation because viewers get to see all the information they need at once. They see the real boats, the sailors





SEA OF DATA Video feeds and position information [diagram, left] travel from boats and helicopters [right] to AC Liveline's headquarters. In that facility, shown here in 2013 during the America's Cup World Series held in Naples, Italy [top], they merge into an augmented video stream that can be broadcast live. In the broadcast production room [center] the show director selects from a variety of video feeds, including the Liveline augmented feed.

themselves, and the wind's effects on the water. But to combine graphics and live video seamlessly has required some serious engineering, involving integrating sensors, telemetry systems, and custom-written software. We call it AC Liveline.

To track a sailing race, we have to measure each boat's position automatically and accurately, updating the measurements continuously. Conventional GPS receivers, which at best can calculate a position within a meter and can occasionally lose track of their locations, aren't good enough for what we need; we want to make our graphics look like they're part of the race itself. If we tag a boat with a supplemental graphic, it must appear to travel smoothly with that boat. And if our tracking is accurate to only 1 meter, then when a boat enters a gate zone half a meter ahead of a competitor, we won't actually know which one got there first, and umpires wouldn't be able to use the data. So we had to develop a system that could reliably give us location data to within 2 centimeters.

In order to position our graphics properly and make them appear to move with the boats, we also need to measure the direction in which the boat is pointing (the heading), the front-to-back tilt (the pitch), and the side-to-side heel (the roll) of each boat to within 0.1 degree. We also need to know the heading, pitch, and roll of the TV camera that's up on a helicopter capturing the overhead view of the race, because we're synchronizing this video with the position data from the boats. Because the zoom lens on that camera would magnify any misalignment, we need to measure its angle with a higher accuracy—to within 0.01 degree—than is needed for the angles of the boats. Any lesser accuracy would mean we'd risk displaying a graphic that appears to be meters away from the corresponding boat. The 2-cm and 0.1-degree levels of position and orientation accuracy for the race yachts let umpires and race managers use our system to help run and officiate races.

Getting the position data down to 2-cm accuracy was tough. We started with a superior kind of GPS receiver that monitors the so-called carrier signals. This isn't the standard GPS receiver found in your car, phone, or athletic-training wristwatch. In those receivers, both the receivers and the GPS satellites simultaneously produce identical strings of digital code. Each receiver then compares the code it received from the satellite with the code it generated. Because of the time it takes the GPS signal to travel from the satellite to the receiver, these strings of code will be slightly out of sync; the receiver looks at the relative timing of the signals from four or more satellites and uses those measurements to calculate its distance from each satellite and its own position on Earth.

But to get even greater precision using the same type of analysis of the signal timing, you need to look at something with a shorter wavelength. That something is the RF carrier on which the code travels. The code itself repeats every 1023 bits, which takes a millisecond, giving it a frequency of about 1 megahertz. The carrier signals, however, are transmitting at frequencies of 1.2 and 1.6 gigahertz. The upshot is that a GPS receiver looking at carrier cycles in addition to the code can determine its position to 2 cm.

ILLUSTRATION BY Emily Cooper

PHOTOS, CLOCKWISE FROM RIGHT: ABNER KINGMAN/ACEA; RICARDO PINTO/ACEA (2)

Achieving 2-cm accuracy requires one more thing. We've added a base station onshore; we surveyed the spot and identified its precise location. Because the reference GPS receiver at our base station knows exactly where it is, it can estimate the effects of atmospheric conditions that cause signal delays. It can then calculate corrections for those delays and send them to the GPS receivers on the boats; those corrections are necessary to get that 2-cm position accuracy.

There are currently 31 satellites operating as part of the GPS system; a receiver typically needs to be able to receive transmissions from four of them in order to pinpoint its location. On occasion, a boat's own carbon wing or the wing of a nearby boat blocks so many satellites that we lose the ability to track its position via GPS. That, for us, would be a disaster. So we needed yet another backup plan. We selected an off-the-shelf navigation system that couples GPS with the inertial navigation system. An INS uses inertial sensors to implement the most basic navigational scheme there is: dead reckoning. The system has internal accelerometers and gyroscopes that constantly measure linear and rotational movement and direction; it also has an onboard processor to calculate navigation information using that data. With an INS on board, the crew no longer need compasses, but they carry them anyway.

BACK ONSHORE, a computer system takes all the position data from the boats and the helicopter–also outfitted with our augmented GPS-INS system–along with the video feed from the camera and matches every location in the real world to a pixel in the camera image. This enables us to place the laylines and the tags identifying the boats and their speeds precisely into the image so that it looks realistic to the viewer.

An enormous amount of calculation is necessary to make that happen. But it's based on some of the most basic principles of fine art. If you've ever taken a basic art class, you've studied perspective. First, you pick a "vanishing point" at what will be a distant place in your drawing. To position an object in the scene, you draw straight lines from the front of the object to the vanishing point, and then align the rest of the object along those lines.

Here, we've turned that around. Our single distant point is the camera. It corresponds, if you will, to the vanishing point–in this case called the point of view. Our system takes all the pixels in the image and calculates imaginary lines that connect each pixel to the camera. Now, say we want to put a boat's name near the boat. We rely on the position data to identify the correct object–the boat–and then use those calculated perspective lines to position the name in relation to the boat so it appears integrated into the scene in a visually pleasing way.

In addition to the data needed for the augmented-reality system, we're streaming 80 megabits per second of video from up to four of the seven HDTV cameras mounted on each boat, and we're sending signals from shore that allow cameramen to remotely adjust each camera's pan, tilt, zoom, and focus. We also send about 500 kilobits per second of data to and from the boats, including things like race boat locations, course boundary changes, locations of course marks, and penalties, and about 150 kb/s to and from the helicopter. We'll be sending data in a section of the 2-GHz band that we licensed for this purpose, using a modulation technique called coded orthogonal frequency-division multiplexing. COFDM spreads a digital transmission across multiple subfrequencies within the allocated frequency band; it's the way digital broadcast television works in most of Europe. It is also the modulation system used in one of the most advanced Wi-Fi standards, IEEE 802.11n. But we're using a time-slotted protocol, which is different from conventional Wi-Fi.

Typically, today's Wi-Fi and Ethernet systems detect in real time when a data packet runs into interference from another data packet sent from another user; the first transmitter then waits a random amount of time and resends the packet. This method is often called carrier sense multiple access with collision detection, or CSMA/CD. In time-slotted protocols, transmissions aren't random but rather scheduled to take turns using the channel. Time-slotted protocols are an older approach that isn't used widely today because they're less flexible and, in cases of unpredictable channel usage, less efficient. But in our case, with steady data rates, time-slotted techniques avoid collisions and we end up gaining in efficiency.

We send the video separately on licensed frequencies in the 3-GHz band. There are up to 14 HD video signals coming from the racing yachts, chase boats, various official boats, and helicopters, and each of those HD signals will be compressed from 1500 down to a range from 5 to 10 Mb/s and transmitted using COFDM.

The magic really happens when we combine the position information from sensors on board the boats with the video and camera position data from the helicopter. Viewers will be able to see not only tiny boats inching along the TV screen but also lines, shapes, and other graphics that appear to be painted on the rolling water.

Creating this illusion starts with putting a time stamp on each frame of the video as it is shot; we'll also be time-stamping the position data from the race boats. We'll use a high-speed PC with a specialized video capture card to bring graphics based on the position data and live video together in a composite

ON THE BAY The Artemis racing team, from Sweden, practices on San Francisco Bay in July, in preparation for the 2013 America's Cup.

image, synchronized by time codes. Our system will then feed the composite image to the television production room, where it will join 19 other live video feeds. There, the director will select the shots that will go out in a single video stream to NBC, the lead broadcaster for the race, and to 30-plus other broadcasters around the world. The whole process delays the live television display of the race less than a second.

One of the challenges is making the graphics look as if they were lying on the water's surface, so that the boats appear to sail over the colored lines and not under them. For this we use a common television technique called chroma keying. You see it in use whenever you watch a TV weather forecaster standing in front of a map; in reality, the forecaster is standing in front of a blue or green screen. A typical green-screen chroma keyer detects where the image is green, and that's where it "draws" the weather map image; otherwise, it draws the foreground image of the newscaster. Boats sailing on an ocean don't have a reliably consistent background–the water's appearance can vary depending on the weather and the direction of the sun. So the AC Liveline system uses a specialized chroma keyer that allows a wide range of background colors; an operator manually picks the correct water color by clicking a mouse over an image of that water.

Not only is our AC Liveline System changing how TV viewers see the race, it is also triggering changes in the sport itself.

Televised sports like NASCAR and Major League Baseball already gather extensive data from tracking systems to enhance the live TV broadcasts. Yet rarely is the tracking data used for officiating the event; umpires still call the balls and strikes in baseball, even though the tracking system could probably do the job more accurately. But in the America's Cup race, the same technology that will help viewers appreciate the race also helps officials make their calls.

Race officials will use the AC Liveline system in a few ways. For the first time, there will be two sets of race umpires: One set will be in boats on the water, as is traditional; the other set of umpires will sit in a booth onshore, watching real-time diagrams of the race action generated by AC Liveline and displayed on large screens.

The booth umpires will make the objective calls that come from knowing boat locations and orientation; for example, they can tell if a boat prematurely starts or sails beyond a boundary. They can also see the position of a competitor's boat when a boat first touches the zone around a mark; in certain situations, an inside boat has the right to round the mark inside the curved path of the other boat, even if it didn't enter the mark zone first. The umpires on the water will make subjective judgment calls that include deciding whether a collision was avoidable–that is, determining if the helmsman of one boat gave the other room and opportunity to maneuver to avoid the collision.

THIS 2013 AMERICA'S CUP is breaking with tradition in one more way: The organizers are making all the data collected publicly available. This open-data policy makes sense in today's Internet world: The basic raw data, including the real-time position of the boats, and race management data such as boundaries and penalties, will be streamed free of charge to the general public as it is being collected during the racing events. Various companies are developing smartphone and tablet apps to exploit the data. Some of these apps are intended primarily for use by fans at the event so they can view live data about the race, such as the time or distance between boats, or listen to onboard audio from a selected boat. Other apps generate a virtual-reality display of race action for those not on-site. The apps announced to date include the official America's Cup Mobile Application and CupExperience.

The teams onshore will have access to the data as well, although the sailors on the water will not. In previous America's Cup races, teams were carefully prevented from getting their hands on any detailed data from the media systems, but the teams worried that some competitor might figure out a way to break into the system and gain an advantage. By making the data publicly available, we essentially made this problem vanish: All the teams are satisfied that they are fairly and evenly treated, because all the data is equally available to all the team members onshore. The sailors aboard the boats will have access only to specific data feeds, giving them their own position and information about the boundaries and the course. The teams have developed proprietary systems to analyze and display this data to the sailors on board.

We hope the technology we've developed for this summer's America's Cup will eventually trickle down to all televised sailing. We also hope that the umpiring and race management tools will become widely used and will permit all high-level national, world, and Olympic competitions to be run more efficiently and be judged more fairly and openly. And we expect that the tools for graphically augmenting video will be applied to other sports that are also typically shot from aerial cameras, such as long-distance car racing, bicycle racing, marathons, and triathlons.

But that's in the future. In the meantime, the battle for the America's Cup is under way in San Francisco and being broadcast around the world. If you watch any or all of the races this month, you'll be part of history. You'll be seeing the very first sailing race designed to appeal to the lay viewer. And someday soon, when you tune in to a boat race at home or at a local sports bar, you may wonder why sailing wasn't always as popular as soccer or football. ■

POST YOUR COMMENTS online at http://spectrum.ieee.org/boatrace0913

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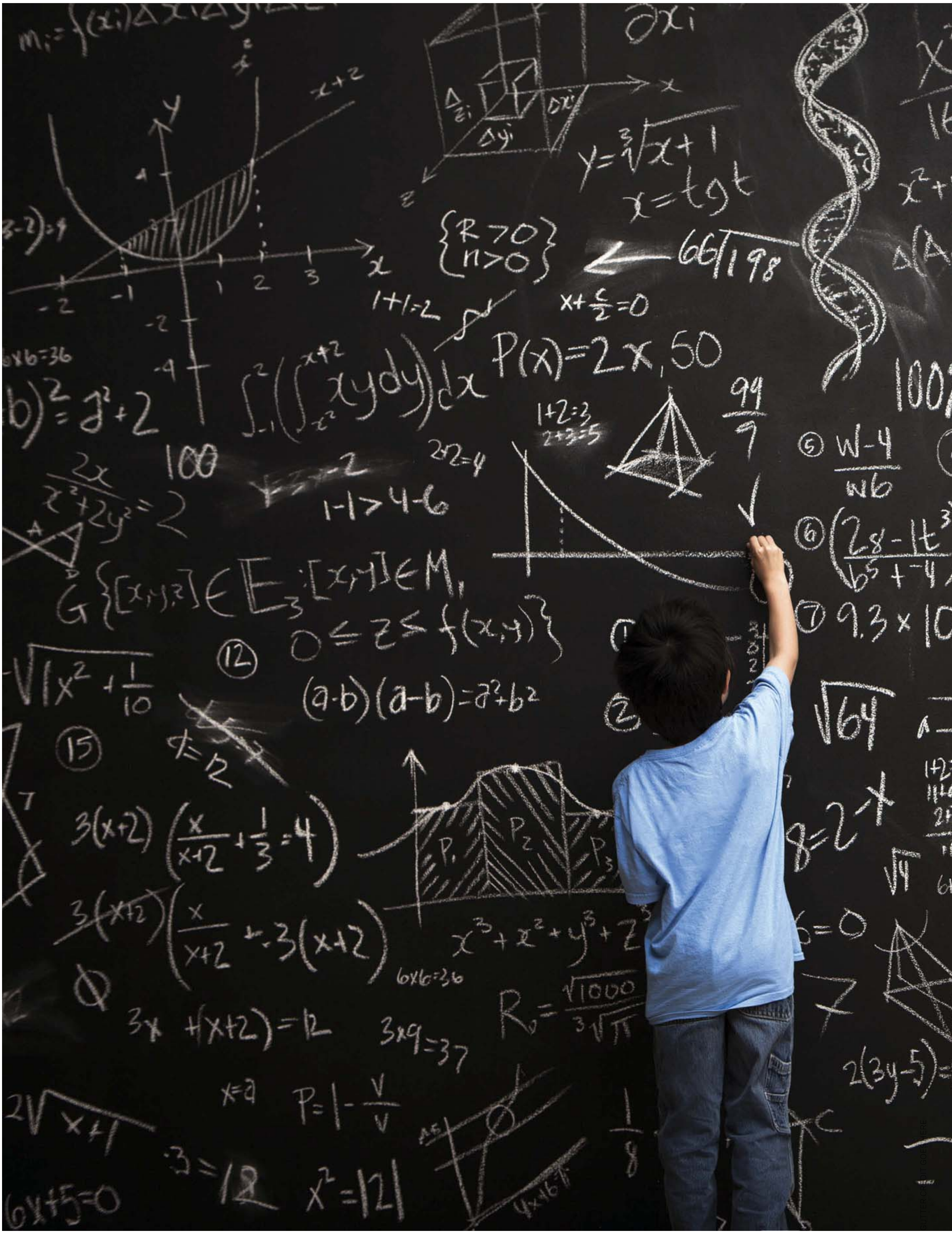

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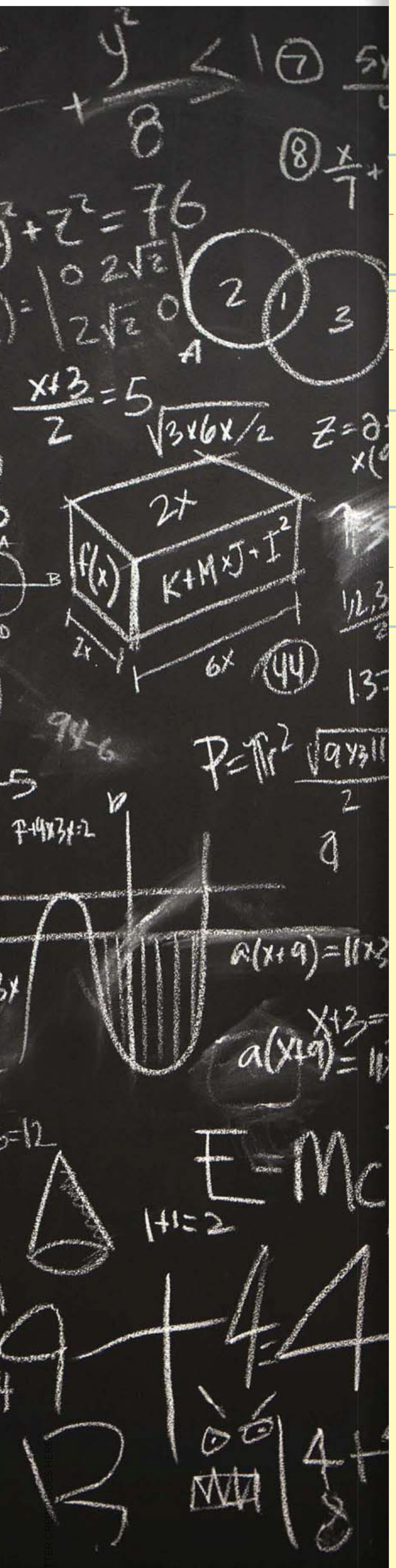


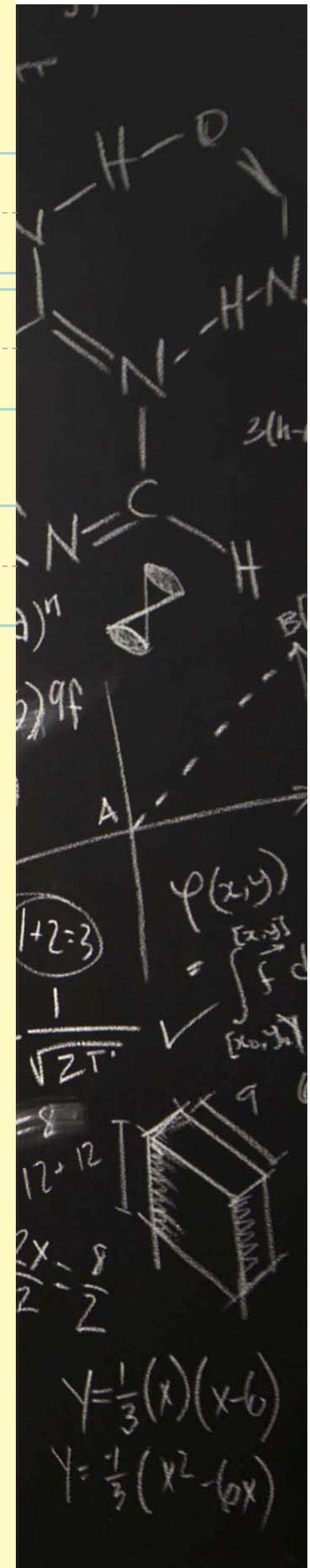
The STEM Crisis Is a Myth

Forget the dire predictions of a looming shortfall of scientists, technologists, engineers, and mathematicians

by **ROBERT N. CHARETTE**

YOU MUST HAVE SEEN THE WARNING A thousand times: Too few young people study scientific or technical subjects, businesses can't find enough workers in those fields, and the country's competitive edge is threatened.

It pretty much doesn't matter what country you're talking about–the United States is facing this crisis, as is Japan, the United Kingdom, Australia, China, Brazil, South Africa, Singapore, India...the list goes on. In many of these countries, the predicted shortfall of STEM (short for science, technology, engineering, and mathematics) workers is supposed to number in the hundreds of thousands or even the millions. A 2012 report by President Obama's Council of Advisors on Science and Technology, for instance, stated that over the next decade, 1 million additional STEM graduates



The STEM Crisis Through the Decades

Predictions of an impending shortage of scientists and engineers are nothing new.

"Right now...there is a sufficiency of engineers, but one of our greatest industrial organizations, after careful study, predicts the entire absorption of this group by the end of 1936, with a probable shortage of available engineers at that time."

—COLLINS P. BLISS, *dean of New York University's College of Engineering, 1934*

"With mounting demands for scientists both for teaching and for research, we will enter the postwar period with a serious deficit in our trained scientific personnel."

—VANNEVAR BUSH, *director of the U.S. Office of Scientific Research and Development, 1945*

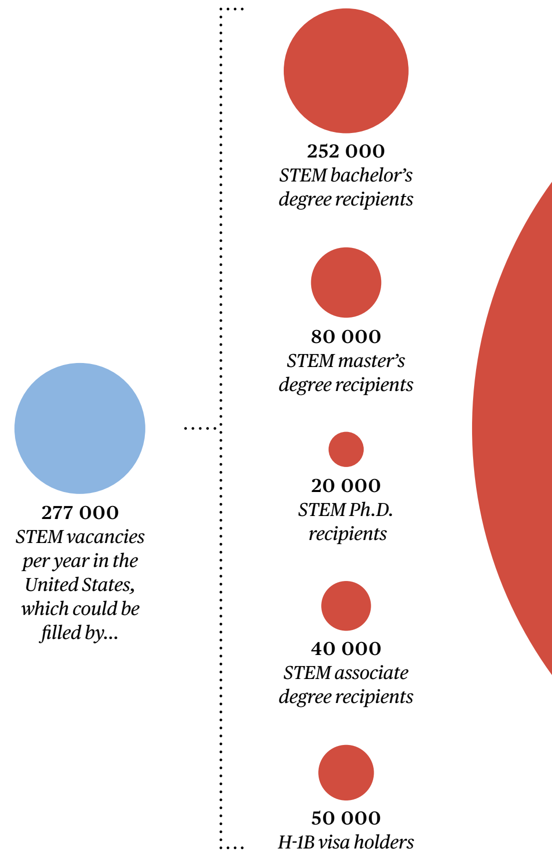
will be needed. In the U.K., the Royal Academy of Engineering reported last year that the nation will have to graduate 100 000 STEM majors every year until 2020 just to stay even with demand. Germany, meanwhile, is said to have a shortage of about 210 000 workers in what's known there as the MINT disciplines—mathematics, computer science, natural sciences, and technology.

The situation is so dismal that governments everywhere are now pouring billions of dollars each year into myriad efforts designed to boost the ranks of STEM workers. President Obama has called for government and industry to train 10 000 new U.S. engineers every year as well as 100 000 additional STEM teachers by 2020. And until those new recruits enter the workforce, tech companies like Facebook, IBM, and Microsoft are lobbying to boost the number of H-1B visas—temporary immigration permits for skilled workers—from 65 000 per year to as many as 180 000. The European Union is similarly introducing the new Blue Card visa to bring in skilled workers from outside the EU. The government of India has said it needs to add 800 new universities, in part to avoid a shortfall of 1.6 million university-educated engineers by the end of the decade.

And yet, alongside such dire projections, you'll also find reports suggesting just the opposite—that there are more STEM workers than suitable jobs. One study found, for example, that wages for U.S. workers in computer and math fields have largely stagnated since 2000. Even as the Great Recession slowly recedes, STEM workers at every stage of the career pipeline, from freshly minted grads to mid- and late-career Ph.D.s, still struggle to find employment as many companies, including Boeing, IBM, and Symantec, continue to lay off thousands of STEM workers.

To parse the simultaneous claims of both a shortage and a surplus of STEM workers, we'll need to delve into the data behind the debate, how it got going more than a half century ago, and the societal, economic, and nationalistic biases that have perpetuated it. And what that dissection reveals is that there is indeed a STEM crisis—just not the one everyone's been talking about. The real STEM crisis is one of literacy: the fact that today's students are not receiving a solid grounding in science, math, and engineering.

IN PREPARING THIS ARTICLE, I went through hundreds of reports, articles, and white papers from the past six decades. There were plenty of data, but there was also an extraordinary amount of inconsistency. Who exactly is a STEM worker: somebody with a bachelor's degree or higher in a STEM discipline? Somebody whose job requires use of a STEM subject? What about someone who manages



A Matter of Supply *vs.* Demand

STEM workers? And which disciplines and industries fall under the STEM umbrella?

Such definitions obviously affect the counts. For example, in the United States, both the National Science Foundation (NSF) and the Department of Commerce track the number of STEM jobs, but using different metrics. According to Commerce, 7.6 million individuals worked in STEM jobs in 2010, or about 5.5 percent of the U.S. workforce. That number includes professional and technical support occupations in the fields of computer science and mathematics, engineering, and life and physical sciences as well as management. The NSF, by contrast, counts 12.4 million science and engineering jobs in the United States, including a number of areas that the Commerce Department excludes, such

PREVIOUS PAGES: JUSTIN LEWIS/GETTY IMAGES; THIS PAGE: TOP: ISTOCKPHOTO; BOTTOM: KEYSTONE-FRANCE/GAMMA-KEYSTONE/GETTY IMAGES

...and
11.4 million
STEM degree holders who currently work outside of STEM

EVERY YEAR U.S. schools grant more STEM degrees than there are available jobs. When you factor in H-1B visa holders, existing STEM degree holders, and the like, it's hard to make a case that there's a STEM labor shortage.

as health-care workers (4.3 million) and psychologists and social scientists (518 000).

Such inconsistencies don't just create confusion for numbers junkies like me; they also make rational policy discussions difficult. Depending on your point of view, you can easily cherry-pick data to bolster your argument.

Another surprise was the apparent mismatch between earning a STEM degree and having a STEM job. Of the 7.6 million STEM workers counted by the Commerce Department, only 3.3 million possess STEM degrees. Viewed another way, about 15 million U.S. residents hold at least a bachelor's degree in a STEM discipline, but three-fourths of them—11.4 million—work outside of STEM.

The departure of STEM graduates to other fields starts early. In 2008, the NSF surveyed STEM graduates who'd earned bachelor's and master's degrees in 2006 and 2007. It found that 2 out of 10 were already working in non-STEM fields. And 10 years after receiving a STEM degree, 58 percent of STEM graduates had left the field, according to a 2011 study from Georgetown University.

The takeaway? At least in the United States, you don't need a STEM degree to get a STEM job, and if you do get a degree, you won't necessarily work in that field after you graduate. If there is in fact a STEM worker shortage, wouldn't you expect more people with STEM degrees to be filling those jobs? And if many STEM jobs can be filled by people who don't have STEM degrees, then why the big push to get more students to pursue STEM?

Now consider the projections that suggest a STEM worker shortfall. One of the most cited in recent U.S. debates comes from the 2011 Georgetown University report mentioned above, by Anthony P. Carnevale, Nicole Smith, and Michelle Melton of the Center on Education and the Workforce. It estimated there will be slightly more than 2.4 million STEM job openings in the United States between 2008 and 2018, with 1.1 million newly created jobs and the rest to replace workers who retire or move to non-STEM fields; they conclude that there will be roughly 277 000 STEM vacancies per year.

But the Georgetown study did not fully account for the Great Recession. It projected a downturn in 2009 but then a steady increase in jobs beginning in 2010 and a return to normal by the year 2018. In fact, though, more than 370 000 science and engineering jobs in the United States were lost in 2011, according to the Bureau of Labor Statistics.

I don't mean to single out this study for criticism; it just illustrates the difficulty of accurately predicting STEM demand and supply even a year or two out, let alone over a prolonged period. Highly competitive science- and technology-driven industries are volatile, where radical restructurings and boom-and-bust cycles have been the norm for decades. Many STEM jobs today are also targets for outsourcing or replacement by automation.

The nature of STEM work has also changed dramatically in the past several decades. In engineering, for instance, your job is no longer linked to a company but to a funded project. Long-term employment with a single company has been replaced by a series of de facto temporary positions that can quickly end when a project ends or the market shifts. To be sure, engineers in the 1950s were sometimes laid off during recessions, but they expected to be hired back when | CONTINUED ON PAGE 50

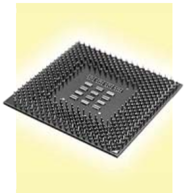
"Our national welfare, our defense, our standard of living could all be jeopardized by the mismanagement of this supply and demand problem in the field of trained creative intelligence."

—JAMES KILLIAN, *president of MIT, 1954*

"From 1972 through 1975, the expected demand for engineers will exceed not only the supply coming from American engineering schools, but also the combined supply from the United States and foreign countries, according to the [Engineering Manpower Commission] estimates."

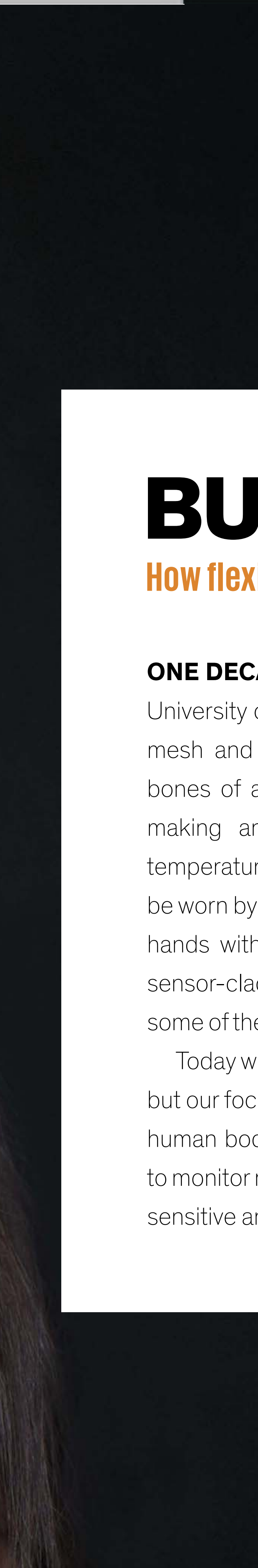
—JOHN W. GRAHAM JR., *president of Clarkson College of Technology, 1970*

"The electronics and information technology industries will be short more than 100 000 electrical and computer science engineers over the next five years."



—AMERICAN ELECTRONICS ASSOCIATION, *1983*

PHOTOS: FROM TOP: AP PHOTO; CLARKSON UNIVERSITY; ISTOCKPHOTO. SOURCES: *STEM* (2011), CENTER ON EDUCATION AND THE WORKFORCE, GEORGETOWN UNIVERSITY; *SCIENCE AND ENGINEERING INDICATORS 2012*, NATIONAL SCIENCE FOUNDATION



BUILDING BIONIC SKIN

How flexible electronics can provide e-skins for humans By Takao Someya

ONE DECADE AGO, my research group at the University of Tokyo created a flexible electronic mesh and wrapped it around the mechanical bones of a robotic hand. We had dreamed of making an electronic skin, embedded with temperature and pressure sensors, that could be worn by a robot. If a robotic health aide shook hands with a human patient, we thought, this sensor-clad e-skin would be able to measure some of the person's vital signs at the same time.

Today we're still working intensively on e-skin, but our focus is now on applying it directly to the human body. Such a bionic skin could be used to monitor medical conditions or to provide more sensitive and lifelike prosthetics.

But whether we're building e-skin for robots or people, the underlying technological challenges are the same. Today's rigid electronics aren't a good fit with soft human bodies. Creating an electronic skin that can curve around an elbow or a knee requires a thin material that can flex and even stretch without destroying its conductive properties. We need to be able to create large sheets of this stuff and embed it with enough sensors to mimic, at least roughly, the sensitivity of human skin, and we need to do it economically. That's a tall order, and we're not there yet. But ultimately, I think engineers will succeed in making e-skins that give people some amazing new abilities.

THE FIRST STEP in making e-skins that can bend around a joint is figuring out how to provide electronics with better mechanical flexibility. Modern integrated circuits, including the microprocessors inside computers and the thin-film transistors behind display screens, are manufactured on rigid substrates like silicon and glass. So the things built with these chips–laptops, flat-panel TVs, and the like–are rigid too.

PHOTO-ILLUSTRATION BY Simon Danaher

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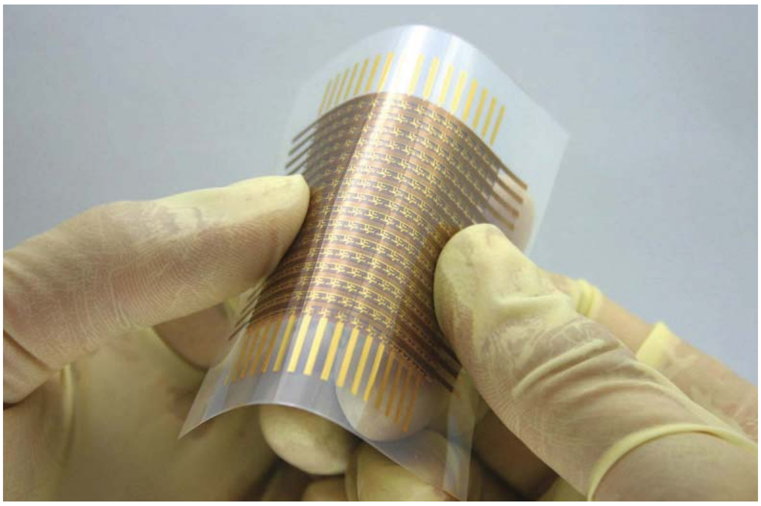
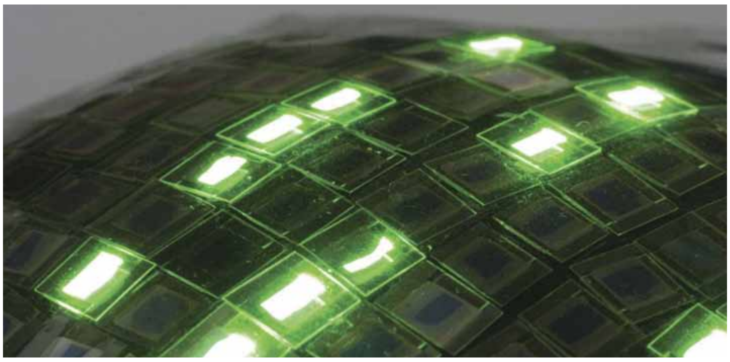
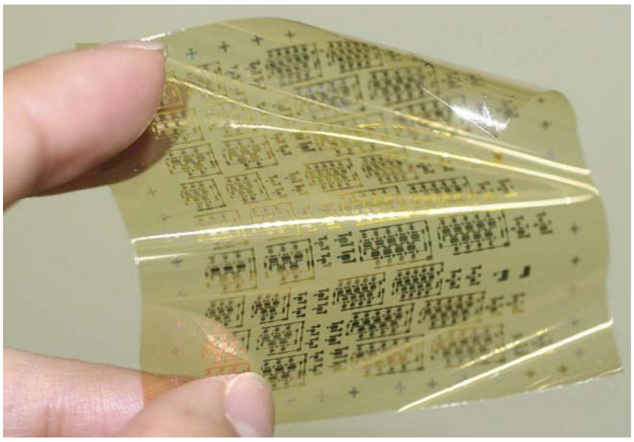
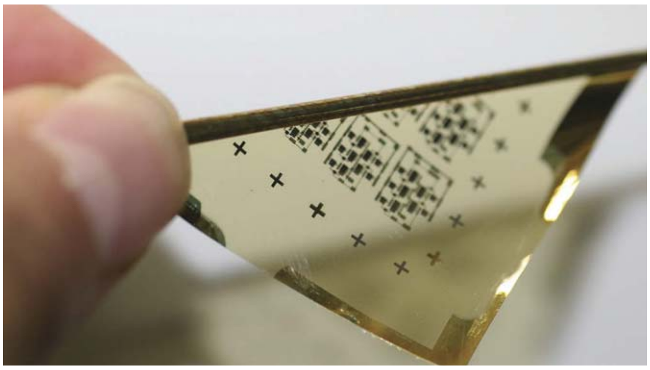


A GOLDEN GLOVE: In 2003, Takao Someya's lab used organic thin-film transistors to create its first flexible, bendable e-skin. Researchers wrapped the material around a mechanical hand to demonstrate the potential applications of e-skin in robotics. The material included pressure and temperature sensors.

BRILLIANT AND BENDABLE: The lab next turned its attention to making materials that could bend and stretch without disrupting the material's conductive properties. Someya integrated organic LEDs into the material to brightly demonstrate its functionality.

CIRCUITS THAT CRUMPLE: These ultraflexible circuits can be tightly bent or rolled like a newspaper—and they'll still work.

PREVIOUS PAGE: ORIGINAL PHOTOGRAPH: PHILIPPE REGARD/CONTOUR STYLE/GETTY IMAGES; THIS PAGE: SOMEYA-SEKITANI GROUP (6)

Manufacturers have already commercialized flexible circuit boards for those passive components that are mechanically flexible, such as wiring. But rigid elements like silicon chips and chip capacitors are still attached to these flexible boards. To make an e-skin, we need greater flexibility: Not only the wiring but also the substrate and all the circuitry must be bendable. We need electronics that can be rolled up, folded, crumpled, and stretched.

Thin-film transistors will be one of the key elements in this electronics revolution. These TFTs can be made of various kinds of semiconductor materials that can be deposited in thin layers, such as amorphous silicon, low-temperature polycrystalline silicon, organic semiconductors, and carbon nanotubes. And there is a range of materials that can serve as flexible substrates for TFTs, such as ultrathin glass, stainless steel foils, and plastic films.

After much experimentation, my group has concluded that plastic films are very promising. They're rugged and hold up well against mechanical strain, they cost very little, and they're compatible with new manufacturing processes that can produce large, flexible sheets of electronic materials—including roll-to-roll manufacturing methods now being developed. To print TFTs on a plastic film, you need to keep the processing temperature low enough to prevent the plastic from changing its shape. TFTs made with organic semiconductors seem promising in that regard, because they can be printed at room temperature.

Thin-film transistors don't just allow electronics to be flexible—they can also help an e-skin mimic the sensitivity of real skin. Consider this: There are more than 2 million pain receptors in a person's skin, which is equivalent to the number of pixels found in a typical high-definition TV. A major obstacle we faced in developing an e-skin was figuring out how many sensors could be integrated into electronic sheets. You can't wire 2 million sensors directly to the driver circuits that control them, because this would mean cramming 2 million contact pads onto a silicon chip.

Our solution was to do exactly what display manufacturers do to control the transistors in their TV screens. They use wiring layouts that allow the CPU to send commands to the transistors attached to individual pixels based on where they lie in a big conductive grid. Using column and row numbers to specify the pixel's address reduces the number of connections necessary. A similar "active matrix" strategy can be used in e-skins with millions of embedded sensors.

The next challenge comes simply from the large area you need to cover. The total surface area of an average adult human's skin exceeds 2 square meters. That's about twice as big as the largest flat-screen LCD TV you can buy at an electronics store. The conventional semiconductor-fabricating machines used in the flat-panel-display industry, such as vacuum-deposition and photolithography tools, are already quite expensive. It wouldn't be economically feasible to use these tools in e-skin applications, which would require covering even larger areas.

But there is another way to make large-area electronics that holds great promise, not just for e-skin research but for the semiconductor industry in general. By using inkjet and other printing processes, manufacturers can significantly reduce production costs. For example, inkjet technology can deliver the exact amount of any substance you want applied to precisely targeted positions, which reduces the waste of raw material. Printing processes can simultaneously apply the coating and the circuitry pattern of thin-film materials, which are usually performed as separate steps when semiconductors are manufactured via lithography. Compared with vacuum-deposition methods, which use a huge amount of electricity to pump the air out of a big stainless-steel chamber, printing processes use minimal power.

IN 2003, my lab at the University of Tokyo developed organic thin-film transistors that we used to create an e-skin prototype for a robotic hand. The material was functional even when rolled around narrow fingers; however, it couldn't bend at the finger joints the way real skin would. We included pressure sensors in this first e-skin, but our real achievement was in using an active-matrix layout for the flexible sensor array. This layout would allow the integration of any kind of sensor array without turning the e-skin into an impossible tangle of wires. That same year one of the pioneers of stretchable electronics, Sigurd Wagner of Princeton University, fabricated transistors made of amorphous silicon and metal wiring on a rubber substrate, demonstrating that elastic electronics were a real possibility.

My team was inspired by Wagner's work, and a few years later, in 2005, we took the next step: making an e-skin that wasn't just flexible but also stretchable. In our first attempt, we manufactured a sheet embedded with transistors and pressure sensors and then used a mechanical punching process to remove the material between the sensor nodes. This created a netlike structure that could be stretched by 25 percent.

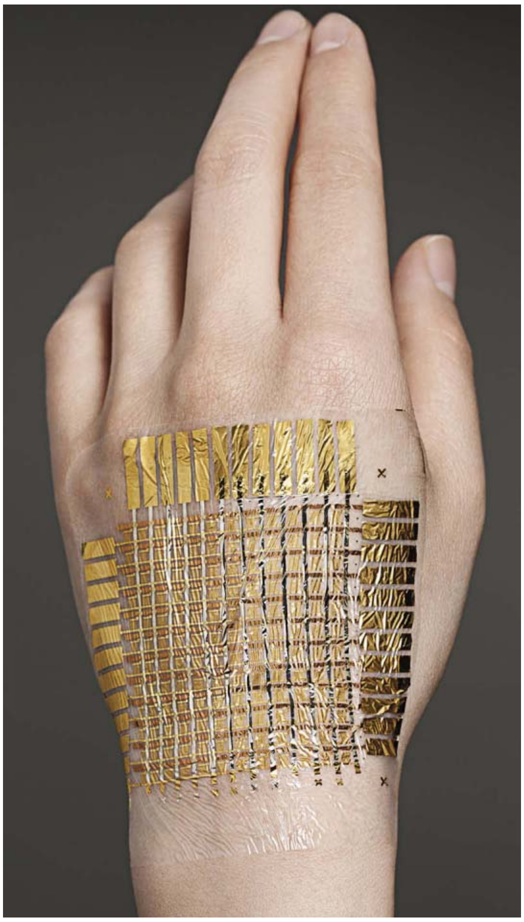
E-SKINS HAVE TO MATCH THE BODY'S MARVELOUS FLEXIBILITY

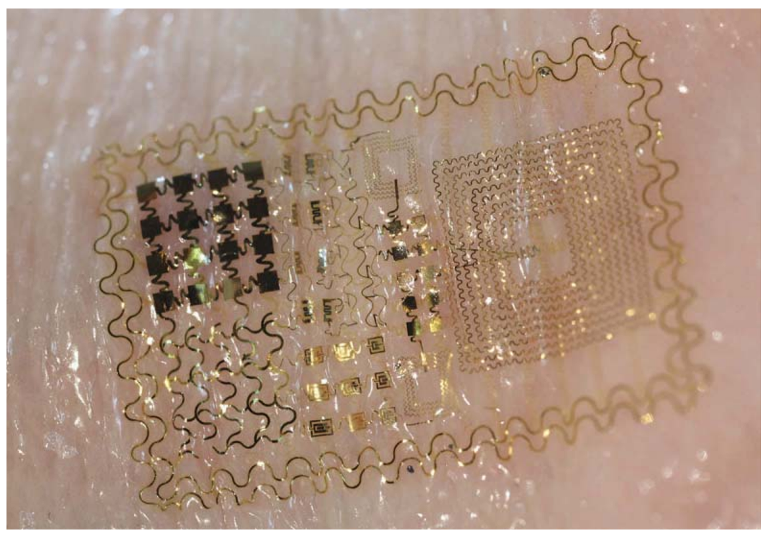
With our next effort, we had even better results. By inventing a printable elastic conductor that can be used for stretchable wires and contacts in integrated circuits, we were able to stretch the material by 140 percent without interfering with its function. We made the conductor out of rubber with carbon nanotubes distributed throughout the material in tangled networks. When the rubber is stretched, those conductive nanotube networks change their shape but do not break. We demonstrated the effectiveness of these conductors by also integrating organic LEDs into the circuits, creating brilliant light-up displays that could be folded in two or curved around a globe.

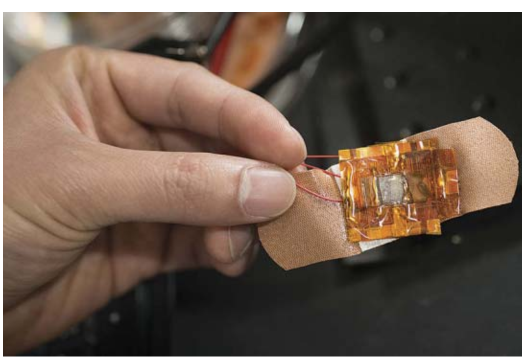
But human bodies do not fold in simple ways, and our e-skin had to match the body's marvelous flexibility. So we set our minds to making ultrathin electronics that could flex and also conform to a dynamic, three-dimensional shape. A nearly imperceptible electronic foil, we thought, could one day be as common as plastic wrap is today.

This July we reported the success of our experiments in the journal *Nature*. We fabricated organic transistors and tactile sensors on an ultrathin polymer sheet that measured 1 micrometer thick—one-tenth the thickness of plastic wrap and light enough to drift through the air like a feather. This material can withstand repeated bending, crumple like paper, and accommodate stretching of up to 230 percent. What's more, it works at high temperatures and in aqueous environments—even in saline solutions, meaning that it can function inside the human body.

Flexible electronics using organic transistors could serve a range of biomedical applications. For example, we've experimented with electromyography, the monitoring and recording of electrical activity produced by muscles. For this system, we distributed organic transistor-based amplifiers throughout a 2-μm-thick film. This allowed us to detect muscle signals very close to the source, which is key to improving the signal-to-noise ratio, and thus the accuracy of the measurements. Conventional techniques typically use long wires to connect sensors on the skin with amplifier circuits, which results in a pretty abysmal signal-to-noise ratio.







THINNER AND THINNER: Someya's latest material [top left] is one-tenth the thickness of plastic kitchen wrap, and it can conform to any body shape. John Rogers's films stick to the skin [top right] or may be laminated on like a temporary tattoo [bottom right]. Radio-frequency communication circuits in the material can forward data from sensors on the skin to a computer. Zhenan Bao's discreet pressure sensor, which can be hidden under a Band-Aid [bottom left], can detect the pulse in a person's wrist.

CLOCKWISE FROM TOP LEFT: SOMEYA-SEKITANI GROUP; JOHN ROGERS (2); L.A. CICERO

And we can imagine more medically urgent applications of such a system. In collaboration with the medical school at the University of Tokyo, we're working on an experiment that will place our amplifier matrix directly on the surface of an animal's heart. By detecting electric signals from the heart with high spatial resolution and superb signal-to-noise ratios, we should be able to zoom in on the exact location of problems in the heart muscle that can lead to heart attacks.

YOUR SKIN IS ESSENTIALLY an interface between your brain and the external world. It senses a tap on the shoulder or the heat from a fire, and your brain takes in that information and decides how to react. If we want bionic skins to do the same, they must incorporate sensors that can match the sensitivity of biological skins. But that is no easy task. For example, a commercial pressure-sensitive rubber exhibits a maximum sensitivity of 3 kilopascals, which is not sufficient to detect a gentle touch.

To improve an e-skin's responsiveness to such stimuli, researchers are experimenting with a number of different techniques. Zhenan Bao and her colleagues at Stanford University created a flexible membrane with extraordinarily good touch sensitivity by using precisely molded pressure-sensitive rubber sandwiched between electrodes. A novel design of the thin rubber layer, using pyramid-like structures of micrometer size that expand when compressed, allowed the material to detect the weight of a fly resting on its surface. With such structures embedded in it, a bionic skin could sense a breath or perhaps a gentle breeze. This kind of sensitivity would be a great benefit in a prosthetic hand, for example, by giving the wearer the ability to grip delicate objects.

In the most recent application of Bao's technology, her team turned the pressure sensors around so that instead of detecting external stimuli, they measured a person's internal functions. The researchers developed a flexible pulse monitor that responds to each subtle surge of blood through an artery, which could be worn on the inner wrist under a Band-Aid. Such an unobtrusive monitor could be used to keep track of a patient's pulse and blood pressure while in the hospital or during surgery.

And we must look beyond just pressure sensitivity: Biological skin has the critical ability to sense many variables at once. The early e-skins produced by my lab adopted an integrated system that simultaneously detected pressure and temperature, and then mapped those stimuli to particular locations on the skin's surface. Our flexible thermal sensors relied on organic diodes, whose electronic properties strongly depend on temperature. One day a glove equipped with such sensors might allow you to gauge another person's emotional response when you shake hands.

Why not get even more ambitious? We make cameras that see more clearly than our own eyes, so why not build super e-skins that have more tactile abilities than our own skins? And there's no need to restrict things to refining human capabilities: An e-skin could also be light sensitive or contain ultrasonic detectors. It's only a question of adding the appropriate flexible electronics.

My group has developed flexible, large-area ultrasonic sensor arrays that could keep both robots and humans out of trouble. An ultrasonic skin covering an entire robot body could work as a 360-degree proximity sensor, measuring the distance between the robot and external obstacles. This could prevent the robot from crashing into walls or allow it to handle our soft, fragile human bodies with more care. For humans, it could provide prosthetics or garments that are hyperaware of their surroundings.

BESIDES ADDING MULTIPLE functions to e-skins, it's also important to improve their electronic properties, such as the speed at which signals can be read from the sensors. For that, electron mobility is a fundamental limiting factor, so some researchers are seeking to create flexible materials that allow electrons to move very quickly.

Ali Javey and his colleagues at the University of California, Berkeley, have had some success in that area. They figured out how to make flexible, large-area electronics by printing semiconducting nanowires onto plastics and paper. Nanowires have excellent electron mobility, but they hadn't been used in large-area electronics before.

Materials like the ones Javey developed will also allow for fascinating new functions for e-skins. My team has developed electromagnetic coupling technology for e-skin, which would enable wireless power transmission. Imagine being able to charge your prosthetic arm by resting your hand on a charging pad on your desk. In principle, any sort of conductor could work for this, but if materials with higher electron mobility are used, the transmission frequency could increase, resulting in more efficient coupling.

Linking sensors with radio-frequency communication modules within an e-skin would also allow the wireless transmission of information from skin to computer—or, conceivably, to other e-skinned people. At the University of Illinois at Urbana-Champaign, John Rogers's team has taken the first step toward this goal. His latest version of an "electrical epidermis" contained the antenna and ancillary components needed for radio-frequency communication. What's more, his electronics can be laminated onto your skin in the same fashion as a temporary tattoo. The circuit is first transferred onto a water-soluble plastic sheet, which washes away after the circuit is pressed on. Doctors could use these tiny devices to monitor a patient's vital signs without the need for wires and bulky contact pads, and people could wear them discreetly beyond the confines of the hospital.

> WHY NOT BUILD **SUPER-SKINS** THAT HAVE MORE TACTILE ABILITIES THAN OUR OWN SKINS?

Rogers and his colleagues tried out a number of applications for their stick-on electronics. In their most astonishing iteration, they applied circuitry studded with sensors to a person's throat where it could detect the muscular activity involved in speech. Simply by monitoring the signals, researchers were able to differentiate among several words spoken by the test subject. The user was even able to control a voice-activated video game. Rogers suggested that such a device could be used to create covert, subvocal communication systems.

Skins that know what we're saying without having to say it, skins that can communicate themselves, skins that extend our human capacities in directions we haven't yet imagined—the possibilities are endless. And while some readers may worry about e-skins being used to invade the privacy of their bodies or minds, I believe the potential benefits of this technology offer plenty of reasons to carry on with the work. For example, the car company Toyota has already demonstrated a smart steering wheel that measures the electrical activity of the driver's heart; imagine a smart skin that can warn a patient of an oncoming heart attack hours in advance.

Human skin is so thin, yet it serves as a boundary between us and the external world. My dream is to make responsive electronic coverings that bridge that divide. Instead of cold metal robots and hard plastic prosthetics, I imagine machines and people clothed in sensitive e-skin, allowing for a two-way exchange of information. Making our mechanical creations seem almost warm and alive and placing imperceptible electronics on humans will change how people relate to technology. The harmonization of people and machines: This is the cyborg future that e-skins could bring. ■

POST YOUR COMMENTS online at http://spectrum.ieee.org/eskin0913

CONTINUED FROM PAGE 43 | the economy picked up. That rarely happens today. And unlike in decades past, employers seldom offer generous education and training benefits to engineers to keep them current, so out-of-work engineers find they quickly become technologically obsolete.

Any of these factors can affect both short-term and longer-term demand for STEM workers, as well as for the particular skills those workers will need. The agencies that track science and engineering employment know this to be true. Buried in Chapter 3 of a 2012 NSF workforce study, for instance, you'll find this caveat: "Projections of employment growth are plagued by uncertain assumptions and are notoriously difficult to make."

SO IS THERE A SHORTFALL of STEM workers or isn't there? The Georgetown study estimates that nearly two-thirds of the STEM job openings in the United States, or about 180 000 jobs per year, will require bachelor's degrees. Now, if you apply the Commerce Department's definition of STEM to the NSF's annual count of science and engineering bachelor's degrees, that means about 252 000 STEM graduates emerged in 2009. So even if all the STEM openings were entry-level positions and even if only new STEM bachelor's holders could compete for them, that still leaves 70 000 graduates unable to get a job in their chosen field.

Of course, the pool of U.S. STEM workers is much bigger than that: It includes new STEM master's and Ph.D. graduates (in 2009, around 80 000 and 25 000, respectively), STEM associate degree graduates (about 40 000), H-1B visa holders (more than 50 000), other immigrants and visa holders with STEM degrees, technical certificate holders, and non-STEM degree recipients looking to find STEM-related work. And then there's the vast number of STEM degree holders who graduated in previous years or decades.

Even in the computer and IT industry, the sector that employs the most STEM workers and is expected to grow the most over the next 5 to 10 years, not everyone who wants a job can find one. A recent study by the Economic Policy Institute (EPI), a liberal-leaning think tank in Washington, D.C., found that more than a third of recent computer science graduates aren't working in their chosen major; of that group, almost a third say the reason is that there are no jobs available.

Spot shortages for certain STEM specialists do crop up. For instance, the recent explosion in data analytics has sparked demand for data scientists in health care and retail. But the H-1B visa and similar immigrant hiring programs are meant to address such shortages. The problem is that students who are contemplating what field to specialize in can't assume such shortages will still exist by the time they emerge from the educational pipeline.

What's perhaps most perplexing about the claim of a STEM worker shortage is that many studies have directly contradicted it, including reports from Duke University, the Rochester Institute of Technology, the Alfred P. Sloan Foundation, and the Rand Corp. A 2004 Rand study, for example, stated that there was no evidence "that such shortages have existed at least since 1990, nor that they are on the horizon."

That report argued that the best indicator of a shortfall would be a widespread rise in salaries throughout the STEM community. But the price of labor has not risen, as you would expect it to do if STEM workers were scarce. In computing and IT, wages have generally been stagnant for the past decade, according to the EPI and other analyses. And over the past 30 years, according to the Georgetown report, engineers' and engineering technicians' wages have grown the least of all STEM wages and also more slowly than those in non-STEM fields; while STEM workers as a group have seen wages rise 33 percent and non-STEM workers' wages rose by 23 percent, engineering salaries grew by just 18 percent. The situation is even more grim for those who get a Ph.D. in science, math, or engineering. The Georgetown study states it succinctly: "At the highest levels of educational attainment, STEM wages are not competitive."

Given all of the above, it is difficult to make a case that there has been, is, or will soon be a STEM labor shortage. "If there was really a STEM labor market crisis, you'd be seeing very different behaviors from companies," notes Ron Hira, an associate professor of public policy at the Rochester Institute of Technology, in New York state. "You wouldn't see companies cutting their retirement contributions, or hiring new workers and giving them worse benefits packages. Instead you would see signing bonuses, you'd see wage increases. You would see these companies really training their incumbent workers."

"None of those things are observable," Hira says. "In fact, they're operating in the opposite way."

SO WHY THE PERSISTENT anxiety that a STEM crisis exists? Michael S. Teitelbaum, a Wertheim Fellow at Harvard Law School and a senior advisor to the Alfred P. Sloan Foundation, has studied the phenomenon, and he says that in the United States the anxiety dates back to World War II. Ever since then it has tended to run in cycles that he calls "alarm, boom, and bust." He says the cycle usually starts when "someone or some group sounds the alarm that there is a critical crisis of insufficient numbers of scientists, engineers, and mathematicians" and as a result the country "is in jeopardy of either a national security risk or of falling behind economically." In the 1950s, he notes, Americans worried that the Soviet Union was producing 95 000 scientists and engineers a year while the United States was producing only about 57 000. In the 1980s, it was the perceived Japanese economic juggernaut that was the threat, and now it is China and India.

You'll hear similar arguments made elsewhere. In India, the director general of the Defence Research and Development Organisation, Vijay Kumar Saraswat, recently noted that in his country, "a meagre four persons out of every 1000 are choosing S&T or research, as compared to 110 in Japan, 76 in Germany and Israel, 55 in USA, 46 in Korea and 8 in China." Leaders in South Africa and Brazil cite similar statistics to show how they are likewise falling behind in the STEM race.

"The government responds either with money [for research] or, more recently, with visas to increase the number of STEM workers," Teitelbaum says. "This continues for a number of years until the claims of a shortage turn out not to be true and a bust ensues." Students who graduate during the bust, he says, are shocked to discover that "they can't find jobs, or they find jobs but not stable ones."

At the moment, we're in the alarm-heading-toward-boom part of the cycle. According to a recent report from the Government Accountability Office, the U.S. government spends more than US $3 billion each year on 209 STEM-related initiatives overseen by 13 federal agencies. That's about $100 for every U.S. student beyond primary school. In addition, major corporations are collectively spending millions to support STEM educational programs. And every U.S. state, along with a host of public and private universities, high schools, middle schools, and even primary schools, has its own STEM initiatives. The result is that many people's fortunes are now tied to the STEM crisis, real or manufactured.

CLEARLY, POWERFUL FORCES must be at work to perpetuate the cycle. One is obvious: the bottom line. Companies would rather not pay STEM professionals high salaries with lavish benefits, offer them training on the job, or guarantee them decades of stable employment. So having an oversupply of workers, whether domestically educated or imported, is to their benefit. It gives employers a larger pool from which they can pick the "best and the brightest," and it helps keep wages in check. No less an authority than Alan Greenspan, former chairman of the Federal Reserve, said as much when in 2007 he advocated boosting the number of skilled immigrants entering the United States so as to "suppress" the wages of their U.S. counterparts, which he considered too high.

Governments also push the STEM myth because an abundance of scientists and engineers is widely viewed as an important engine for innovation and also for national defense. And the perception of a STEM crisis benefits higher education, says Ron Hira, because as "taxpayers subsidize more STEM education, that works in the interest of the universities" by allowing them to expand their enrollments.

An oversupply of STEM workers may also have a beneficial effect on the economy, says Georgetown's Nicole Smith, one of the coauthors of the 2011 STEM study. If

"Already spot shortages exist in some science fields in the United States, and unless dramatic changes are made in the way we educate all of our students, including our most talented, the shortages will increase."
—U.S. OFFICE OF EDUCATIONAL RESEARCH AND IMPROVEMENT, *1993*

"U.S. companies face a severe shortfall of scientists and engineers with expertise to develop the next generation of breakthroughs."

—BILL GATES, *chairman of Microsoft, 2008*

"There is a skills gap in this country—for every unemployed person in the United States, there are two STEM job postings. The gap will only widen if we don't engage now to address STEM education at the elementary and high school levels."

—RICHARD K. TEMPLETON, *chairman, president, and CEO of Texas Instruments, 2013*

TOP: MICROSOFT; BOTTOM: TEXAS INSTRUMENTS

STEM graduates can't find traditional STEM jobs, she says, "they will end up in other sectors of the economy and be productive."

The problem with proclaiming a STEM shortage when one doesn't exist is that such claims can actually create a shortage down the road, Teitelbaum says. When previous STEM cycles hit their "bust" phase, up-and-coming students took note and steered clear of those fields, as happened in computer science after the dot-com bubble burst in 2001.

Emphasizing STEM at the expense of other disciplines carries other risks. Without a good grounding in the arts, literature, and history, STEM students narrow their worldview—and their career options. In a 2011 op-ed in *The Wall Street Journal*, Norman Augustine, former chairman and CEO of Lockheed Martin, argued that point. "In my position as CEO of a firm employing over 80 000 engineers, I can testify that most were excellent engineers," he wrote. "But the factor that most distinguished those who advanced in the organization was the ability to think broadly and read and write clearly."

A broader view, I and many others would argue, is that everyone needs a solid grounding in science, engineering, and math. In that sense, there is indeed a shortage—a STEM knowledge shortage. To fill that shortage, you don't necessarily need a college or university degree in a STEM discipline, but you do need to learn those subjects, and learn them well, from childhood until you head off to college or get a job. Improving everyone's STEM skills would clearly be good for the workforce and for people's employment prospects, for public policy debates, and for everyday tasks like balancing checkbooks and calculating risks. And, of course, when science, math, and engineering are taught well, they engage students' intellectual curiosity about the world and how it works.

Many children born today are likely to live to be 100 and to have not just one distinct career but two or three by the time they retire at 80. Rather than spending our scarce resources on ending a mythical STEM shortage, we should figure out how to make all children literate in the sciences, technology, and the arts to give them the best foundation to pursue a career and then transition to new ones. And instead of continuing our current global obsession with STEM shortages, industry and government should focus on creating more STEM jobs that are enduring and satisfying as well. ■

Q. If a student came to you for advice, would you encourage him or her to pursue a career in STEM?

IEEE Spectrum recently posed that question to a select group of IEEE members. Nearly three-quarters of respondents said they would "strongly encourage" the student to take such a career path because it is "interesting and stimulating work" and one in which a person "can make a difference in the world."

For other results from the latest *IEEE Spectrum* Forecasters Survey, visit http://spectrum.ieee.org/static/ieee-spectrum-forecasters

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UNIVERSITY SPOTLIGHT

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

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University of Michigan, Ann Arbor

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Expertise in communications, digital signal processing, digital electronic design, microprocessor applications, or control systems is preferred. Some teaching and industrial experience is also preferred but not required. Applicants must demonstrate the potential for outstanding teaching, for performing research in a relevant area of electrical engineering, for establishing a record of scholarly peer-reviewed work, and for serving the mission and goals of the University.

The Department of Engineering enrolls approximately 110 undergraduate students and offers the Bachelor of Science in Engineering with concentrations in computer, electrical, materials, and mechanical engineering.

Loyola University Maryland is a dynamic, highly selective, Jesuit Catholic institution in the liberal arts tradition and is recognized as a leading independent, comprehensive university in the northeastern United States. Located in a beautiful residential section of Baltimore with Graduate Centers in Timonium and Columbia, Loyola enrolls over 3,800 students in its undergraduate programs and more than 2,200 students in its graduate programs. Applicants must submit the following online (https://careers.loyola.edu): a cover letter listing teaching and research interests, a curriculum vitae, and contact information for three references. For full consideration applications must be received by October1, 2013. The University welcomes applicants from all backgrounds who can contribute to its educational mission. Loyola is an Equal Employment Opportunity Employer, and seeks applications from underrepresented groups, regardless of religious affiliation. Additional information is available at **www.loyola.edu**.

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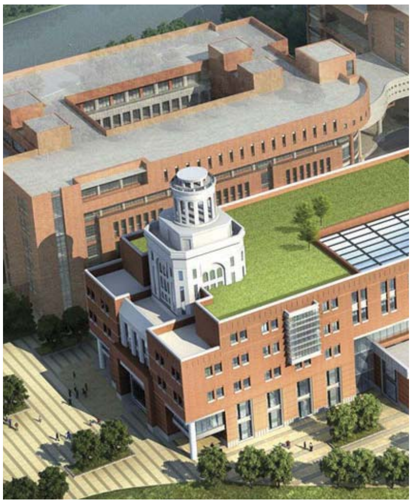
Joint Institute of Engineering



FACULTY POSITIONS AVAILABLE IN ELECTRICAL/COMPUTER ENGINEERING

Sun Yat-sen University & Carnegie Mellon University are partnering to establish the **SYSU-CMU Joint Institute of Engineering (JIE)** to innovate engineering education in China and the world. The mission of the JIE is to nurture a passionate and collaborative global community and network of students, faculty and professionals working toward pushing the field of engineering forward through education and research in China and in the world.

JIE is seeking **full-time faculty** in all areas of electrical and computer engineering (ECE). Candidates should possess a doctoral degree in ECE or related disciplines, with a demonstrated record and potential for research, teaching and leadership. The position includes an initial year on the Pittsburgh campus of Carnegie Mellon University to establish educational and research collaborations before locating to Guangzhou, China.

This is a worldwide search open to qualified candidates of all nationalities, with an internationally competitive compensation package for all qualified candidates.

PLEASE VISIT: **sysucmujie.cmu.edu** for details

SHUNDE INTERNATIONAL

Joint Research Institute

RESEARCH STAFF POSITIONS AVAILABLE IN ELECTRICAL/COMPUTER ENGINEERING

SYSU-CMU Shunde International Joint Research Institute (JRI) is located in Shunde, Guangdong. Supported by the provincial government and industry, the JRI aims to bring in and form high-level teams of innovation, research and development, transfer research outcomes into products, develop advanced technology, promote industrial development and facilitate China's transition from labor intensive industries to technology intensive and creative industries.

The JRI is seeking **full-time research faculty** and **research staff** that have an interest in the industrialization of science research, which targets electrical and computer engineering or related areas.

Candidates with industrial experiences are preferred.

Applications should include a full CV, three to five professional references, a statement of research and teaching interests, and copies of up to five research papers.

Please submit the letters of reference and all above materials to the address below.

Application review will continue until the position is filled.

EMAIL APPLICATIONS OR QUESTIONS TO: **sdjri@mail.sysu.edu.cn**

SUN YAT-SEN UNIVERSITY Carnegie Mellon University

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Faculty Position in Distributed Computing Systems Engineering

at the Ecole polytechnique fédérale de Lausanne (EPFL)

The Institute of Electrical Engineering at EPFL invites applications for a **tenure track assistant professor** in the area of **Distributed Computing Systems Engineering.** Recruitment to a tenured senior position may be considered in exceptional cases.

A strong expertise is requested in the broad fields of mainstream as well as non-conventional Computing and Communication Systems Engineering, comprising hardware, software and interfaces. Research areas of interest include, but are not limited to: (a) cyber-physical systems and networked computing systems, (b) interfaces of data-acquisition systems with the physical world, (c) smart peripherals and dedicated accelerators (d) real-time reconfigurable systems.

The successful candidate is expected to initiate independent, creative research programs and actively participate in undergraduate and graduate teaching.

Significant start-up resources and state-of-the-art research infrastructure will be available. Salaries and benefits are internationally competitive.

Applications should include a cover letter with a statement of motivation, curriculum vitae, list of publications and patents, concise statement of research and teaching interests, and the names and addresses of 5 references. Applications must be uploaded in PDF format to the recruitment web site:

http://distributed-computing.epfl.ch

Candidate evaluation will begin on **15 December 2013.**

Enquiries may be addressed to:
Prof. Yusuf Leblebici
Search Committee Chair
E-mail: iel-search@epfl.ch

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

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

The Petroleum Institute, Abu Dhabi, United Arab Emirates

Laboratory Engineer – Electrical Engineering Program

THE PETROLEUM INSTITUTE

Position Description:

The Electrical Engineering Department at The Petroleum Institute in Abu Dhabi, United Arab Emirates, is inviting applications for two full-time Lab Engineering positions, one in the area of Electric Drives and the other one in the area of Instrumentation. The applicant must have at least a minimum of 3 years hands-on experience in Lab teaching.

Responsibilities: Assist in planning, preparing specification, procurement, and installing equipment in EE labs. Assist in developing, implementing and instructing EE laboratory courses. Responsible for the maintenance and safety of the EE labs and their equipment. Responsible for inventory of the EE labs supplies and their equipment. Assist in writing EE lab manuals, procedures, and safety instructions in coordination with the course instructor and/or the EE Program Chair. Provide support and training to new lab instructors and technicians. Lab Engineers report to the EE Program Chair and his/her activities will be in coordination with one or more faculty members.

Qualifications and other required skills: A Master degree in Electrical Engineering from a recognized university. At least 3 years of experience relevant to the above job responsibilities. Experience with Matlab, micro-controllers and Labview is a must. Strong oral and written communication skills in English. Interpersonal skills and ability to liaise with management, co-workers, and students.

Salary/Benefits: Salary is competitive and commensurate with qualifications and experience, with an excellent benefits package. The UAE levies no income taxes.

Institution: The Petroleum Institute was created in 2001 with the goal of establishing itself as a world-class institution in engineering education and research in areas of significance to the oil, gas, and the broader energy industries. The PI's sponsors include Abu Dhabi National Oil Company and four major international oil companies. The campus has modern instructional laboratories and classroom facilities. For additional information, please refer to the PI website: www.pi.ac.ae.

To Apply: Interested candidates should submit online (http://www.pi.ac.ae) a letter of interest and a detailed resume listing qualifications and experience. The closing date is September 30th, 2013. Only shortlisted applicants will be notified.

UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

The Faculty of Engineering and Applied Science at the University of Ontario Institute of Technology (UOIT), invites applications for the Canada Research Chair (Tier II): Electric Energy Storage Systems. Twenty faculty members and 400 graduate and undergraduate students within the Faculty are in the areas of Electrical, Computer and Software Engineering. For more information please visit **http://www.engineering.uoit.ca/** For full position details and application procedures, please visit **http://www.uoit.ca/academicpostings**

A&M | ENGINEERING TECHNOLOGY & INDUSTRIAL DISTRIBUTION
TEXAS A&M UNIVERSITY

DEPARTMENT HEAD
DEPARTMENT OF ENGINEERING TECHNOLOGY AND INDUSTRIAL DISTRIBUTION
TEXAS A&M UNIVERSITY

The Dwight Look College of Engineering (**http://engineering.tamu.edu**) at Texas A&M University (**http://www.tamu.edu**) invites applications and nominations for the position of head of the Department of Engineering Technology and Industrial Distribution (**http://etidweb.tamu.edu**).

Engineering Technology and Industrial Distribution (ETID) is unique among the Look College's 12 departments due to its strong focus on industry- and government- supported applied research and undergraduate education. Through the synergy of experiential learning-based academic programs in Electronic Systems, Industrial Distribution, and Mechanical and Manufacturing, the department's 24 tenure/tenure-track faculty members and 9 lecturers have the broad range of expertise necessary to facilitate solution of industry and society's most pressing problems. The department currently has over $17M in endowments; and in 2011, had $2.2M in research expenditures, almost $1M dollars in gifts and donations to support education, and approximately $500K in industry-targeted professional development courses. Each year, ETID graduates over 300 students from its three undergraduate programs and over 40 students from its distance learning Masters of Industrial Distribution. The college seeks a visionary leader who can continue to grow the department's successes in areas such as industry-centric research/continuing education activities and STEM outreach including the possibility of establishing national leadership in engineering education research.

Candidates must possess a Ph.D. degree or equivalent in an engineering or related field, and must qualify as a tenured full professor in the department. The ideal candidate should have notable accomplishments and experience in a combination of academic and/or industry leadership, teaching, research and scholarship. The preferred start date for this position is January 1, 2014. Remuneration and other perquisites will be competitive.

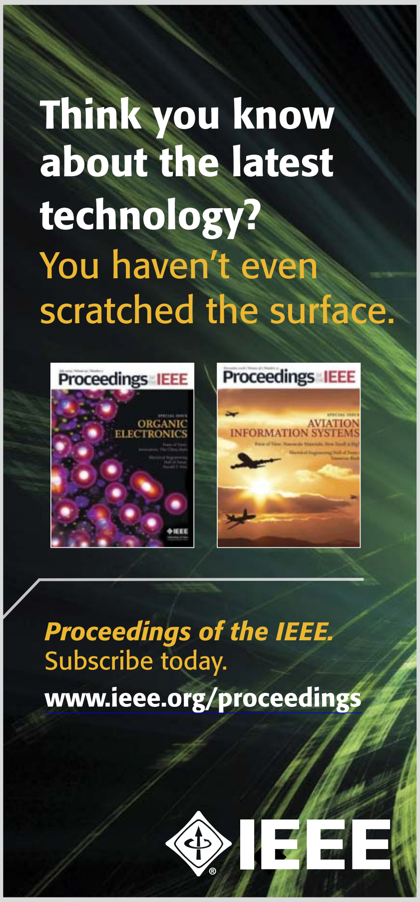
The university and the college provide a strong base of support for the department. Support from industry and alumni are exceptional. Texas A&M University is a land-grant, sea-grant and space-grant institution, and one of the five largest universities in the United States with approximately 50,000 students, including about 11,200 engineering students in 12 departments. Texas A&M is located in Bryan/College Station, Texas, a community of about 200,000, in the center of the triangle formed by Dallas/Ft. Worth, Houston, and San Antonio. Specific duties and responsibilities include: 1) providing intellectual and philosophical leadership of faculty, staff and students for increasing synergistic academic, research, extension and service programs; 2) managing and coordinating the department's human and fiscal resources; 3) serving as liaison for the department to the Look College and the Texas A&M Engineering Experiment Station (TEES) (**http://tees.tamu.edu**); 4) representing the department to industry, state and federal agencies, private organizations, partners and collaborators; and 5) providing leadership for continued acquisition of internal and external resources.

Interested persons with nationally recognized academic, research and industry accomplishments are encouraged to apply. The department head will hold a 12-month tenured professor position. As head of the department, the candidate will report to the dean of engineering who also holds the positions of vice chancellor and director of TEES.

Applicants should submit a cover letter indicating their interest in the position and vision for the department, an up-to-date curriculum vitae, and the contact information for five references. The review of applications will begin on September 1, 2013 and will continue until the position is filled.

For additional information or submission of applications contact:
Dr. M. Nazmul Karim
ETID Search Committee Chair
Department Head, Artie McFerrin Department of Chemical Engineering
Texas A&M University
Jack E. Brown Engineering Bldg.
3122 TAMU Room 255A
College Station, TX 77843-3122
Phone: (979) 845-9806
Email: nazkarim@che.tamu.edu

Texas A&M provides equal opportunity to all persons regardless of race, color, religion, sex, national origin, disability, age or veteran status and encourages applications from members of groups underrepresented in engineering.



THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Joint Faculty position in Electronic and Computer Engineering and Mechanical and Aerospace Engineering

The Department of Electronic and Computer Engineering (ECE) and the **Department of Mechanical Engineering** (MECH) (will be renamed as Department of Mechanical and Aerospace Engineering with effect from 1 September 2013) at the Hong Kong University of Science and Technology invite applications for a joint faculty position at the rank of Assistant Professor in the interdisciplinary area of modern avionics. Applicants should have a PhD with demonstrated strength in research and a commitment to teaching. Successful candidates are expected to lead an active research program, and to teach both graduate and undergraduate courses. He/She is expected to supervise graduate students and provide a link between faculties in ECE and MECH to nurture the avionics area into the aerospace program. Areas of research and interests may include: high-performance and low-power embedded space & airborne systems (FPGA/SoC), unmanned aerial vehicle (UAV), modern digital navigation systems, inertial measurement and reference units, flight management systems, autopilot, auto landing and fly-by-wire systems, cockpit to air traffic control, flight deck to cabin crew/passenger intra-communications, modern phase array and SAR radar applications, collision avoidance systems, as well as other related areas with specialized applications in modern Integrated Modular Avionics (IMA).

The Hong Kong University of Science and Technology is a world renowned, international research university in Asia's most vibrant city, Hong Kong. Its Engineering School has been consistently ranked among the world's top 25 since 2004. The high quality of our faculty, students and facilities provide for outstanding opportunities for faculty to pursue highly visible research programs. All formal instruction is given in English and all faculty members are expected to conduct research and teach both undergraduate and graduate courses. The Departments of ECE and MECH have excellent computing resources, and state-of-the-art teaching and research laboratories. Currently the Department of ECE has about 40 faculty members, 800 undergraduate students and 350 postgraduate students. The Department of MECH has 21 Faculty members, about 400 undergraduate students and 280 postgraduate students. The University is committed to increasing the diversity of its faculty and has a range of family-friendly policies in place.

Starting salary will depend on qualifications and experience. Fringe benefits including medical and dental benefits, annual leave and housing will be provided where applicable. Initial appointment will normally be on a three-year contract. A gratuity will be payable upon successful completion of contract. Re-appointment will be subject to mutual agreement.

Applications including full curriculum vitae, list of publications, names of five referees addressed to Professor Vincent Lau, Chair of the Search Committee, and should be sent by email to eesearch@ust.hk. Applications will be considered until the position is filled.

More information about the departments is available on the website http://www.ece.ust.hk and http://www.me.ust.hk.

(Information provided by applicants will be used for recruitment and other employment-related purposes.)

UESTC 1956

Candidates of **"Thousand Talents Plan", "Cheung Kwong Scholars Program"** and scholars with doctorate degrees from renowned overseas universities are invited to join UESTC!

University of Electronic Science and Technology of China (UESTC), formerly Chengdu Institute of Radio Engineering, is renowned as the birth-place for the electronic industry of china. Currently, UESTC is one of members of the "Project 211" and "Project 985" of Chinese universities. In 2012, the discipline of Electronic Science and Technology has been ranked No. 1 in China.

UESTC is situated in a historic and cultural city — Chengdu that is the political, commercial, technological and cultural center in the southwest of China. Chengdu has always been an irresistible attraction due to opportunities in social and economic development, and career advancement. Chengdu has been listed in "Top Ten Chinese Cities of Economic Vitality" and "Chinese Cities of the Best Quality of Life".

Remunerations and Benefits: Salary and startup funds are highly competitive, which is commensurate with academic experience and accomplishment. UESTC also offers a comprehensive benefit package that includes housing. Outstanding professors and scholars who have been selected into China's "Thousand Talents Plan" or "Cheung Kwong Scholars Program" can anticipate additional supports and benefits.

Academic Discipline: We are seeking candidates in all, but it is not limited to, cutting edge areas of Electronic and Information Sciences and Technologies.

Application Requirements: Doctoral degree certificate and excellent academic records; Well-developed research agenda; Great potential in instruction;

Contact information: Mr. Chuandong Zhang, Human Resource Department, University of Electronic Science and Technology of China, No. 2006, Xiyuan Avenue, West Hightec Zone, Chengdu, Sichuan, 611731, P.R. China. Email: uestchr@gmail.com

For additional information, please visit **http://www.uestc.edu.cn**

Faculty Positions
Electrical Engineering
Abu Dhabi, United Arab Emirates

PI
المعهد البترولي
THE PETROLEUM INSTITUTE
University & Research Center

Description: The Electrical Engineering Department at The Petroleum Institute in Abu Dhabi, United Arab Emirates, is inviting applications for two full-time faculty positions, one in the area of Instrumentation and the other in the area of Power System Protection. Both positions are open for all faculty ranks.

Position Description: Successful candidates are expected to teach undergraduate/graduate courses, supervise undergraduate/graduate students, engage in appropriate levels of service to the institute and the profession, initiate/conduct research activities and attract funding, disseminate research results in high-profile publications in their respective fields of expertise.

Qualifications: Candidates must have an earned Ph.D. degree in Electrical Engineering, or in a closely related discipline, from an accredited university, and possess an excellent and demonstrated teaching and research expertise in the sought specialties mentioned above.

Salary/Benefits: The total compensation package includes a tax-free 12-month base salary, and a benefits allowance that covers relocation, housing, initial furnishings, utilities; transportation (interest-free automobile purchase loan), health insurance, end-of-service benefit and annual leave travel. Applicants will be required to pass a pre-employment health examination.

To Apply: Interested candidates should submit online (http://www.pi.ac.ae) a letter of interest and a detailed resume listing qualifications and experience. The closing date is January 15th, 2014. Only shortlisted applicants will be notified.

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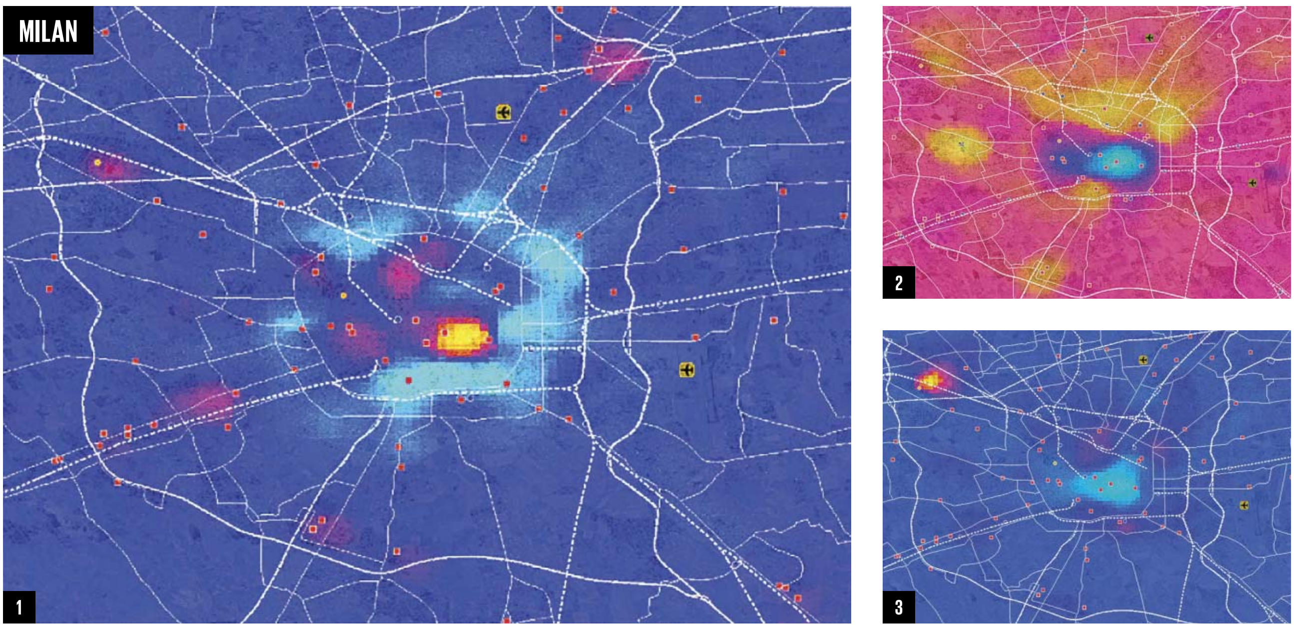
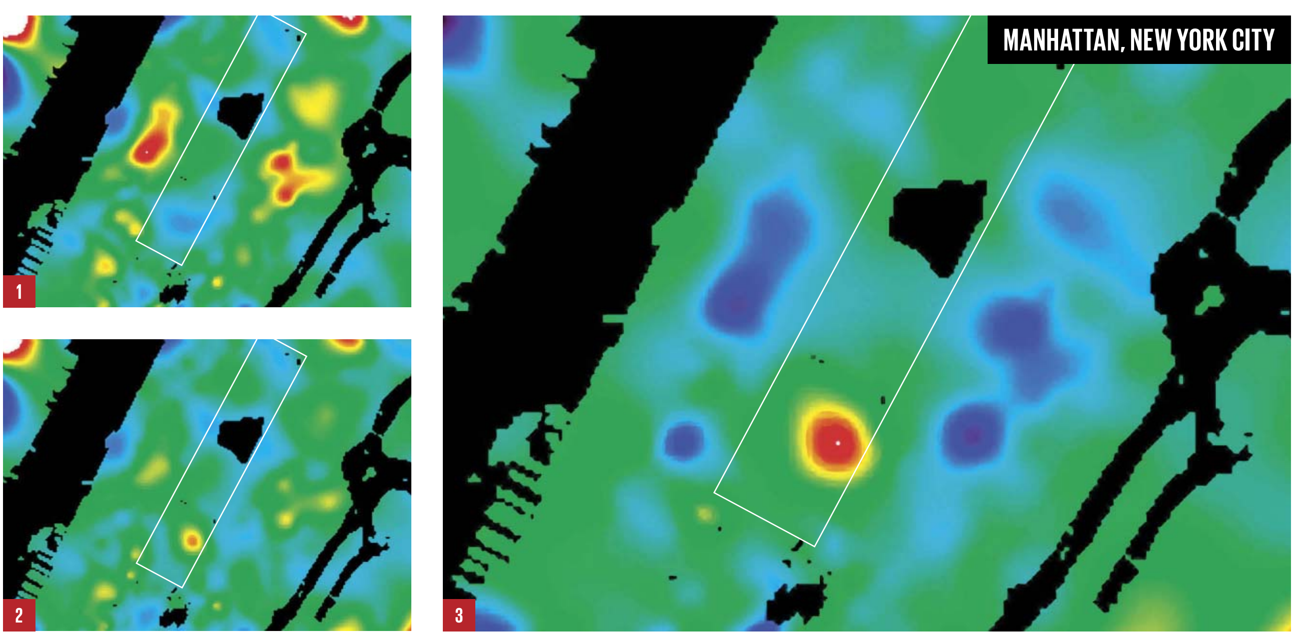
TEN MILLION CENSUSES PER DAY

PHONE DATA SHOW CITIES ON THE MOVE

To determine the ebb and flow of city dwellers, public officials have typically resorted to looking around and counting. But now censuses can be taken every few milliseconds, as phones ping cellular networks and reveal their location. ● For instance, Italian and American researchers generated usage maps for Milan and the borough of Manhattan in New York City using anonymized cellular data. Paolo Tagliolato, a postdoc at the Polytechnic University of Milan, says such anonymized data are effectively free and always up to date. Conversely, he says, Milan's last comparable citywide survey was costly, involved 750 000 interviews, and hasn't been updated since 2002. **—MARK ANDERSON**

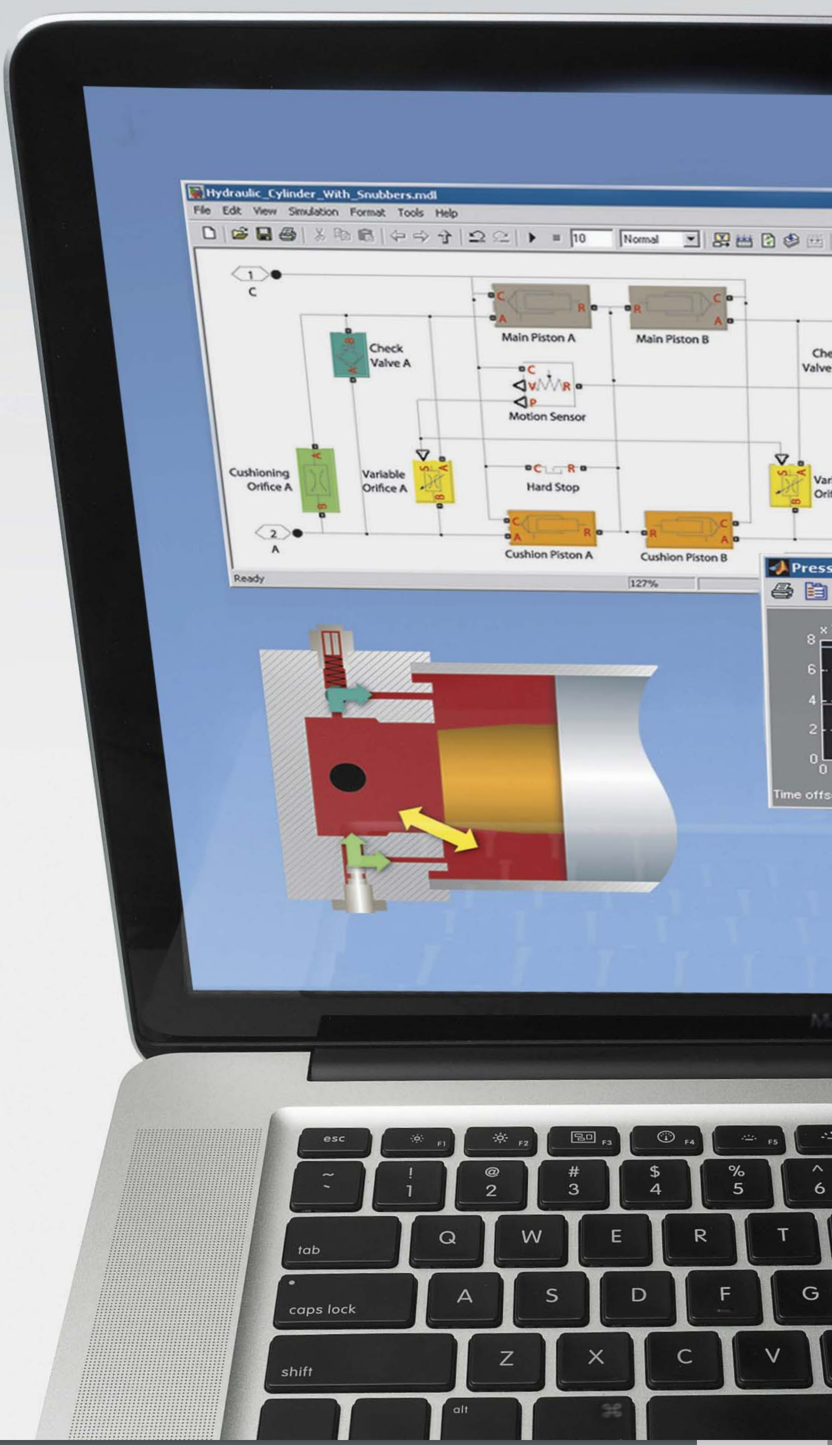


1. Between 10 a.m. and 8 p.m. on Saturdays, shopping and leisure activities in Milan's city center dominate. Sites like museums on the outskirts also show up. 2. From 8 p.m. to midnight on Saturday, patterns shift, as people congregate in the residential areas that ring the center (background activity has more pink due to a different color scale). 3. This data, captured between midnight and 8 a.m. during the 2009 Milan Design Week, reveal overnight activity northwest of the city in preparation for daily events.



1. Usage data captured on a Saturday afternoon in February 2011 show high calling activity from the wealthy residential areas bordering New York City's Central Park. 2. A Saturday afternoon the following July reveals a different pattern, with cellphone activity shifting to the southern end of Central Park. 3. Subtracting the winter map from the summer map reveals the calling pattern more clearly, as wealthier residents leave the city during summer weekends and those who remain flock to the park.

SOURCES: RAMÓN CÁCERES, JAMES ROWLAND, CHRISTOPHER SMALL, AND SIMON URBANEK, "EXPLORING THE USE OF URBAN GREENSPACE THROUGH CELLULAR NETWORK ACTIVITY"; FABIO MANFREDINI, PAOLA PUCCI, AND PAOLO TAGLIOLATO, "DERIVING MOBILITY PRACTICES AND PATTERNS FROM MOBILE PHONE DATA"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Main Piston B
Check Valve A
Motion Sensor
Cushioning Orifice A
Variable Orifice A
Hard Stop
Cushion Piston A
Cushion Piston B
Ready