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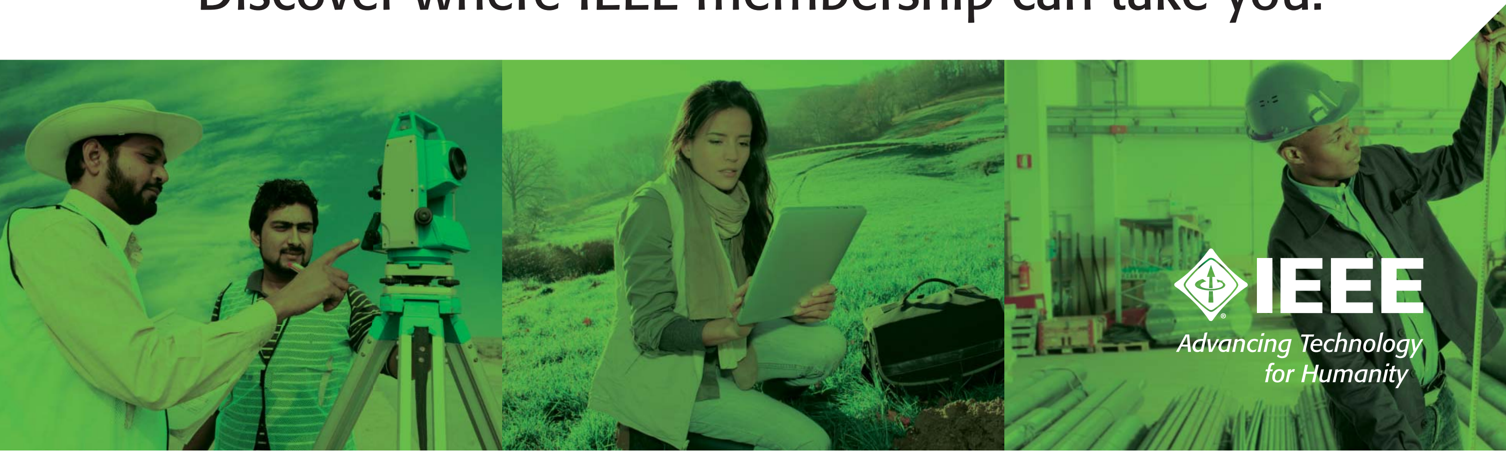

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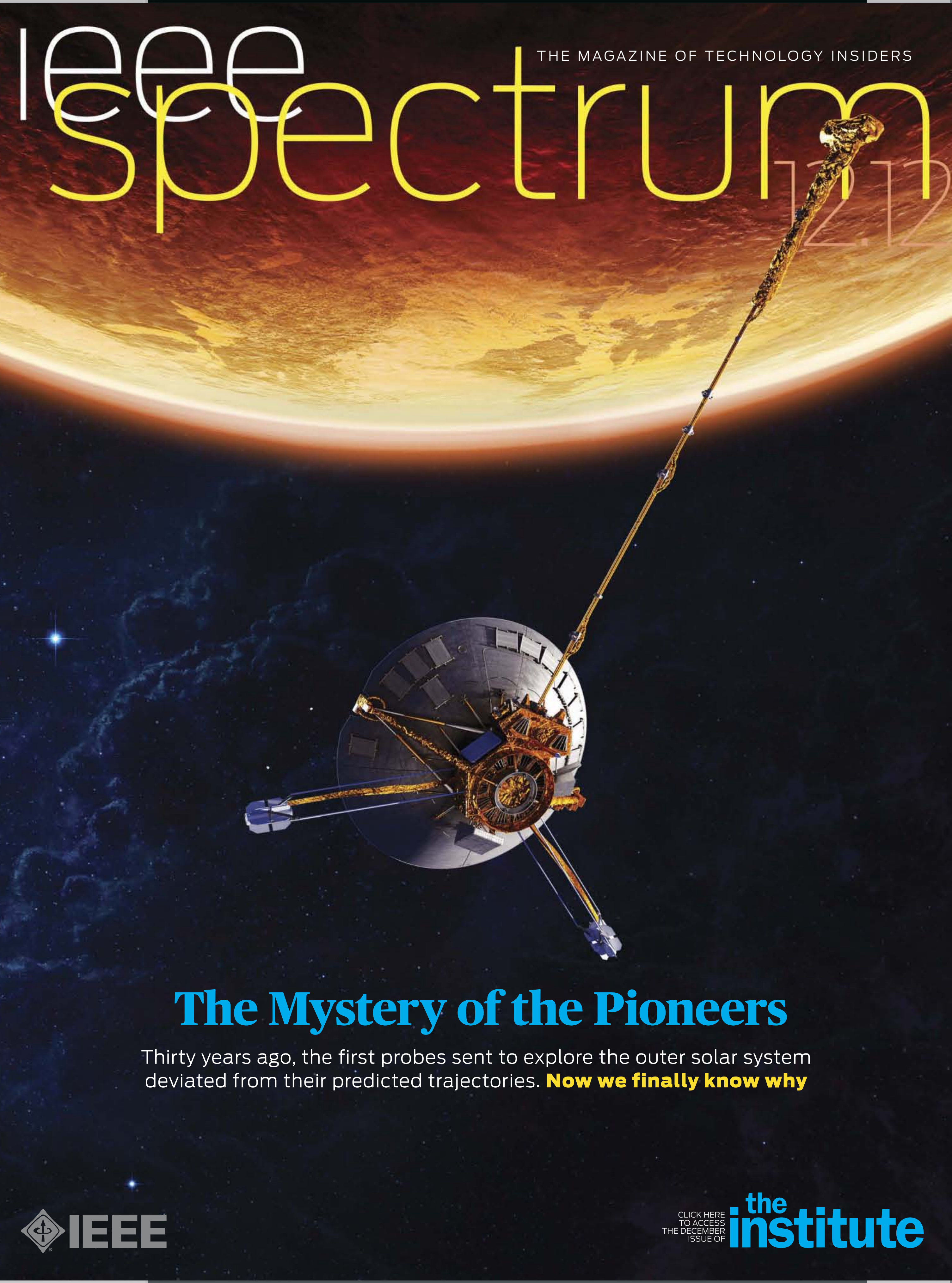

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The Mystery of the Pioneers

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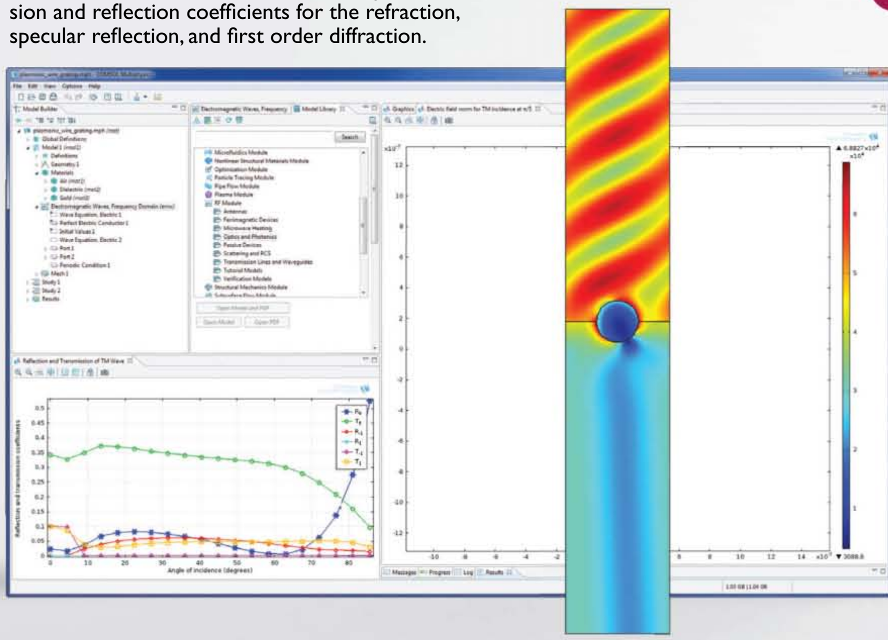

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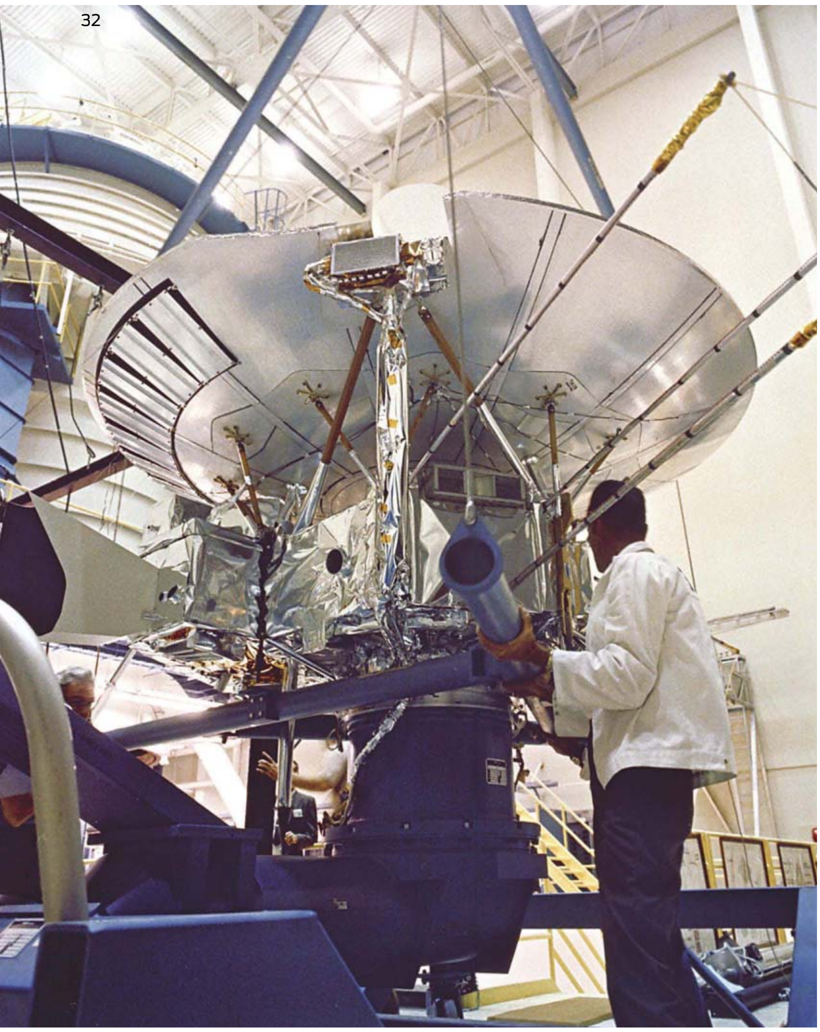

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Titans of Innovation

The sixth annual Patent Power Scorecard is a who's who of global innovation, based on an analysis of the patent portfolios of more than 5000 businesses, universities, government agencies, and other organizations. On *IEEE Spectrum*'s behalf, 1790 Analytics looked at portfolios in such technology categories as aerospace, communications, and software. Each portfolio is ranked using a set of objective measures that gauge the portfolios' overall quality, not just their size. Read more at http://spectrum/ieee.org/patentscorecard1212.

THEINSTITUTE.IEEE.ORG AVAILABLE 7 DECEMBER

LIFE SCIENCES: THE MARRIAGE OF ENGINEERING AND BIOLOGY

This month, *The Institute* takes a look at IEEE and its members' work in the life sciences. IEEE Fellow Rashid Bashir and his team of researchers in Illinois are using nano-biotechnology to develop chip-based sensors that can detect cancer cells earlier than traditional methods.

SMALLER, CHEAPER SURGICAL ROBOTS
Robots have made it easier for surgeons to perform minimally invasive surgeries, but the current systems can be clunky and expensive. That's why IEEE Fellow Guang-Zhong Yang and other engineers are developing compact, flexible robots that can also reduce patients' recovery time.

DELVING DEEPER INTO LIFE SCIENCES
IEEE has introduced a number of resources, including a Web portal and a newsletter, to keep members informed about this growing field.

ONLINE WEBINARS & RESOURCES AVAILABLE AT http://spectrum.ieee.org/webinar

5 December: Taming the Complexities of Software-Driven Innovation to Reduce Project Cost and Risk

6 December: Chip/Package/Board: Constraint-Driven Co-Design

11 December: From Labs-on-Chips to Cellular Machines: Interfacing Engineering and Biology at the Micro- and Nanoscale

13 December: Simulation of EMI in Hybrid Cabling for Combining Power and Control Signaling

18 December: IBM Rational Helps Deliver Next-Generation Automotive Infotainment Systems

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back story

The Robots Are Coming... to Your iPad

EARLY THIS YEAR, *IEEE Spectrum*'s office in New York City played host to a little yellow dancing bot, a Korean humanoid, and a pair of furry mechatronic seals. Those robots and others came to be photographed for a project that *Spectrum* is unveiling now, called Robots for iPad. It's an app that runs on any iPad model, including the new iPad mini, and it's available in Apple's App Store. Read all about it in our annual gift guide, in this issue.

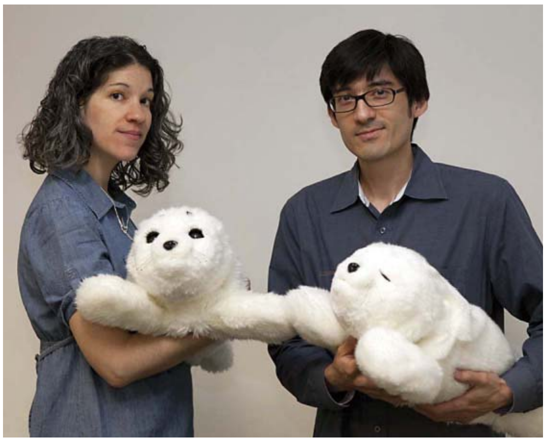
The app, a comprehensive collection of photos, animations, and videos of more than 100 robots from all over the world, is the culmination of nearly a year's work by a small team of editors and developers led by Harry Goldstein, *Spectrum*'s editorial director for digital projects. "Building an app from scratch was a tremendous learning experience," he says.

The idea arose in a brainstorming session between Senior Associate Editor Erico Guizzo and Photo & Multimedia Editor Randi Silberman Klett. "We wanted a topic that was appealing for a stand-alone app, and robots were the perfect choice," recalls Guizzo. "Who doesn't like robots?"

Guizzo and Klett [photo] started out by sketching their app on paper. Next, they designed the user interface, detailing how all the buttons and screens should work. The developers then translated those specifications into code. The final and most time-consuming step was creating all the content.

"The highlight is the interactives," says Klett. "You can make robots spin or dance by touching the screen." To create this feature, Klett photographed some of the robots herself at *Spectrum*'s office. But other robots—some as big and heavy as refrigerators—couldn't be easily transported. So Klett dispatched photographers to robotics labs all over the world.

"It was a big challenge to capture these images," she says. "But when you see these huge robots spinning under your fingertip, it's really satisfying." ❑



CELIA GORMAN

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, The Data is in *IEEE Spectrum*, Vol. 49, no. 12 (INT), December 2012, p. 60, or in *IEEE Spectrum*, Vol. 49, no. 12 (NA), December 2012, p. 84.

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contributors

LYNN CLAUDY has made a career out of entering industries during major technological shifts. He began engineering phonograph cartridges around the time compact discs emerged. When he joined the National Association of Broadcasters, television stations were preparing to go digital. Now NAB's senior vice president for technology, he says, "I'm just waiting for the next transition." He describes what that might look like in "The Broadcast Empire Strikes Back" [p. 46].

ROBERT CREIGHTON started developing airborne wind-energy systems while pursuing an MBA at the University of Wisconsin–Madison. There he discovered the sport of kiteboarding, which he took up so he could learn how to wrangle large kites. It paid off: The company he founded is among several building sophisticated kite-power prototypes, which he describes in "Wind-Energy Industry: Go Fly a Kite!" [p. 40]. "One regret I have is that we haven't had the time or money to have my engineering team spend more time kiteboarding," he says.

VIKTOR T. TOTH and **SLAVA G. TURYSHEV** write about their lengthy investigation of the unexpected deceleration of two deep-space probes—Pioneer 10 and 11 [p. 32]. Toth is a software engineer in Ottawa, Ont., Canada, and Turyshev is a theoretical physicist at NASA's Jet Propulsion Laboratory, in Pasadena, Calif. They each devoted years to solving the mystery of the Pioneer anomaly. Turyshev recalls many late nights spent reading navigational data from more than 400 magnetic tapes he'd found in moldy cardboard boxes beneath a staircase at JPL. "It took about as much time to clean the tape reader as it did to actually use it," he says.

PAUL WALLICH, an *IEEE Spectrum* contributing editor, frequently writes about his home-brew projects. In this issue he reports on his homemade autonomous flying drone [p. 23]. He says the drone's four propellers gave him pause: "I am not at all sure I like building devices with sharp, fast-moving parts!"

KAZUO YANO, SONJA LYUBOMIRSKY, and **JOSEPH CHANCELLOR,** coauthors of "Sensing Happiness" [p. 26], are not your typical collaborators. Yano, an IEEE Fellow at Hitachi Central Research Laboratory, is known for his work on nanostructured-silicon devices and advanced CMOS logic. Lyubomirsky is a professor of psychology at the University of California, Riverside, where Chancellor is a Ph.D. candidate. In 2008, Yano happened to read Lyubomirsky's best-selling book, *The How of Happiness: A Scientific Approach to Getting the Life You Want.* He wondered if the wearable sensor he'd helped develop might be useful in her research on happiness. He contacted Lyubomirsky, and the two, later joined by Chancellor, agreed to work together on a small but intriguing study measuring worker well-being.

CLOCKWISE FROM TOP LEFT: NATIONAL ASSOCIATION OF BROADCASTERS; JULIE ROBICHAUX; ROB CUSHING

spectral lines

The Pursuit of Corporate Happiness

If you work at a company with 50 or more employees, chances are you've filled out an annual employee satisfaction or engagement survey. You answered questions about your working conditions, your bosses, the money you make, and the benefits you get, as well as questions that try to capture your emotional attachment to the job you do and the people you work with.

Your responses, whether made thoughtfully, in haste, in anger, or indifferently, were correlated with those of your fellow workers and statistically analyzed to give your bosses a snapshot of workplace well-being. The premise is that happy, satisfied, and engaged workers are more productive and efficient.

But what if we could dispense with the surveys? What if managerial honchos could gather that same information directly, not just once a year but every minute of every workday—say, from various kinds of sensors? It may sound like science fiction, but it's already here. That's the concept behind the technology developed and described by Hitachi researcher Kazuo Yano, an IEEE Fellow, and his colleagues in this issue's "Sensing Happiness."

The idea is that by wearing biometric sensors at the office—in company identification badges, for example—employees and employers can gain insights into themselves and the ways they work together as a team. The sensors measure the wearer's movements, interactions with others, location, and voice level. Those measurements then get uploaded to a central data center, where they're stored and analyzed. Much the way embedded sensors gauge the health of bridges and buildings, these wearable sensors offer a fine-grained view of what's really going on in the workplace.

The resulting information is used to study many aspects of work and working life, including the effectiveness of corporate mergers, the impact on workers of "happiness boosting" exercises, and the effectiveness of office layouts—do the most fruitful exchanges occur in the kitchen or in the conference room? The sensors can also help assess workers' daily patterns of activity and mood and how they correspond to peaks in productivity and focus. And it's not just an academic exercise: When people are given the results of such monitoring, they're able to improve the way they work and interact.

MIT researcher Alex "Sandy" Pentland, a pioneer and proponent of behavioral biosensing and what he calls reality mining, says that "data mining is about finding patterns in digital stuff. I'm more interested specifically in finding patterns in humans." It's these patterns that are being used to evaluate and change individual and organizational behavior.

Of course, not all of us relish the prospect of becoming a node in a computer-generated pattern. Data may be value free, but the algorithms used to analyze them, and the people who interpret the results, are not. So a certain amount of trepidation is warranted about who would control—and own—the digital profiling of everything about us, including our habits and personalities.

Pentland has been outspoken about the need to study potential problems and to take the legal steps necessary to protect us from digital profiling and misused databases. First and foremost, we must understand what the data can and cannot tell us. Then come the other key issues, the ones related to privacy, control, ownership, and rights. When gigabytes of data exist about you and your habits, it should be reasonable for you to ask who controls it or has access to it.

Pentland's proposed solution is easy to state and hard to implement: You should have the right to access any and all personal data, you should be allowed to control who collects such data, and finally, you should be able to control the data itself. It should be your right to use it, amend it, or even destroy it, he insists.

Biometric sensing in the workplace has the potential to override the biases and blind spots that managers invariably carry with them, and to provide insights into patterns and routines they could never deduce for themselves. But the best bosses will continue to follow management guru Peter Drucker's always relevant advice: The best way to find out what's going on in your workplace is to push away from your desk, walk the floor, and see for yourself—that is, when you're not wading through terabytes of employee biosensor data.

—Susan Hassler

Photographer: Dan Saelinger; Stylist: Birte von Kampen

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ILLUSTRATION: BRANDON PALACIO; ORIGINAL IMAGES: ISTOCKPHOTO

Forever Flash

A new design allows flash memory to last longer by healing itself

IN THE world of memory chips, flash is king. But it's not perfect. It wears out after being programmed and erased about 10 000 times. That's fine for a USB dongle that you'll probably lose in a year, but not ideal for the solid-state drives of server farms. And the same problem keeps manufacturers from using flash to replace other types of computer memories. This month, at the 2012 IEEE International Electron Devices Meeting, engineers from Macronix plan to report the invention of a self-healing NAND flash memory that survives more than 100 million cycles.

What's more, that may not even be the real limit. "We do not know what would eventually cause the device to fail, since we have not seen the end-of-life signals yet," says Hang-Ting Lue, a project deputy director at Macronix, which is located in Hsinchu, Taiwan. To test for 1 billion cycles would take several months, he says.

The key to superlong-lasting flash lies in stealing some tricks from an up-and-coming memory technology that some hope will eventually push flash aside.

A flash memory cell looks like an ordinary CMOS transistor: source and drain regions with a channel of silicon between them, a layer of insulation above the channel, and the gate above that. The major difference is a layer of material called a floating gate, which is embedded inside the transistor's gate insulation. The bit is stored in that layer when electrons are driven to "tunnel" through the insulation and get stuck in the floating gate. Erasing the bit requires driving the electrons out again.

But these write-erase cycles degrade the insulation, and eventually the cell will fail. To compensate for this weakness in solid-state drives, designers have to adopt elaborate schemes to ensure that no particular set of bits is overwritten too often. Annealing would heal the damage, but the thinking was that it could be done only by heating the whole chip for hours at around 250 °C.

update

Macronix engineers saw a solution in a competing technology, phase change RAM. In PCRAM, a bit is stored in a material called a chalcogenide glass, which can be either conductive or insulating. The bit's material switches between those states when briefly heated in a particular way. According to Lue, Macronix researchers noticed that heating the glass to its melting point had a kind of healing effect on their PCRAM. (They reported those results at the IEEE International Reliability Physics Symposium in April 2012.)

Macronix engineers figured that a similar trick would work for flash, so they redesigned a flash memory chip to include tiny onboard heaters that could anneal small groups of memory cells. The redesign required quite a few changes. The biggest one, says Lue, was altering the gate electrode so that it could carry current to heat the memory cells. That alteration, which included the addition of diodes, took up so much space that the Macronix team had to devise a new architecture for its memory arrays to squeeze it all in, he adds.

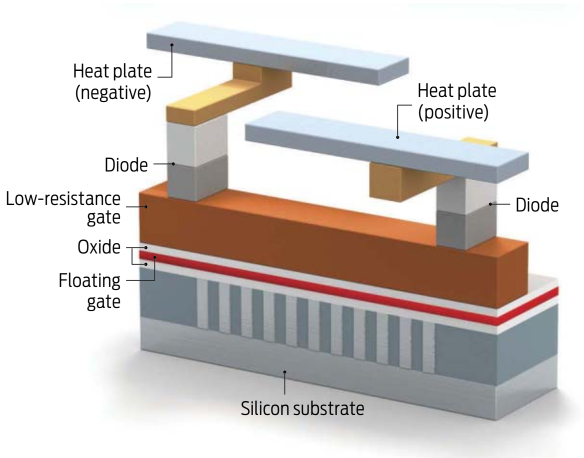
The modified structure enables current to pass through the transistor's gate to generate pulses of heat a few milliseconds long. Researchers found that temperatures exceeded 800 °C but that the hot spot was restricted to the area near the gate. The chips were able to heal themselves through this onboard annealing to the point that even after 100 million cycles, the researchers claim, the memories held data well.

You might think all this heating would be bad for battery life. The "refreshing" does require a substantial amount of power, Lue concedes, but the annealing can be done infrequently and one sector at a time, while the device is inactive but still connected to the power source. "It's not going to drain your cellphone battery," he says.

The experimental memory yielded another surprise: The heating allowed faster erasing, something that was thought to be independent of temperature. "Further down, this may evolve into a 'thermally assisted' mode of operation that gives both better performance—such as the faster erasing—and better endurance flash memory," Lue says. Faster erasing could eventually result in flash taking over from dynamic RAM, the volatile but fast computer memory, but it would take a lot to get there. "Flash is not a random access memory, and the architecture will need to be completely different," he says.

Lue says Macronix intends to capitalize on the self-healing flash breakthrough, but he would not give details about how and when. He was more forthcoming about when the flash industry should have worked in this technology. 'It took a leap of imagination to jump into a completely different regime...very high temperature and in a very short time," says Lue. "Afterward, we realized that there was no new physics principle invented here, and we could have done this 10 years ago."

—Yu-Tzu Chiu



HOT STUFF: Current flowing through the memory cells' gate heats and heals the oxide layers.
ILLUSTRATION: EMILY COOPER

New King of Security Algorithms Crowned

A five-year hunt for a new cryptographic hash scheme leads to the discovery that the old one was really good

A new cryptographic hash algorithm, proclaimed the winner of a five-year competition in October, is literally a solution in search of a problem.

Basically, cryptographic hash algorithms are a way to ensure information security. They are typically used in digital signatures and in establishing connections with secure websites. Data that is run through a hash algorithm produces a shorter string of bits; this string acts as a kind of digest of the data. Any change to the data changes the bit string. The resulting string, therefore, acts as a fingerprint of the data, guaranteeing that no one has tampered with it.

The winning algorithm, called Keccak, was submitted by a team of four researchers from European semiconductor company STMicroelectronics: Guido Bertoni, Joan Daemen, Gilles Van Assche, and Michaël Peeters (who now works at NXP Semiconductors).

Keccak is the culmination of a contest launched in 2007 by the National Institute of Standards and Technology (NIST). At the

4.4 MILLION Number of IT jobs that "Big Data" will generate by 2015, according to Peter Sondergaard, global head of research at Gartner.

time, the IT industry was concerned that the current cryptographic standard, called Secure Hash Algorithm-2 (SHA-2), was on the verge of being cracked. Its predecessors were falling like flies, and the cryptographic community feared that there wouldn't be enough time to invent a new algorithm before SHA-2 fell as well.

But SHA-2 proved a lot tougher than expected. "The train wreck that we feared never happened," says Tim Polk, manager of the cryptographic technology group at NIST. "One of the things we learned [in the course of the competition] is that SHA-2 is a really good algorithm."

As a result, when Keccak (also known as SHA-3) was crowned in mid-October, the news was met with a big "So what?"

But Keccak is an important advance, argues Polk, because it uses an entirely different technique from previous cryptographic algorithms. SHA-2 and its predecessors are based on block-cipher technology. They use a compression function to process fixed-length blocks of data and then generate a digest. Block-cipher technology is "something we understand very well and have been doing for a long time," says Polk.

In contrast, Keccak uses a "sponge function," a technique that didn't even exist when SHA-2 was invented. Rather than processing data in blocks, Keccak applies a permutation process—a rearranging—absorbing all the data and then squeezing out a fingerprint , says Van Assche, senior security engineer at STMicroelectronics.

Because its design is such a departure from those of previous algorithms, Keccak is not susceptible to the same methods of code cracking, says Polk. That makes it an excellent alternative and ensures that if either SHA-2 or Keccak is broken, the other will likely stand strong to take its place.

In addition, Keccak's design makes it particularly useful in embedded applications, which require small chips that use very little power. According to Polk, a circuit that executes Keccak would use less real estate on a semiconductor than one that performs SHA-2, while still providing good performance at low cost.

But no one really knows how, whether, or when the new algorithm could be used. Its very existence might open up some new possibilities, says Polk: "Sometimes you find that when you get algorithms with new properties, then you get new innovative applications that maybe people never pursued before."

Another benefit of the competition was that it proved the strength of SHA-2. Having the cryptographic community hack away at SHA-2 for five years without finding any weaknesses has increased confidence in it. "In cryptography, it's much easier to say something is broken than it is to say something's secure," Polk says. In fact, NIST is recommending that companies stick with SHA-2 rather than adopt the new algorithm. "If people are already using SHA-2, we strongly encourage them to stay with it," says Polk. "There is no reason to abandon SHA-2."

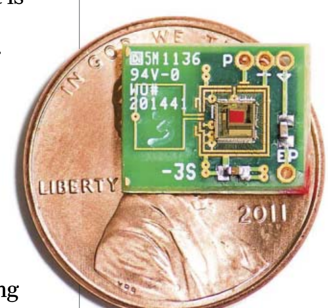
Bob Cromwell, an engineer who runs his own computer consulting business, agrees. Ensuring that organizations are running even SHA-2 is still an issue. This year, for example, the authors of a piece of malware called Flame were able to forge a code-signing certificate in Windows, because Microsoft had not disabled the use of an old hash algorithm, MD5, in parts of its operating system. The attackers were able to generate a false certificate, which opened the way for them to distribute the malware to Windows computers as if it were an update from Microsoft.

"Our biggest problem is not trying to push the leading edge—it's pulling the lagging tail forward," says Cromwell. —Tam Harbert

news briefs

Ear Power

There's a natural battery in your ear, and doctors and engineers at MIT and Harvard have devised a way to use it to power a wireless transmitter. They tapped into a chemical gradient in the inner ears of guinea pigs, where the voltage difference is higher than in any other part of a mammal's body. What they got out was about 1 nanowatt. That was too small for even their ultralow-power radio chip, so they designed a power conversion system that could gather enough charge to operate the radio once every 40 seconds to 4 minutes.



TOP: HENRIK JONSSON/ISTOCKPHOTO; BOTTOM: PATRICK P. MERCIER

8 511 251 Peak number of electricity customers without power in 21 U.S. states following Hurricane Sandy.

update

Powerful PVs Approach 50 Percent Efficiency

Start-up Solar Junction thinks it has the right recipe in a triple-cell scheme

Silicon Valley start-up Solar Junction has raised the bar for solar efficiency to 44 percent, and even higher values are in the cards: The company has a road map for reaching 50 percent efficiency and beyond.

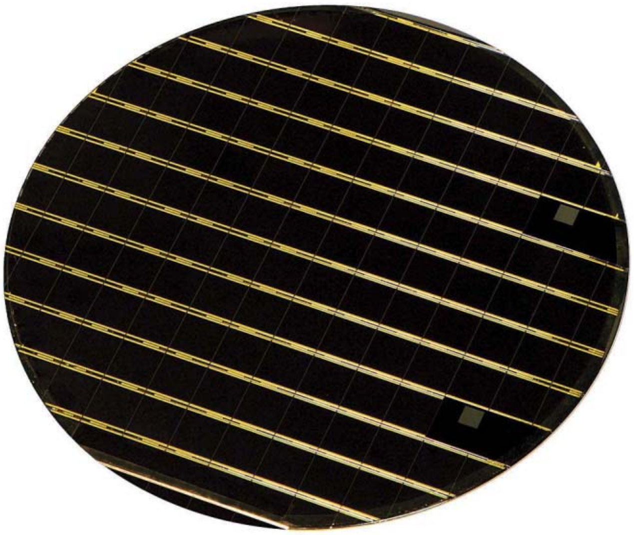
To break the efficiency record, Solar Junction built a cell with three regions, known as junctions, that are stacked on top of one another; each absorbs a different spectral region of the sun's rays. The result is a device that delivers far more energy than conventional cells do. Ordinary photovoltaics have just a single junction. Each junction in the triple-junction cell operates at a different output voltage, and they are connected in series, so the total power produced gets a boost.

Manufacturing a triple junction is not a first, but the type of material that Solar Junction uses for the bottom cell, known as dilute nitride, is new. In this case, the material is made up of gallium indium arsenide antimonide with a splash of nitrogen.

Dilute nitrides have a checkered history. In the middle of the last decade, they were the key ingredient in a new generation of telecom-wavelength lasers that failed to win significant sales. "It wasn't for yield or lack of performance. It was because the telecom industry crashed, and that choked off any new products," explains Homan Yuen, Solar Junction's vice president of research and development.

In triple-junction cells, dilute nitrides are destined to make a big impact because they offer unprecedented versatility, says Yuen. This material's composition can be tuned to optimize the power that the cell harnesses from the sun's infrared energy. But what's really important is that engineers can make those tweaks while independently controlling the spacing of the atoms in the dilute nitride's crystal. Even tiny mismatches between this nitride's crystal lattice and that of the layers below and above can crush efficiency.

The 44 percent figure is remarkable on its own, but what's going to keep Solar Junction's new cell from just being another one for the record books is that the process can be extended to produce four-, five-, or even six-junction cells. This will increase the output voltage of photovoltaics and ultimately let them yield more power (the product of current and voltage).



SUPER SOLAR: Solar Junction's photovoltaic cell breaks efficiency records. *PHOTO: SOLAR JUNCTION*

The upshot of all this optimization is that the company will be able to boost efficiency past the coveted 50 percent mark, according to Solar Junction engineers, who've already mapped out a path to that goal. They will begin by inserting a bottom germanium junction to form a four-junction cell with better performance in the infrared. Further gains will then result from replacing the single dilute nitride layer with a pair of dilute nitride layers, before a sixth junction is added at the top of the structure, which will improve the cell's ultraviolet efficiency.

Multijunction cells are very expensive to produce because their structure is formed using painfully slow deposition techniques on small, costly substrates. So to make the photovoltaic systems that use them cost-competitive with those based on silicon, you need mirrors and lenses to focus sunlight, concentrating it by a factor of several hundred onto cells no bigger than a fingernail.

Concentrating sunlight not only trims costs, it also boosts cell efficiency, because it increases the output voltages at each junction. In Solar Junction's case, the record-breaking efficiency resulted from concentrating sunlight by a factor of 947 on a cell from a production run.

Installations of photovoltaic systems based on this technology must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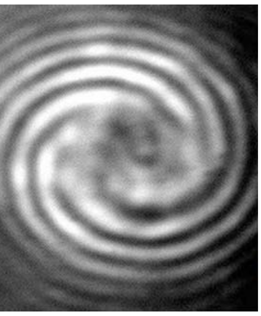


swivel and tilt from dawn to dusk to ensure that sunlight always hits an array of cells head-on. Despite that complexity, such PV systems are quickly becoming more popular in dry, sunny climes. According to IMS Research, in Wellingborough, England, 90 megawatts will be deployed in 2012, rising to 1.2 gigawatts by 2016. This rapid growth is spurred by the low cost of the energy that these systems generate over their lifetime. The multijunction PV systems can undercut silicon cells by 12 percent in some locations, and at the efficiencies Solar Junction is now seeing, this gap could widen.

"Cells are one of the main contributors to the total system costs," explains Jemma Davies of IMS. "By increasing efficiency and concentration, the output per cell is increased, and the cost per watt decreases." —Richard Stevenson

news briefs

Chip Twists Light
Researchers in the United Kingdom and China have made a microchip capable of emitting laser beams that twist. The lasers have a peculiar property known as orbital angular momentum, which many experts think will let telecom firms pack a greater number of channels of data onto the same optical fiber. The chip could replace a large system of multiple bulky modulators. The invention came even as skepticism intensified that the use of orbital angular momentum in the RF part of the spectrum would actually improve data rates [see "A New Twist on Radio Waves," *IEEE Spectrum*, May 2012].

The Cost of Christmas Tablets

Thinking of buying a tablet for the holidays? The world's top tech companies sure hope so. How much they'll make up front from that purchase varies quite a bit, according to preliminary teardowns by IHS iSuppli.

Amazon Kindle Fire HD (Wi-Fi only/ 16 gigabytes)
Materials: US $165
Price: $199
Margin*: $34

Samsung Galaxy Note 10.1 (Wi-Fi only/16 GB)
Materials: $260
Price: $499
Margin*: $239

Apple iPad Mini (Wi-Fi only/16 GB)
Materials: $188
Price: $329
Margin*: $141

New iPad (Wi-Fi only/ 16 GB)
Materials: $306
Price: $499
Margin*: $193

Google Nexus 7 (16 GB)
Materials: $159
Price: $249
Margin*: $90

Microsoft Surface RT (32 GB with touch cover)
Materials: $271
Price: $599
Margin*: $328

** Less intellectual property, manufacturing, and other costs. Source: IHS iSuppli (Figures are rounded to the nearest dollar. Prices are as of 6 November 2012)*

LEFT: XINLUN CAI, JIAN WEI WANG, MARK G. THOMPSON, & SIYUAN YU

update

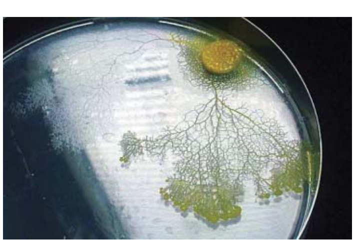
Is Slime Mold Smarter Than a Roomba?

The humble protozoan glop can do some amazing things

There are a lot of similarities between the popular home robot and the forest-floor goop you wish you hadn't stepped in. Following a combination of programmed cues, an iRobot Roomba responds to its environment, detecting dirt and vacuuming it up. Slime mold, or *Physarum polycephalum*, functions in a similar way, behaving in accordance with a list of genetically inherited rules. It's a simple, single-celled organism that digests detritus and leaves behind a trail of slime wherever it goes. What makes slime mold remarkable is that when threatened, all the individual cells in the area combine, creating a larger organism—a collective entity capable of solving problems that a Roomba would find challenging.

So, is slime mold smarter than a Roomba? We'll lay out the arguments. You be the judge.

—Celia Gorman



SLIME REMEMBERED: Slime mold avoids its own tracks [top left].

PHOTO: AUDREY DUSSUTOUR

SLIME MOLD	ROOMBA
Slime mold has a **memory for its external environment** that rivals those of some robots, researchers at the University of Sydney found this summer. As it oozes around, *Physarum* consumes food, so covering the same ground twice would be a waste of energy. By reading the chemical cues in its own slime, or slime left by other slime mold, it can avoid areas that have already been depleted of tasty rotten leaves. This skill is comparable to what's known as externalized spatial memory in a robot.	Roomba has **no memory of what your living room looks like**. Every time it starts up, it's starting over. Of course, this is exactly what it was designed to do. It would be possible to build a Roomba that remembers, but that would require more internal memory and processing power.
Slime mold can design a transportation network. In two different experiments, it re-created massive transit systems in miniature. Researchers set out tasty treats to represent population centers, and slime mold spread out to find them, duplicating the Tokyo rail system and the Canadian highway system.	Roomba **can't compete at urban planning**, but it can identify particularly gritty spots on a floor to do some focused cleaning.
Slime mold **doesn't have a brain**, but it can sense and react to its surroundings without one.	A Roomba's brain is made up of an **ARM processor core and thousands of lines of software code**. The CPU is coupled to infrared, piezoelectric, and RF sensors.
Slime mold **has been inspiring computer scientists** since the 1960s. Some of the math underlying the workings of video games, the Internet, and robots stems from studies of slime mold.	Roomba **helped inspire the creation of a household robotics industry** worth hundreds of millions of dollars.
Slime mold **evolves**.	Roomba gets **updated**, with a new generation of robots arriving every year or so.
Slime mold **can control a robot**. In 2005, Japanese researchers engineered an interface that let a slime cell control a hexapod robot.	Roombas **control themselves**.
Slime mold makes things **slimy**.	Roomba makes things sparkling **clean**.

TOP LEFT: MATT MEADOWS/GETTY IMAGES; TOP RIGHT: iROBOT

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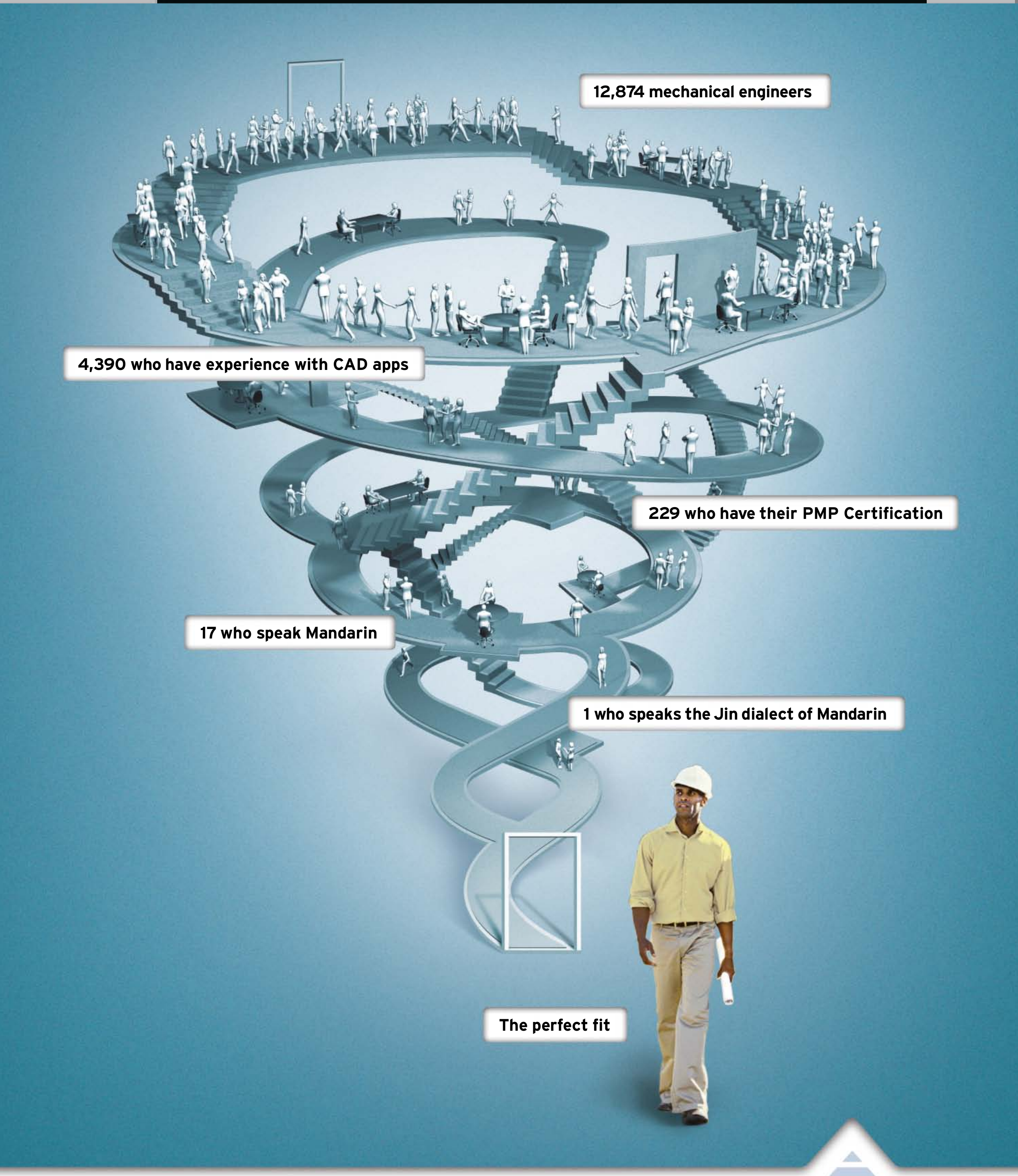
12,874 mechanical engineers
4,390 who have experience with CAD apps
229 who have their PMP Certification
17 who speak Mandarin
1 who speaks the Jin dialect of Mandarin
The perfect fit

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the big picture

Light House

This 75-square-meter glass structure, whose roof is covered with photovoltaic panels, demonstrates that it's possible to draw nearly all the power needed for heating, cooling, and lighting a building—as well as charging an electric vehicle—from the sun. The structure, built in just 11 days by a team of university students from Rhône-Alpes, France, represents the top two floors of an imagined "nanotower" that would house several families and provide both private and common spaces. It beat out houses built by 17 other student teams from around the world to win the Solar Decathlon Europe 2012 competition, held in Madrid in September.

PHOTO: SOLAR DECATHLON EUROPE

tools & toys

The Gift Guide

Our holiday roundup of high-tech items for all budgets

CLASSY COMPUTER: A retro-looking machine comes from a past that never was.
PHOTOS: RICHARD NAGY/ DATAMANCER ENTERPRISES

The Clacker

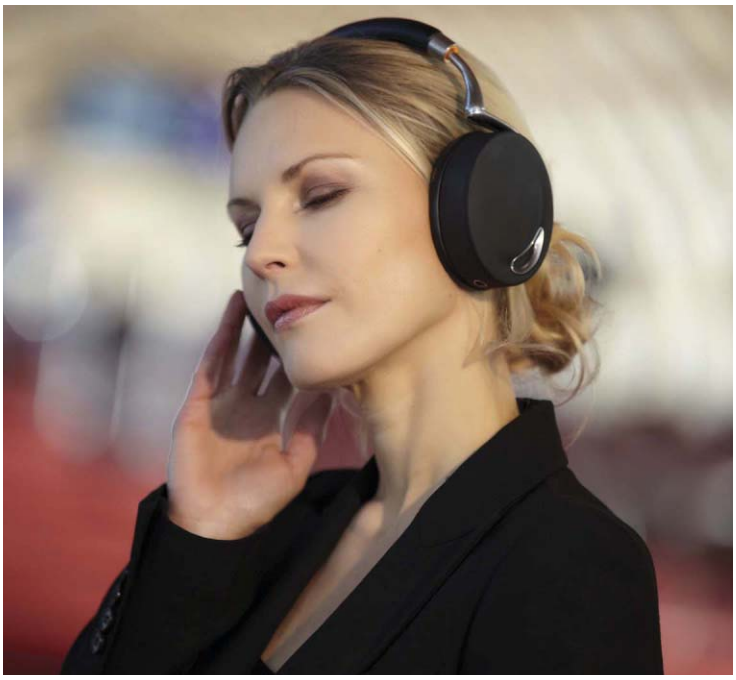
THIS STEAMPUNK PC comes from Datamancer Enterprises. Moving parts from an old projector and a flickering LED light make it appear as if the image on the LCD screen is being rear-projected from a film strip, while gears below whir to evoke Charles Babbage's Difference Engine (both mechanisms can be turned off). The vintage speaker horns have been retrofitted with a modern sound system. The keyboard enclosure and keys are engraved, while the mouse is built from a telegraph key. A gold-foil map serves as a mouse pad. Made to order, the hand-built case will house a current high-end gaming PC. The price for the complete system is between US $15 000 and $25 000. —STEPHEN CASS

Automatons on Tap

Brought to you by the editors behind *IEEE Spectrum*'s award-winning Automaton blog, the Robots iPad app (US $5, available on iTunes) is a celebration of mindful machines. Using hundreds of photos and videos, the app has detailed entries for 126 of the most notable robots built from 1961 to today (there's also a timeline of robotics that goes back to 1495). The first industrial robot, Unimate, the Mars rover Curiosity, and Honda's Asimo are included, alongside a host of other machines from 19 countries.

Yes, we're shamelessly tooting our own horn here. But we're proud of this app, because it captures the passion that animates *Spectrum*'s robotics coverage and distills it into a rich collection that goes beyond our day-to-day reporting. The highlight of Robots is its collection of interactive graphics. These allow users to rotate a robot through 360 degrees or see it perform an action, such as having NASA's robonaut lift weights. The interface is structured so that someone with a casual interest in robotics can easily find plenty of entertainment (such as rating the creepiness factor of various androids), while robot mavens can drill down for things like power requirements. —S.C.

A version of this review appeared online in November.

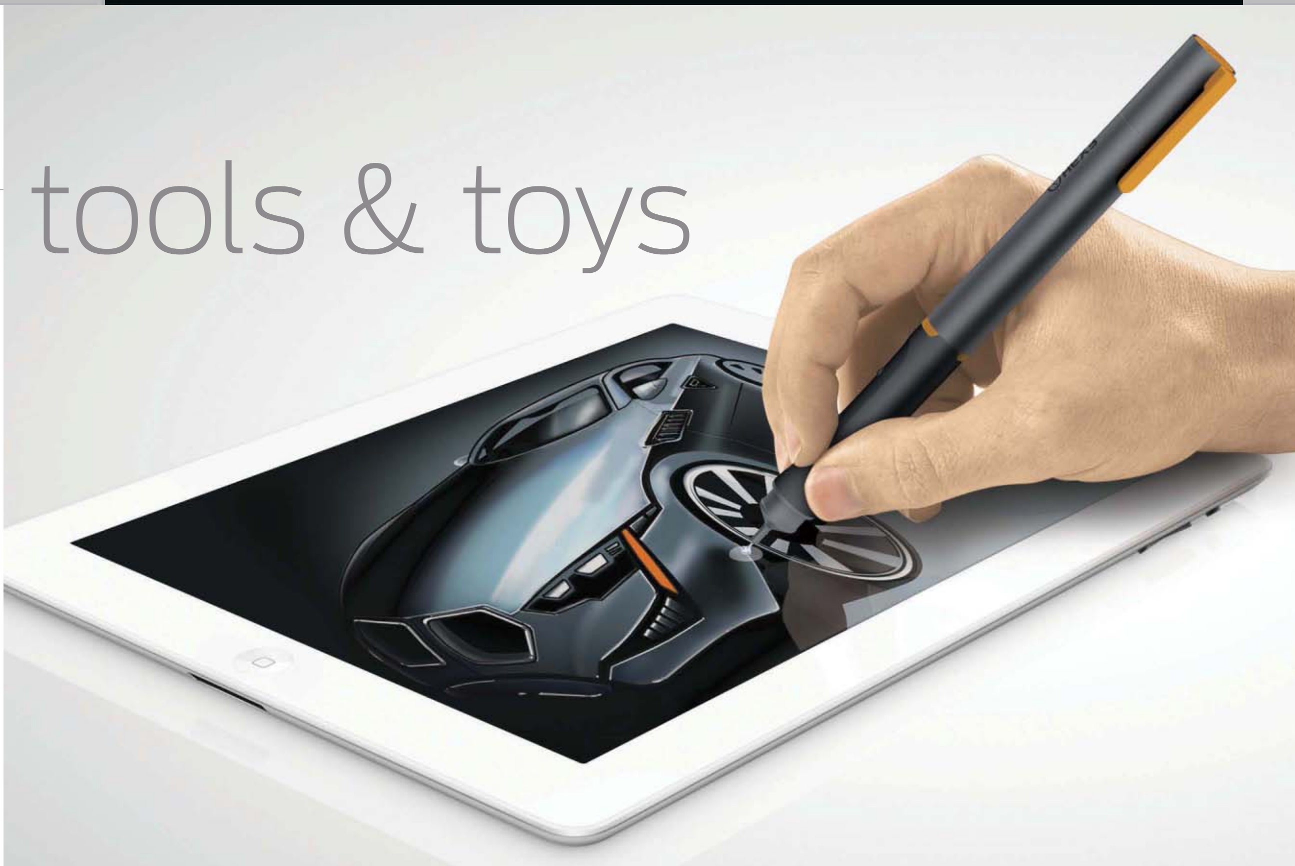


TOP: BRIDGET COLLINS; BOTTOM: PARROT

Smart Sound

For less than US $100, you can get several beefy, bass-heavy headphones with 40-millimeter neodymium drivers and a frequency response ranging from a few hertz to somewhere just north of 20 kilohertz. So what justifies the $400 price tag for the Parrot Zik, when it has essentially the same noisemakers? For starters, Parrot has cut the cord. The headphones connect wirelessly to iOS and Android smartphones via Bluetooth or Near Field Communication. And there's also an active-noise-cancellation system. But the key feature is the gesture control. With the phone in your pocket or on your desk, you can control the volume, skip back and forth, pause a song, and answer a call (using a built-in mic) by swiping or tapping a finger on a touch-sensitive surface on the right ear cup. If you pull the headphones off your ears, a sensor stops the music. The music resumes where it left off when you put the Zik back on. —Willie D. Jones

tools & toys



The Pen Strikes Back

TOUCH SCREENS should be a natural fit for designing and creating art. Like pencil on paper, a touch screen allows users to see their creations appear on the surface they're working on. But touch screens are designed to respond to fingertips, which have limited precision.

Simple styluses designed to mimic the electrical characteristics of a finger can help make more precise marks, but changes in pressure are still ignored. This makes it cumbersome to smoothly vary the darkness of a line, for example. The Jaja Stylus (US $90) solves this problem—it's a pressure-sensitive stylus that can work with any touch-screen gadget equipped with a microphone. The stylus communicates pressure information via ultrasound signals. Currently, only a few apps take advantage of this information—including Autodesk's SketchBook Pro—but more are expected.

For those who prefer the feel of actual paper but still want an easy way to store their notes and sketches digitally, the Evernote Smart Notebook (pocket, $25; large, $30) is the thing. Created through a partnership between notebook maker Moleskine and software developer Evernote Corp., the notebook is printed with dotted lines on each page. When you take a picture of a page with Evernote's smartphone app [below], the lines provide cues for aligning the page for digital conversion. In addition to a handwriting-recognition system that lets you search entries stored in the cloud, you get a supply of stickers to label entries in the notebook, which Evernote can use to tag notes with keywords such as "travel."

—S.C.

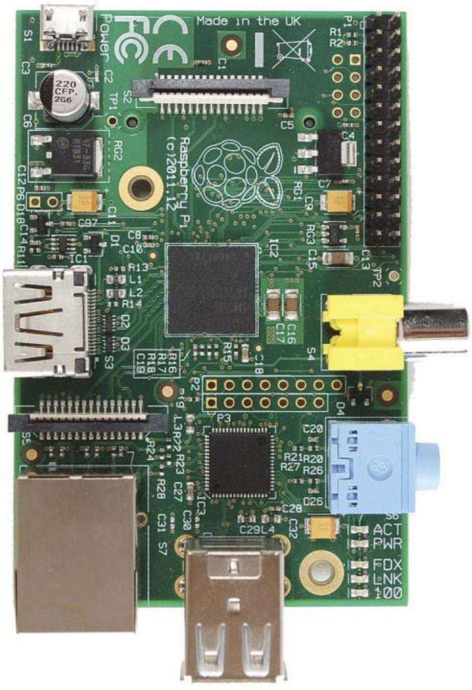
CLOCKWISE FROM BOTTOM LEFT: HEX3 (2); EVERNOTE

hands on

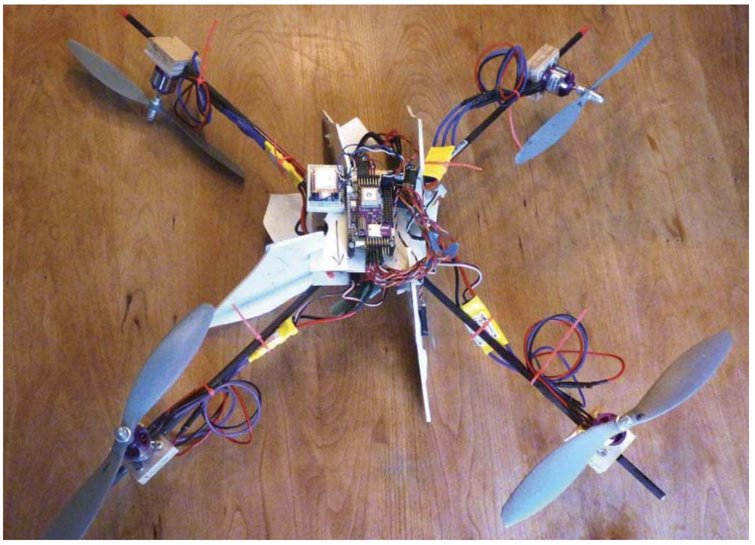
Basic Bytes

At first glance, this stripped-down microcomputer looks as though the words “some assembly required” should appear on the box. But the Model B Raspberry Pi (US $35) is a surprisingly capable PC. Powered by a 5-volt micro-USB connector, it has analog and HDMI outputs capable of providing high definition video. Two standard USB sockets let you hook up a keyboard and mouse (if you want to attach even more peripherals, simply use a USB hub). An Ethernet port provides network connectivity.

The ARM-based processor at the heart of the Raspberry Pi can run a number of variants of Linux. (The operating system is stored on an SD card loaded into a built-in reader.) The primary purpose of the system is to give kids around the world a cheap way to learn programming with something powerful enough to run relatively complex software. But, like the Arduino microcontroller before it, it’s rapidly being adopted by hobbyists for all sorts of home-brew projects. —S.C.



LEFT: ADAFRUIT INDUSTRIES; RIGHT: PAUL WALLICH



Arducopter Parenting

Building a drone to accompany a child to school

On school-day mornings, I walk my grade-school-age son 400 meters down the hill to the bus stop. Last winter, I fantasized about sitting at my computer while a camera-equipped drone followed him overhead.

So this year, I set out to build one. For the basic airframe, I selected a quadcopter design for its maneuverability and ability to hover. Construction was straightforward: You can buy a quadcopter kit with all the pieces or, as I did, get parts separately and spend more time on system integration.

On the mechanical side, there’s a central frame to hold the electronics, spars of aluminum to support the motors and propellers, and legs to cushion the quadcopter’s landing (I made a few extra sets of legs out of foam board for easy replacement).

On the electronics side, there’s a main control board plus sensors, batteries, a power distribution board, power controllers for the motors (which draw tens of amperes, not what you’d manipulate with ordinary microcircuitry) and a radio receiver for standard remote-control flying, plus an RF modem for computerized control—I got both control systems for redundancy.

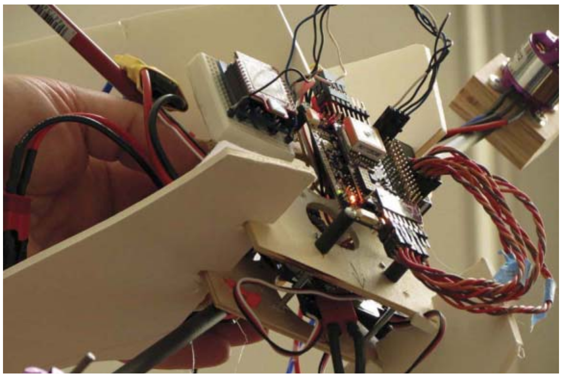
For the main control board, I chose an ArduPilot Mega, mostly because it integrates everything I needed—the CPU, input/output ports, a three-axis gyroscope and accelerometer, and a barometric altitude sensor. A daughterboard soldered on top holds a thumbnail-size GPS unit, a magnetometer (compass), and a slot for microSD card storage. The whole board is powered by a 5-volt feed from one of the motor controllers. (When programming it on the ground, you can power the board via a USB connection.)

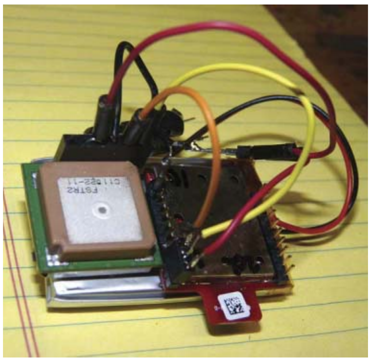
To see the world from the quadcopter’s point of view, you

hands on

can put together a fancy video-transmission rig, or just do as I did—strap on a smartphone and fire up your favorite video chat app. The motors I got can lift a few kilograms, but my surveillance drone's total weight comes closer to 1 kilogram, for a good margin of maneuverability.

As for the software, open-source enthusiasts have been working for several years on code that not only keeps a copter stable in flight but also maintains whatever altitude the controller commands (based on barometric sensing or an ultrasonic range finder). It can also fly an autonomous course through whatever GPS waypoints you choose to upload.





ELECTRONIC TRAIL: An RF modem connected to the control board of the drone [top] receives signals from a tracking device consisting of a GPS receiver and an RF modem [bottom]. The drone then flies to a nearby position.

PHOTOS: PAUL WALLICH

On the ground control side, the flight software can connect to a number of PC-based graphical user interfaces that overlay the quadcopter's position and other data on a map in real time. The Mission Planner Utility, the best-documented ground station software, is Windows only, but others, such as Qgroundcontrol, run on Windows, Mac OS X, or Linux. I installed Mission Planner on a Windows desktop to initialize the ArduPilot Mega's firmware and calibrate all its sensors and controls. I used Qgroundcontrol on the Linux box in the basement and on my spouse's MacBook during actual flight.

Getting the quadcopter built and into the air was almost too easy. The hard part was getting it to locate and track its quarry. After looking into long-distance RFID systems, I decided to go with a GPS beacon instead. Reading an RFID tag from meters rather than centimeters takes more amplification and a fancier antenna than I was willing to have my quadcopter carry. And the open-source flight software already has a "follow-me" mode that will keep the copter an arbitrary distance from a GPS position delivered by radio.

So my attention turned to creating a beacon that could fit unobtrusively in my child's backpack. Initially I thought I would have to tie a GPS chip and radio transmitter together using a microcontroller, but some recent innovations simplified the job.

A conventional RF modem can only pass on data that's sent to it, but the latest generation (such as the Synapse Wireless RF266) can also run scripts in a tiny-but-useful subset of the Python programming language, cutting out the separate microcontroller entirely. You can easily program the modem to transmit a GPS position to the copter only when the beacon has moved, and to go to sleep (and send the GPS chip to sleep too) when the beacon hasn't moved for a few minutes. It makes for a smaller beacon—mine is about the size of a large thumb—powered by a coin-cell battery. Depending on your target's movement patterns, a single coin cell might last for a week.

So, did it work? Mostly. The copter is skittish when it's windy, and GPS guidance is good to 10 meters at best. Because my particular front yard is only about 15 meters across, with a long, tree-edged driveway leading to the street, I either have to follow automatically above the treetops—where I can't really see what's going on—or else supplement the autopilot with old-fashioned line-of-sight remote control. Which somewhat defeats the original plan of staying warm and dry while a drone does my parenting.

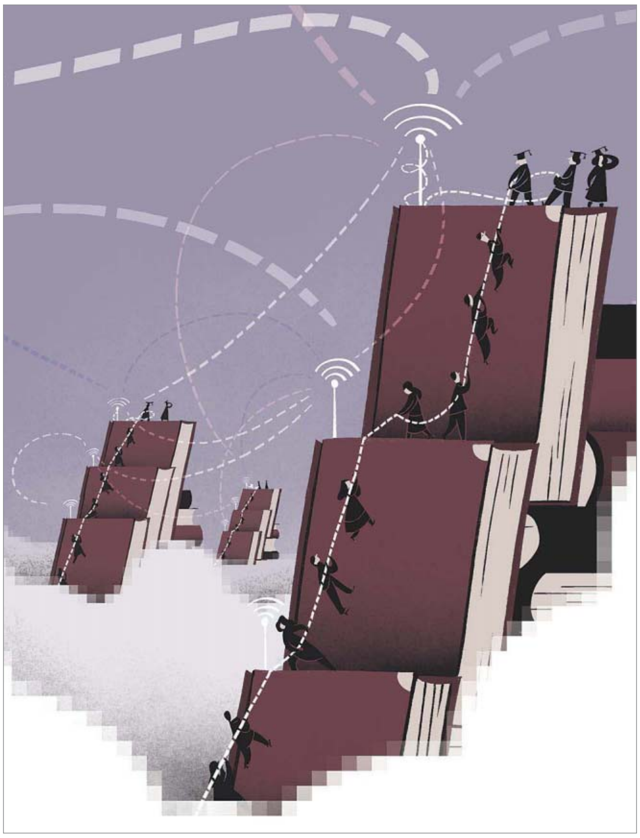
I have fixes in the works: more sonar units for collision avoidance, maybe even an "optical flow" sensor for better position control—some enthusiasts have figured out that the same tiny image array that lets a mouse figure out how fast it's moving over your desktop surface can be augmented with a longer lens to determine how fast a copter is passing over the landscape. But the hardware and the software are both still in flux, so probably not this flying season.

The other big problem is the quadcopter's rechargeable battery life. Just hovering in the air requires 2 to 3 amperes; moving around or fighting a breeze expends twice that or more. A typical 2200-milliampere-hour lithium-ion battery gives me just enough time to fly to the bus stop, wait a few minutes for the bus, and fly back, so no following to the school playground. (Attaching more batteries at roughly 200 grams per pack pretty quickly runs into diminishing returns.)

So until the batteries improve by another order of magnitude or so, I'll have to do most of my watching the old-fashioned way, in person.

—Paul Wallich

technically speaking BY PAUL McFEDRIES



ROMAN MURADOV

I'm in the Mood for MOOCs

We started talking about what it meant to have lots and lots of people learning together. Somewhere in there, I called them a massive open online course, for which I have been often chastised. —Dave Cormier, education researcher

IF YOU DECIDED to learn a piece of music, a piano concerto, say, you'd likely start by getting a copy of the score to study. However, what if you came away from that study with only the knowledge that the score consisted of 1432 A notes, 1268 Es, 745 G-sharps, and so on? Have you learned the piece? No, of course not—it's not the number of notes that matters.

That's kind of the idea behind a new theory of learning called **connectivism**. To the **connectivist**, a branch of knowledge isn't a set of isolated facts to be memorized. Instead, it's actually a large set—or really a network—of connections, and learning is nothing more or less than traversing them. In the same way that you become proficient in a piece of music by playing its notes in order in an expressive way—that is, traversing its connections—you become proficient in a subject by participating in it. You see and appreciate the connections inherent in the subject, even creating new connections based on your experience.

This learning-by-doing approach has been called **activity theory**, and it's finding a home in many 21st-century learning environments because technology makes it so much easier to actively engage in a subject's **connective knowledge**. For example, you can document your learning in a free blog hosted by Blogger or WordPress; you can engage other people who are also learning (or have already learned) the topic through Facebook or Twitter; you can use online resources to store and share bookmarks related to the field; you can even create your own wiki.

Alternatively, you can sign up for a **MOOC**, a massive open online course. MOOCs are free, open to anyone, and designed to handle an extremely large number of students. You might think that MOOCs would cover only esoteric subjects offered by obscure schools, but that's not the case. Such august institutions as MIT, Harvard, Stanford, Princeton, and Caltech have offered online courses recently. These are not off-curriculum pet projects but rather actual degree courses offered simultaneously to a few tuition-paying students on campus and to thousands of would-be learners auditing online. (At least for now, only the tuition payers earn credits toward a degree.) Most of these courses get a few thousand online participants, although an artificial-intelligence MOOC given by Stanford in late 2011 filled a whopping 160 000 virtual seats.

The materials created for these courses are called **OpenCourseWare**. They are "open" in the sense that they're shared freely online, although they tend, at least at the MOOCs run by those big-time institutions, to have fairly rigid frameworks in which the materials themselves are defined in advance and are unchanged as the course progresses. However, other MOOCs—particularly those run by private companies such as Udacity—tend to incorporate **open design** principles that enable participants to control what they learn, how they learn it, and whom they interact with during the course. In this way, the MOOC becomes a kind of network of learners who spontaneously form new connections and even help direct the course and its objectives.

Of course, MOOCs have their detractors. Some call them *monstrous open online courses*. They complain that they're chaotic and prevent meaningful student-teacher interaction and, if expanded to any meaningful degree, will lead to mere **broadcast education** and ultimately to an undefined **MOOCopalypse**.

Until recently, **e-learning** was most prominently associated with the **novelty degree**—a degree from a nonexistent university or college (or sometimes a fake degree from an existing university or college). Now we might be heading into a golden age of **virtual education**, where high-quality courses are available to everyone and not just those who can afford US $40 000 a year for tuition. Now that's a tune I'd like to study. ❑

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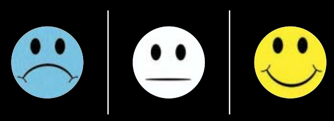

Sensing Happiness

Wearable sensors can help lift workers' spirits and create more-effective teams

by KAZUO YANO, SONJA LYUBOMIRSKY *&* JOSEPH CHANCELLOR

photography by DAN SAELINGER

THE UNMANAGEABLE IN-BOX, the cellphone and laptop that keep you electronically tethered to the office, the endless 30-second distractions from incoming e-mail and text messages. Sound familiar? The same advances in computers and telecommunications that have brought about tremendous gains in productivity have also made the work lives of professionals a misery. No wonder that these days many people's dream vacations include thoughts of tossing their mobile phones into a mountain stream and fully unplugging.

But what if instead of creating stress, technology made people enjoy life more?

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Engineering happiness is not as radical as it sounds. Over the last decade, engineers, computer scientists, psychologists, and other researchers have shown they can do just that. Specifically, by monitoring and analyzing a person's sleep patterns, exercise and dietary habits, and vital statistics like body temperature, blood pressure, and heart rate, they can pinpoint trouble spots in the person's daily routine and then suggest modifications that measurably improve that individual's outlook and well-being. Building on those studies, a range of consumer products now on the market let you try those things at home, with the ultimate goal of making you healthier and happier. ["How I Quantified Myself," in the September 2012 issue of *IEEE Spectrum*, looked at several such gadgets.]

The same kind of technology that's helping people improve their personal lives can yield positive results in the workplace: better communication, better teamwork, and greater job satisfaction on all levels of the organization. Perhaps most intriguing, it can help workers achieve that satisfying feeling of being fully immersed in, energized by, and happy about whatever they are doing. Seem too good to be true? In fact, it's perfectly possible, and it isn't magic. But to achieve the best results takes the proper mix of engineering and psychology.

FROM THE TECHNOLOGY SIDE, what's driving this activity is the convergence of three trends: miniaturization, wireless communication, and better batteries. With off-the-shelf hardware you can readily build a small sensor that can record gigabytes of behavioral data yet weighs just a few tens of grams, so it doesn't impose a burden on the user or disrupt daily activities.

In the early 2000s, MIT professor Alex ("Sandy") Pentland was one of the first researchers to propose using wearable sensors to study people's well-being. Back then, conventional wisdom held that the best way to measure a person's state of mind was to use interviews or written surveys. But it turns out that the vast majority of human communication isn't verbal. Nonverbal cues such as intonation, posture, and gestures can be much more important than formal language. Let's say you're listening to a coworker: Even if you don't say a word, your facial expressions will quickly reveal whether you're interested, bored, or downright dissatisfied.

Pentland's idea was to use a wearable sensor containing microphones, accelerometers, and infrared transmitters, which he called the sociometer, to detect the pitch of a person's voice as well as his or her movements and thereby gain a window into the wearer's experiences, social patterns, and quality of communication. At the time, however, electronic technology wasn't quite up to the task. Early sensors weighed nearly 200 grams and didn't have much storage or processing heft or a very long battery life.

Subsequently, Pentland's team collaborated with one of us (Yano) and his group at Hitachi to extend the usefulness of these devices. Hitachi then commercialized the units and incorporated them into a sociometric sensor called the Business Microscope, which it released in 2009.

In its latest incarnation, the Hitachi Business Microscope (HBM) is about the size of a name tag and weighs a mere 33 grams. You wear it around your neck on a lanyard, as you would a name badge at a conference. Inside its plastic case are six infrared transceivers, an accelerometer, a flash memory chip, a microphone, a wireless transceiver, and a rechargeable lithium-ion battery that allows the badge to operate for up to two days at a time.

The HBM measures the wearer's body movements and voice level, as well as the ambient air temperature and illumination. It tallies body movements—including head nods, arm waving, stretching, finger pointing, and other nonverbal communication—

STYLIST, PREVIOUS PAGE AND THIS SPREAD: BIRTE VON KAMPEN

much as a pedometer counts a person's steps. That is, the accelerometer measures each motion in the x, y, and z axes. Later those measurements are translated into a single value that indicates the degree to which you are moving about in space.

The sensor can tell when two or more wearers are in close proximity using its six infrared transceivers, which point in different directions to cover a wide area in front and to the sides of the wearer. When these transceivers detect another badge within 2 meters, the two badges exchange IDs. Each badge then records the time, duration, and location of the interaction. To determine location, the badge listens for signals from the nearest "beacon," an infrared apparatus that constantly broadcasts its location ID; beacons are strategically placed around the space that's being monitored—on conference room tables, users' desks, and so on. Each badge's small LCD screen displays the time, temperature, the number of other HBM wearers you've met that day, and how physically active you've been.

The badge also collects information about the types of exchanges that take place. For example, sitting with colleagues in a conference room listening to a presenter drone on for hours is very different from having an animated conversation around the coffee machine. The HBM can discern that difference, again by monitoring people's movements and measuring the energy level of their voices.

Before leaving the office each day, a user places the badge in a "cradle," which recharges the battery and also downloads the stored information. These measurements are transmitted over the Internet to Hitachi's data center for analysis and long-term storage. Periodically, the system provides users with reports on the activities that are being monitored.

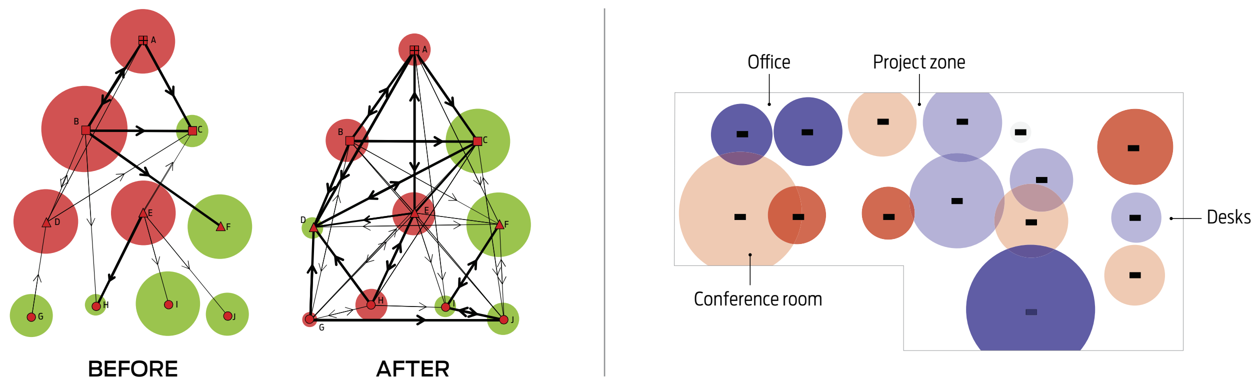
Since the HBM's introduction three years ago, hundreds of organizations, including banks, information service companies, design firms, research institutes, call centers, and hospitals, have used it to collect about 10 terabytes of behavioral data, amounting to half a million person-days. Of course, understanding people's subjective experience requires more than just recording how they move or to whom they talk. And to make sense of all those data, you need a scientific framework of human behavior.

EACH PERSON HAS his or her own motivations, feelings, and goals—all of which affect behavior. But these underlying factors may not necessarily be apparent to casual or even trained observers. Does a person's erratic movements indicate distress or giddiness? Do fewer than the normal number of social interactions one day mean that a person is depressed, or just engrossed in an engaging activity? Engineers need a way of distilling sensor data into meaningful mental states.

For that, we turn to the emerging field of positive psychology. Unlike traditional psychology, which focuses on problems—stress, depression, anxiety, obsessions, and mood swings, to name a few—positive psychology looks at desirable mental states (including happiness) and sought-after character traits (such as self-control and generosity), as well as the internal and external factors that contribute to well-being.

You might think that happiness is something ineffable, an elusive state of being that defies quantification and analysis. But over the past decade, one of us (Lyubomirsky) and her collaborators at the University of California, Riverside, have conducted many studies that demonstrate that happiness can, in fact, be systematically measured.

These findings can be counterintuitive. For example, most of us tend to believe we will be happier when we marry, buy a house, or get a raise. It turns out, though, that such external circumstances contribute in only a small way to our long-



PARSING INTERACTIONS: In the diagrams of "pitcher-catcher" relationships at left, red circles represent "pitchers"—people who are more talkative—and green circles are the less communicative "catchers." At the start of the study, office communication is mainly one-way, as shown by the arrows. By the end, two-way interactions are the norm. In the space-utilization map at right, the circle size shows the amount of time workers spend at various locations in an office, and the color corresponds to activity (red being active, blue being passive). *SOURCE: HITACHI HIGH TECHNOLOGIES*

term level of happiness. Likewise, many people suppose that a relationship setback, professional failure, or financial crisis will make them much more unhappy than it actually does. It turns out that most people adapt to both positive and negative circumstances much faster than they expect.

What *does* make a difference in happiness are people's habits and activities. Even simple actions like expressing gratitude and performing acts of kindness can make you feel measurably better. The conclusion? Changing activities, rather than fixating on ideal circumstances, is the best way to boost happiness.

The benefits of happiness go beyond just feeling good. In 2005, Lyubomirsky and her colleagues documented how happiness and positive feelings improve people's personal and professional lives. For example, happy people tend to be more creative, are more productive at work, and go on to earn higher salaries. You read that right: Getting a raise won't make you happier, but if you're already happy, more money is likely to come your way as a side benefit. Hard statistics about these positive outcomes—higher salaries, better performance evaluations, and greater longevity—help win over skeptics to the value of happiness research.

BUSINESS SCOPE: Hitachi's wearable sensor monitors workers' movements and interactions.

In the workplace, one manifestation of being happy is your ability to achieve a state of full engagement, or "flow," a term psychologist Mihaly Csikszentmihalyi at Claremont Graduate University, in California, coined to describe this phenomenon. When it happens, hours pass by like minutes, and you forget about outside worries. Nearly everyone experiences flow at some point or another, including knowledge workers such as engineers and scientists, whose jobs require a great deal of focused creativity and problem solving. As it turns out, technology can help identify this cherished state of mind.

IN ONE SMALL BUT INTRIGUING STUDY, Yano, his colleague Koji Ara, and Csikszentmihalyi looked at whether you could quantify when people had reached that special state of being "in the zone." In this experiment, participants were asked to keep a diary of their feelings and corresponding activities throughout the day. Their HBM data—particularly the rhythm of their movements as measured by the accelerometers—were then compared with their diaries. There was no one movement or one type of activity that corresponded to a state of flow, nor was there a particular time of day during which workers were better able to focus intensely in this way. And that makes sense, given people's individual styles and quirks.

The key indicator of flow turned out to be consistency in movement. For some people, that consistent movement was slow; for others it was fast. Some were morning people; others favored the afternoon or evenings. Regardless, when participants experienced flow, their motions became more regular, as they lost themselves in a challenging but engrossing activity. When they compared their HBM data to their daily diaries, participants were often surprised to see that their mental state had such an obvious digital signature. Once people became aware of their daily patterns, they could better schedule their work to take advantage of times when they were most likely to be in this mental state.

A more straightforward yet illuminating way that we've used wearable sensors in the workplace is to document social interactions. You can, for example, examine which locations in an office tend to host the most frequent and active discussions, and which areas are underused or prone to passive interactions. Restructuring the office layout based on such results might well lead to more fruitful collaborations.

In many cases, these sociometric data reveal very different patterns of communication than what you might infer from a company's organizational chart. Let's say you're trying to gauge the effects of a corporate merger. Ideally, you want the two companies to become completely integrated, despite what may have been different cultures and work processes. Sensor data can tell you the extent to which what were formerly two groups are actually coming together, because they show who really talks with whom and how often.

In one early experiment, the HBM was used to study the merger of two product-design units within a company. One month after the combination, the resultant group remained for

HITACHI HIGH TECHNOLOGIES

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the most part two separate entities. Even the head of the group at first continued to interact mainly with his old coworkers. Indeed, things were so bad that there were a full six degrees of conversational separation between an average worker and the big boss. That's rather shocking, considering that about the same number of steps of acquaintanceship separate any two people chosen at random, a phenomenon that social psychologist Stanley Milgram first studied in the 1960s (and that later spawned the party game "Six Degrees of Kevin Bacon").

So how can such a dysfunctional office work better? As part of this experiment, managers and employees received regular sociometric reports that included diagrams showing who was talking to whom, and everyone was encouraged to make adjustments to bring people together. By the end of the three-month experiment, the head of the group and others were collaborating much more closely with their new coworkers, and the social hierarchy had flattened out. What's more, workers were reporting greater satisfaction and productivity.

In another small study (the first collaboration among the three of us), we looked at boosting worker satisfaction. We also measured people's movements to see if there was any correlation between happiness and physical activity. Our study, conducted over a six-week period, involved a Japanese office with 32 employees. Half of the participants practiced a happiness-boosting exercise—namely, writing down three positive things that had happened that week at work. The remaining participants merely listed work tasks they had completed that week. To control for the placebo effect, all the participants were told that their assignment was designed to make them happier.

Relative to the control group, participants who recounted positive events reported greater happiness, intrinsic motivation, life satisfaction, and connectedness with others. These benefits persisted for a month after the study concluded. The benefits are all the more striking considering the simplicity of the exercise: A mere 10 minutes of writing about "good things" produced measurable differences.

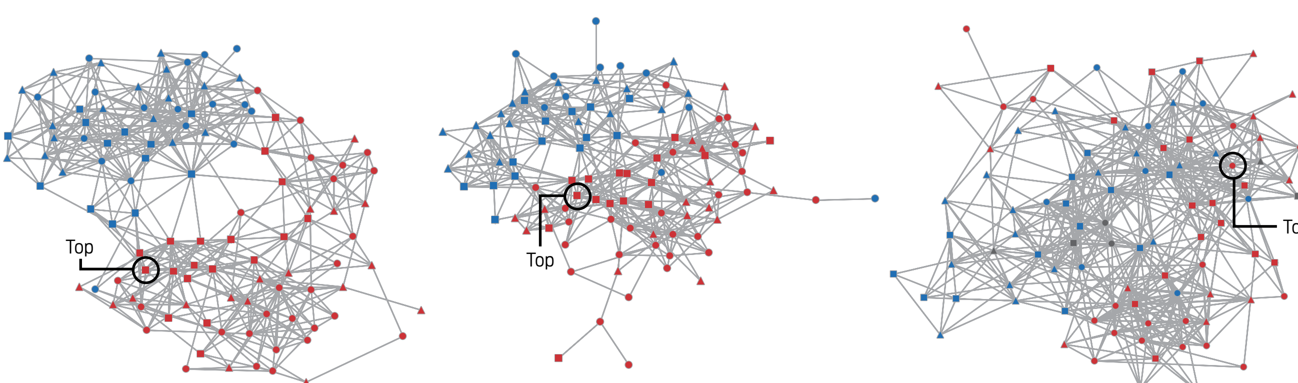
We also looked for differences in participants' daily routines. We found that employees who practiced recalling positive events started arriving at work with more energy (as measured by their movements) and reaching their peak levels of physical activity earlier in the day. In addition, they spent less time interacting with coworkers. In other words, as participants felt better, they devoted more time to work and less time to socializing, becoming more active, engaged, and diligent in their tasks. Of course, a healthy organization needs a certain level of social interaction, as we saw in the company merger described above. But this study highlights the importance of balancing face time with personal achievement.

These results also show how sociometric data and more subjective survey results can complement each other: Objective measures record concrete changes in behavior, and subjective measures explain these changes in terms of people's thoughts and feelings.

RESEARCH COLLABORATIONS between engineers and psychologists are only just beginning. We fully expect that as the use of wearable sensors spreads and more data accumulate, people will find new ways to deploy these biometric monitors.

Of course, no "happiness" sensor will ever be perfect. But it doesn't need to be. When the thermometer was invented four centuries ago, it was very imprecise, and yet it still yielded valuable information. Over time its design was refined, and now it's indispensable. We believe happiness sensors will follow a similar evolution. Although there will always be a degree of uncertainty in assessing people's mental states, wearable sensors are already better than traditional tools for gauging well-being, being relatively unobtrusive, effortless to use, and relatively inexpensive to manufacture.

In time, more businesses will make use of these sensors, to measure worker behavior and satisfaction, to study the effectiveness of new practices and procedures, perhaps even to cultivate flow. In this way employers should be able to create environments that boost positive engagement and overall productivity. That would indeed be a happy outcome. ❑

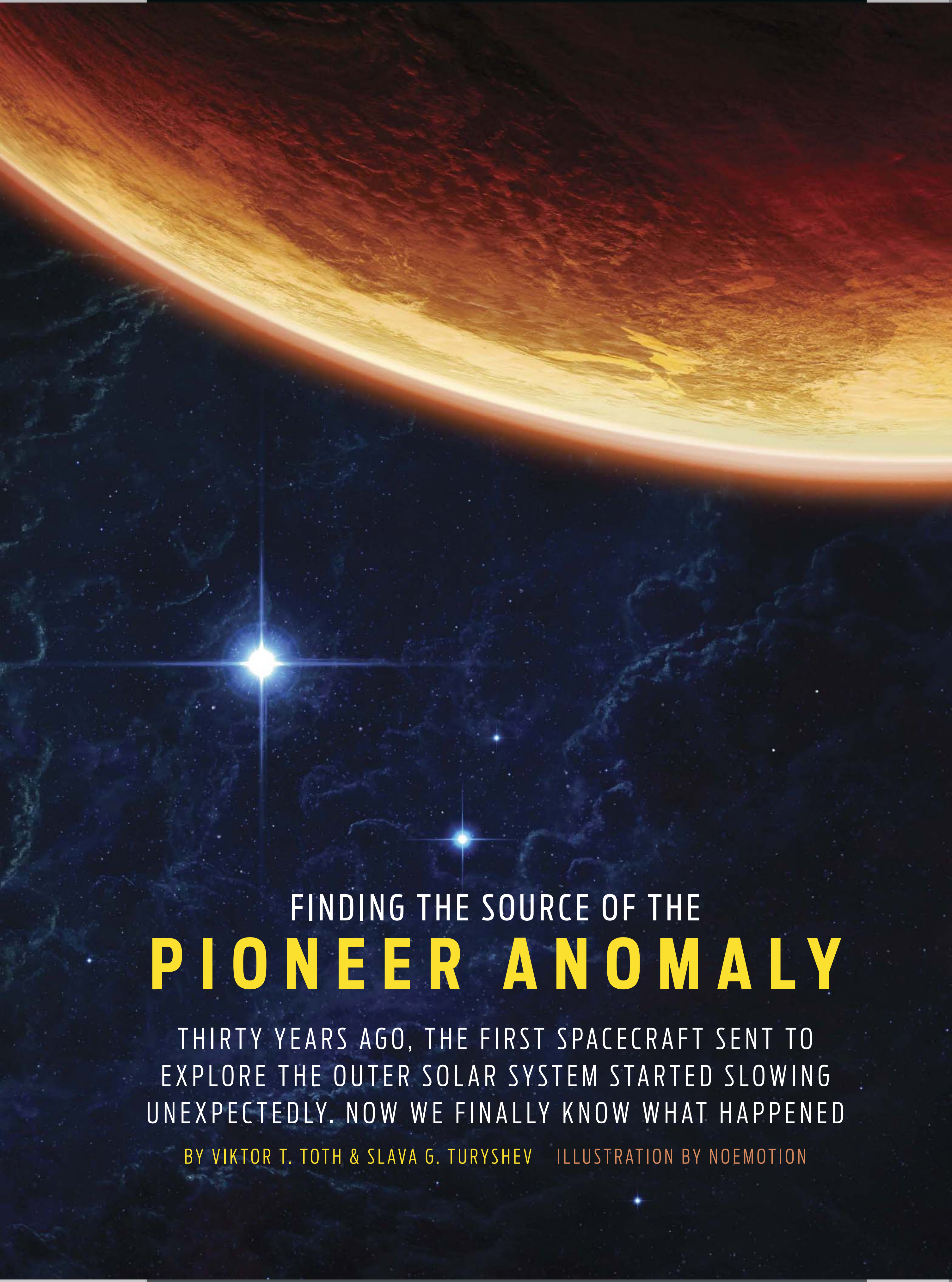


BASELINE
Average distance to top: 5.9 steps

1 MONTH AFTER FEEDBACK
Average distance to top: 5.0 steps

3 MONTHS AFTER FEEDBACK
Average distance to top: 3.7 steps

TWO BECOME ONE: A month after the merger of two divisions, the employees [shown as red and blue nodes] remained highly segregated, and their social interactions followed a hierarchical pattern. The average degree of separation between the head of the organization and the typical worker, as judged by daily conversation links, was almost six. Even the head of the merged group [circled in black] primarily interacted with coworkers from his old division. After managers received feedback on these patterns and took steps to improve communication, the merged group became much more integrated, indicated by more connections between blue and red nodes and a flattened hierarchy, the average distance shrinking to fewer than four steps. *SOURCE: HITACHI HIGH TECHNOLOGIES*

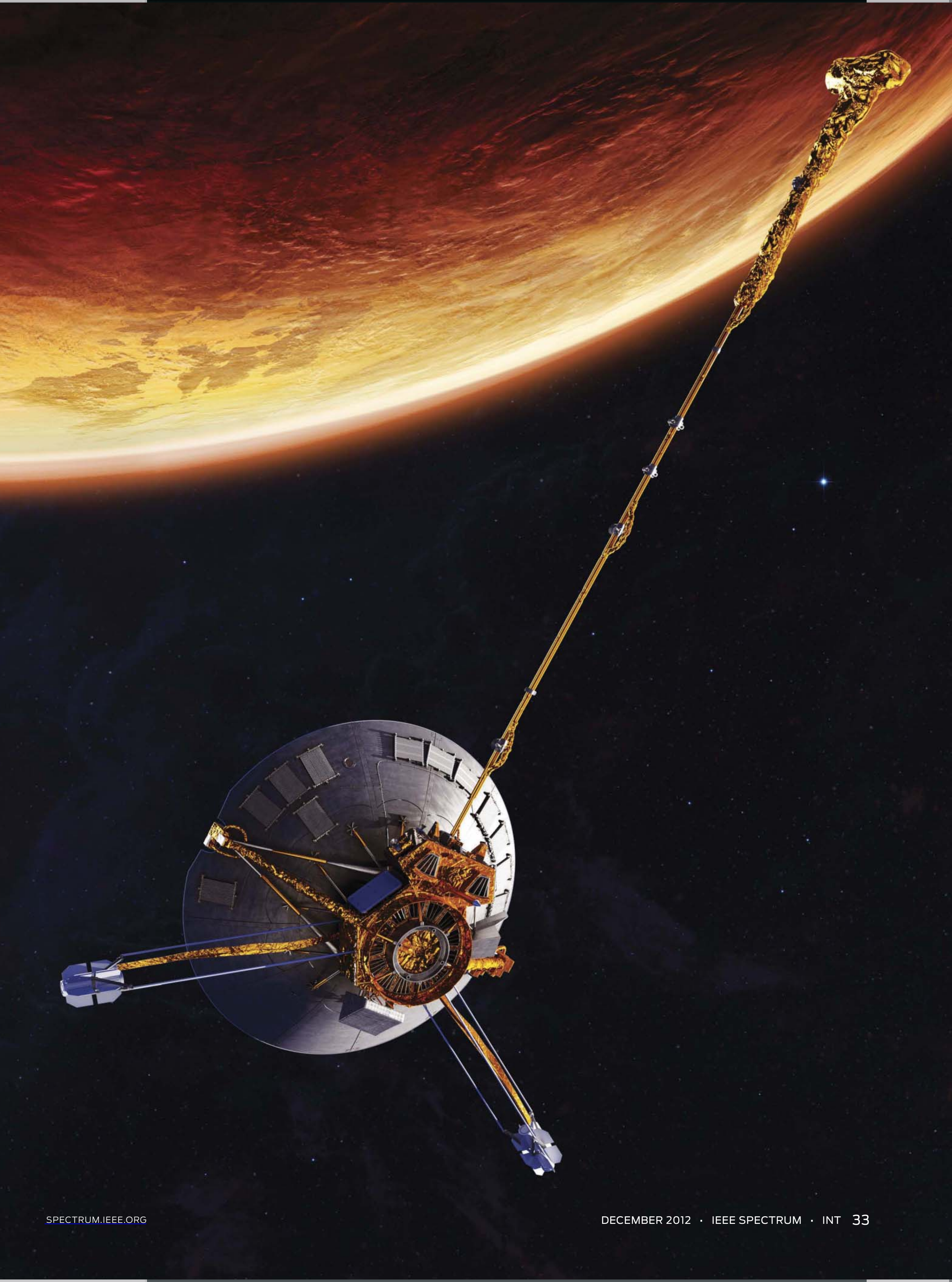


FINDING THE SOURCE OF THE

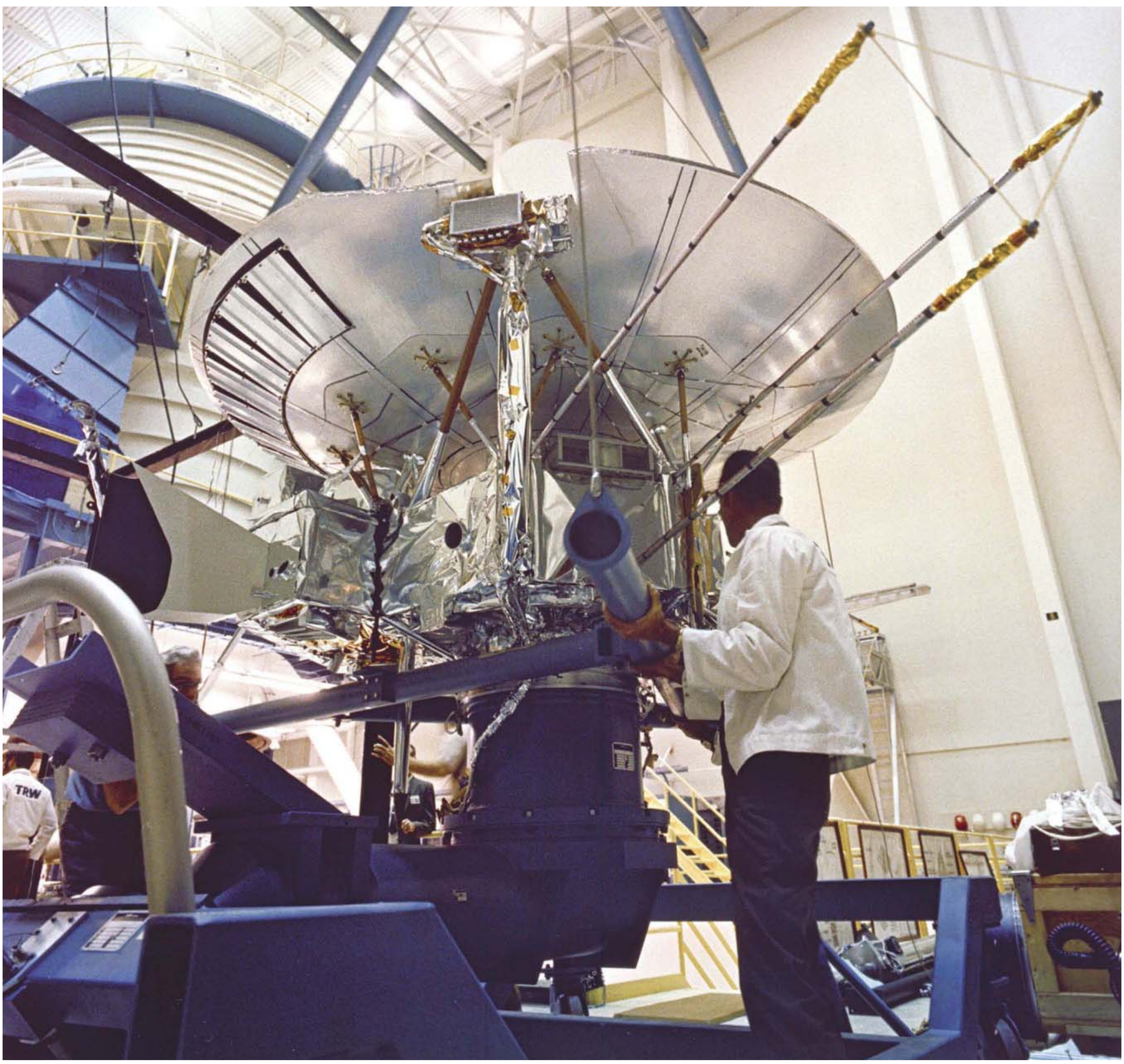
PIONEER ANOMALY

THIRTY YEARS AGO, THE FIRST SPACECRAFT SENT TO EXPLORE THE OUTER SOLAR SYSTEM STARTED SLOWING UNEXPECTEDLY. NOW WE FINALLY KNOW WHAT HAPPENED

BY VIKTOR T. TOTH & SLAVA G. TURYSHEV ILLUSTRATION BY NOEMOTION



SOME 40 YEARS AGO, A QUARTER-TON LUMP OF CIRCUITS AND SENSORS SLIPPED EARTH'S SURLY BONDS, SPED PAST THE MOON AND MARS, AND HURTLED TOWARD JUPITER. THE PROBE, PIONEER 10, AND ITS SISTER SHIP, PIONEER 11, WHICH FOLLOWED A YEAR LATER, WERE TRUE TRAILBLAZERS. THEY GAVE HUMANITY ITS FIRST CLOSE-UP GLIMPSES OF WORLDS BEYOND THE SOLAR SYSTEM'S ASTEROID BELT. THEY ALSO LEFT BEHIND A MYSTERY—ONE THAT HAS SIMULTANEOUSLY BAFFLED AND INSPIRED ASTROPHYSICISTS FOR YEARS.



Like many puzzles, this one started out with just a small hint that something was amiss. Not long after Pioneer 10 and 11 had passed beyond the orbits of Jupiter and Saturn, their navigators began to notice something unexpected. Both spacecraft seemed to be slowing down more than controllers had predicted they would, as if some force were tugging them ever so subtly backward toward the sun.

The magnitude of this deceleration was minuscule, just one ten-billionth of the gravitational acceleration that we experience on Earth's surface. Such a small effect didn't seem out of place at first. It would have shown up as a simple correction, the sort that spacecraft navigators routinely apply to accommodate fuel leaks and other small, transient deviations in spacecraft behavior. No one would have blinked an eye if it hadn't been for one troubling detail: For years, as the spacecraft sped deeper and deeper into space, that tiny discrepancy stuck around. And no one could figure out where it came from.

When the discovery of this strange anomaly was finally announced in 1998, more than 15 years after it was first detected, it didn't take long for potential explanations to emerge. Studies of distant stellar explosions had just shown that the universe is expanding at an accelerating rate. The magnitude of the Pioneers' deceleration was in just the right ballpark to suggest that we might be seeing a manifestation of this same expansion within our own solar system. But that was just one possibility. Some suspected the two spacecraft were being tugged by an unseen cloud of dark matter or else were exposing a breakdown in the laws of gravitation at large distances. Others thought the spacecraft might have unearthed the first evidence of extra dimensions or exotic "mirror matter."

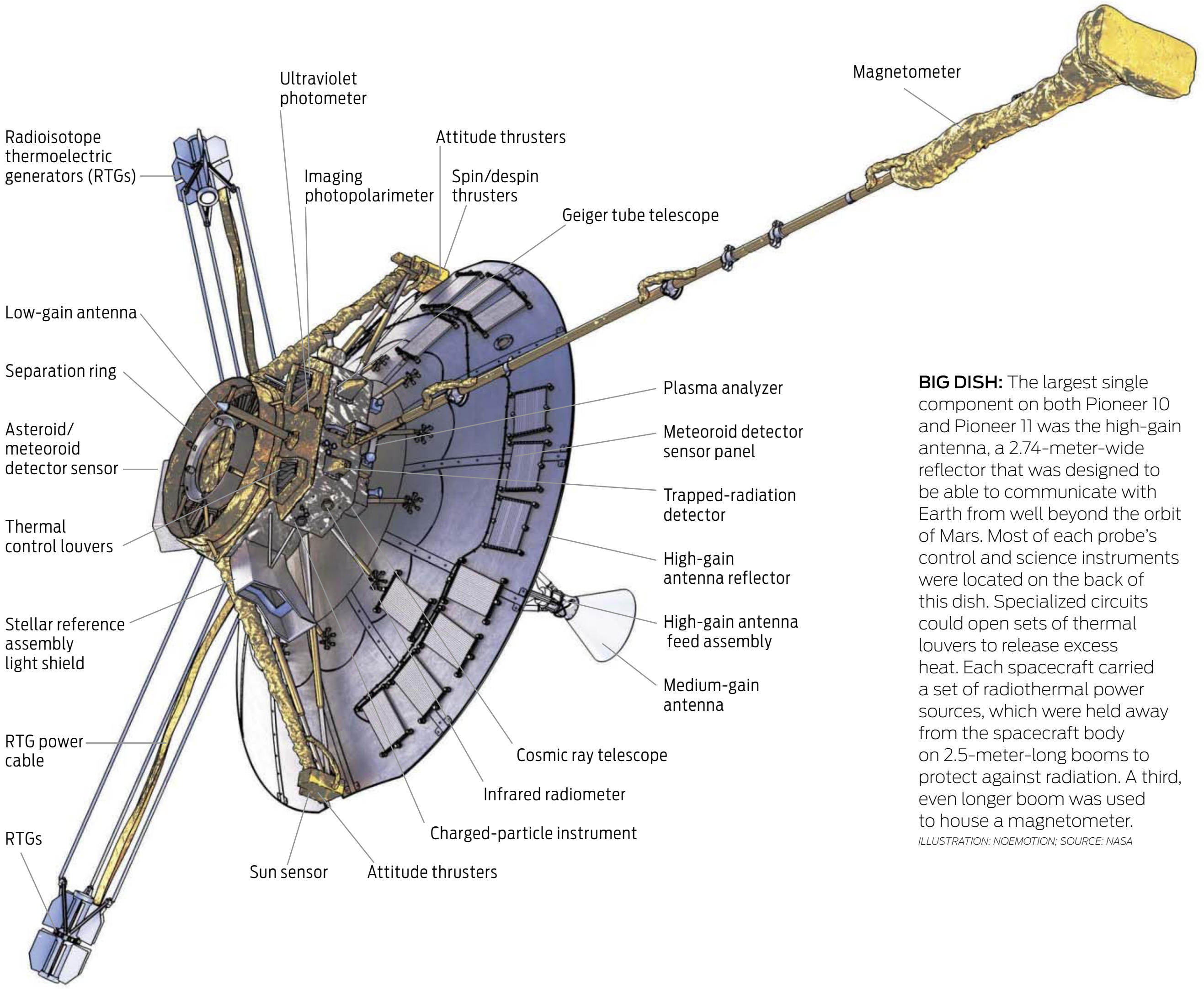
All told, hundreds of papers have been written that attempted to explain the Pioneer anomaly with new physics. But none of the proposed explanations has been entirely satisfactory, and there has always been the possibility that some more mundane mechanism—perhaps some aspect of the spacecraft themselves—was responsible. Now, after a dedicated search for lost spacecraft records, detailed study of onboard sensor and navigational data, and careful modeling of the spacecraft and their trajectories, we believe we finally know the answer. Our effort to identify the source of this anomaly is in part a detective story and part a cautionary tale about the importance of preserving seemingly uninteresting data.

WHEN IT COMES TO UNDERSTANDING the Pioneer anomaly, it helps to start more or less at the beginning. When Pioneer 10 and 11 were conceived in the mid-1960s, no spacecraft had yet been sent past the orbit of Mars. No one knew how risky it would be to cross the asteroid belt between Mars and Jupiter or how difficult it would be to withstand the zones of intense radiation that encircle the gas giant. But Pioneer 10 and 11's designers nevertheless reckoned they had what they needed to make these missions work.

Out by Jupiter, the intensity of sunlight is about 4 percent of what it is in Earth orbit, far too dim to power the solar panels of the day. So each spacecraft carried a set of four radioisotope thermoelectric generators (RTGs), positioned a safe distance away from the spacecraft's sensitive instruments on two long booms, a bit like a

BUILDING UP: Engineers put some of the finishing touches on Pioneer 10 at a TRW facility in Redondo Beach, Calif. [left]. The 258-kilogram spacecraft launched on 2 March 1972 from Cape Canaveral, Fla. [right], atop a three-stage launch vehicle, which accelerated the spacecraft to a speed of nearly 52 000 kilometers per hour, a record for the time. About 11 years later, Pioneer 10 became the first spacecraft to cross the orbit of Neptune, then the farthest planet from the sun.

PHOTOS: LEFT: AMES RESEARCH CENTER/NASA; RIGHT: NASA



BIG DISH: The largest single component on both Pioneer 10 and Pioneer 11 was the high-gain antenna, a 2.74-meter-wide reflector that was designed to be able to communicate with Earth from well beyond the orbit of Mars. Most of each probe's control and science instruments were located on the back of this dish. Specialized circuits could open sets of thermal louvers to release excess heat. Each spacecraft carried a set of radiothermal power sources, which were held away from the spacecraft body on 2.5-meter-long booms to protect against radiation. A third, even longer boom was used to house a magnetometer.
ILLUSTRATION: NOEMOTION; SOURCE: NASA

pair of rabbit ears. These generators converted heat from the radioactive decay of plutonium-238 pellets directly into electricity using bimetallic thermocouples. The RTGs were ultra-reliable: They contained no moving parts, and the 88-year half-life of the fuel meant the spacecraft would have adequate power for decades.

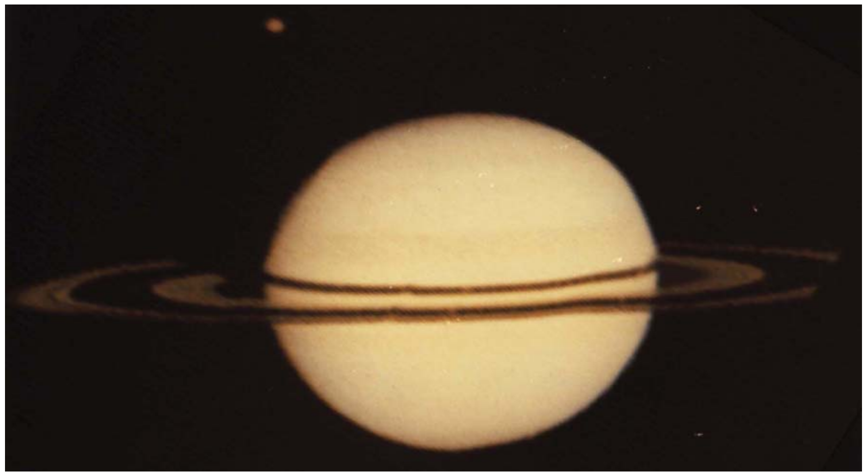
To communicate with Earth, each spacecraft was equipped with a 2.74-meter-wide parabolic antenna. It was decided early on that the probes would be stabilized by spinning them along the axis of their antennas. This kept each spacecraft's antenna pointed in a consistent direction, cutting down on the need for frequent attitude corrections. If an antenna were to fall out of alignment with Earth, incoming signals would hit the antenna off-axis. Special circuits would then pick up on the modulation of the signal that would arise as it wobbled back and forth across the antenna while the spacecraft rotated. These circuits would then fire hydrazine thrusters to correct the spacecraft's orientation.

Armed with this basic technology, Pioneer 10 and 11 set off where no man or probe had gone before, on trajectories that would eventually take them to nearly opposite ends of the solar system. After its launch on 2 March 1972, Pioneer 10 traversed the asteroid belt and swung past Jupiter in December 1973, its off-axis single-pixel photodetector spinning slowly to construct pictures of the giant planet. Pioneer 11, which launched on 6 April 1973, performed an even more ambitious mission: flying past Jupiter a year after Pioneer 10, and then using the gas giant's gravity to change course—performing one of the first of the now-common "slingshot maneuvers." The spacecraft flew beneath Saturn's rings some five years later.

The probes, of course, continued hurtling through space after their planetary flybys. As Earth receded into the distance, our planet's apparent motion around the sun diminished as well. Consequently, the thrusters needed to fire less and less often every year to adjust the orientation of Pioneer 10 and 11's homeward-directed antennas. That turned the spacecraft into largely ballistic objects, and as such, nearly ideal probes of the effect of external forces like gravity.

At this point, a group of researchers led by astronomer John D. Anderson at NASA's Jet Propulsion Laboratory (JPL) set out to use navigational data on these mostly passive probes to make high-precision measurements of the gravitational environment of the outer solar system. The team, which included one of us (Turyshev), was specifically looking for subtle changes in trajectory that might be caused by the tug of as-yet-undiscovered planets or else very-long-wavelength gravitational waves produced during the big bang. Neither signal turned up. Instead, the investigation uncovered something completely unexpected and far harder to interpret.

OUTER PLANETS: This image of Saturn and its moon Titan [right] was reconstructed from pixel-by-pixel measurements made by Pioneer 11 on Wednesday, 26 August 1979, when the spacecraft was nearly 3 million kilometers from the planet. The composite of Jupiter pictures [below right] was constructed from Pioneer 10 data and shows the growth in the apparent size of the giant planet as the spacecraft approached, and its receding crescent as the spacecraft passed behind it. *PHOTOS: AMES RESEARCH CENTER/NASA*

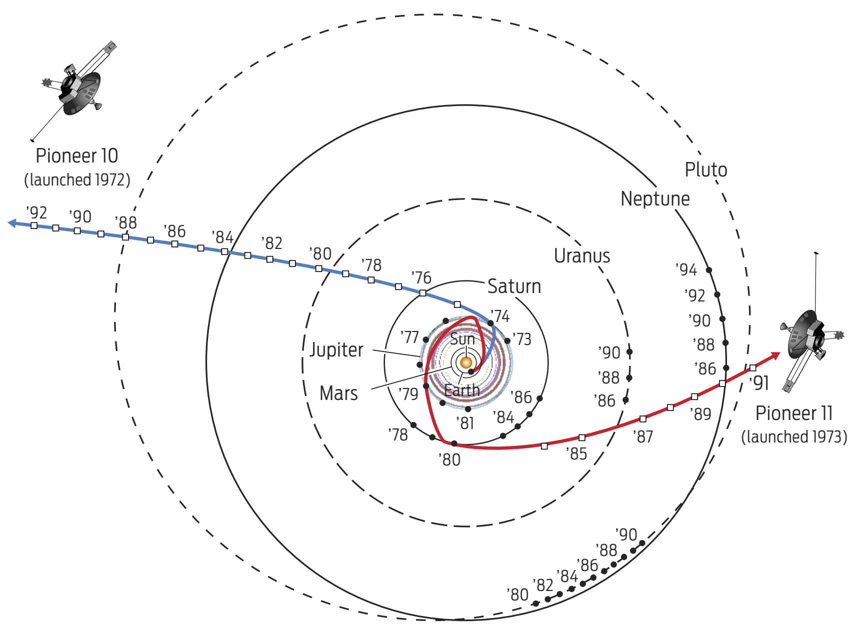


TO USE PIONEER 10 AND 11 as gravity probes, Anderson's team relied primarily on signals that were originally sent from Earth using NASA's Deep Space Network, a collection of large radio antennas located at three sites around the world. These antennas sent out a 2.11-gigahertz radio signal, which was received by the Pioneer spacecraft. The spacecraft, which did not have their own precision oscillators, used the frequency of the incoming beam to tune their return signals to 2.29 GHz.

The well-known Doppler effect (of passing-train fame) says that the received frequency of a radio signal changes if the source and the receiver are moving relative to each other. By measuring how far a Pioneer signal shifted from 2.29 GHz, ground operators could tell what the spacecraft's line-of-sight velocity was with respect to Earth. After that, it was all a matter of time and analysis. Repeated measurements of line-of-sight velocity over a sufficiently long arc of a spacecraft's trajectory could be used to constrain its path.

Of course, to tease out any unknown effects, the team had to think of everything that could alter the probes' motion or the frequency of the signals they sent. JPL navigators had to build a model that took into account, among other things, the gravitational influence of all known solar-system bodies, solar weather, solar radiation pressure, the influence of general relativity on the time of flight of signals, excess moisture in Earth's atmosphere above the transmitting or receiving station, and the precession of Earth's pole.

When these factors were fed into the model of each probe's trajectory, the team expected to see their received radio signals match within a few millihertz of predictions. But they didn't. Beginning in 1980, Anderson and his colleagues noticed a much more significant deviation—on the level of a few tens



IN FLIGHT: Pioneer 10 and 11 both made close flybys of Jupiter that resulted in dramatic changes to their trajectories. With Pioneer 11, navigators used the giant planet's gravity to deliberately "slingshot" the spacecraft so that it would fly past Saturn in 1979. As the probes continued on, their hyperbolic paths became straighter and straighter. *ILLUSTRATION: GEORGE RETSECK; SOURCE: NASA* of millihertz. It quickly became clear that the discrepancy was not just random noise.

The accuracy of the navigational model could be restored if a small, constant sunward force was presumed to be acting on the spacecraft. But the team had no ready explanation for such a force in the realm of known physics. When discovery of the anomaly was finally announced in the pages of *Physical Review Letters* in 1998, theoretical physicists quickly responded with proposals. But there were lingering doubts. It was still quite possible that some mundane physical explanation, such as leaky thrusters, might account for the force.

Thermal radiation was a leading candidate. The Pioneers' RTGs were very inefficient. The generators supplied roughly 100 watts (more at launch) of electricity to each probe's systems, but in doing so they radiated a good 2.5 kilowatts of heat into space. The slight deceleration experienced by the Pioneers could be explained away by a tiny asymmetry. If only 60 W more heat had radiated off the back of each probe, behind the antenna, conservation of momentum would cause them to recoil just enough in the other direction, toward Earth, to explain the anomaly.

To follow up, the JPL team spent the next several years preparing a comprehensive study. They processed more than 10 years' worth of Doppler measurements from Pioneer 10 and nearly four years of similar data from Pioneer 11. They compiled a thorough inventory of all possible sources of error and bias, including onboard heat. Ultimately, they produced a paper in 2002 that ran nearly 60 pages (one of the longest articles ever published in *Physical Review D*) addressing all these questions in detail.

The team concluded that thermal recoil was probably not responsible for the Pioneer anomaly, for two reasons. One, because the RTGs were extended from the body of each spacecraft on 2.5-meter-long booms, it didn't seem likely that there would be enough excess heat bouncing off the craft (the team estimated it was likely just one-tenth of what was needed to account for the effect). Two, the deceleration of both spacecraft seemed constant in magnitude, even decades into the mission. If the RTGs were responsible for the Pioneer anomaly, the team argued, the effect should have diminished in magnitude as the Pu-238 decayed and produced less power, and thus, less heat.

But nagging doubts remained. The issue of the thermal-recoil force was answered using relatively crude, back-of-the-envelope estimates. And while a constant push seemed to fit the anomaly very well, no one could really exclude the possibility that it was in reality diminishing over time.

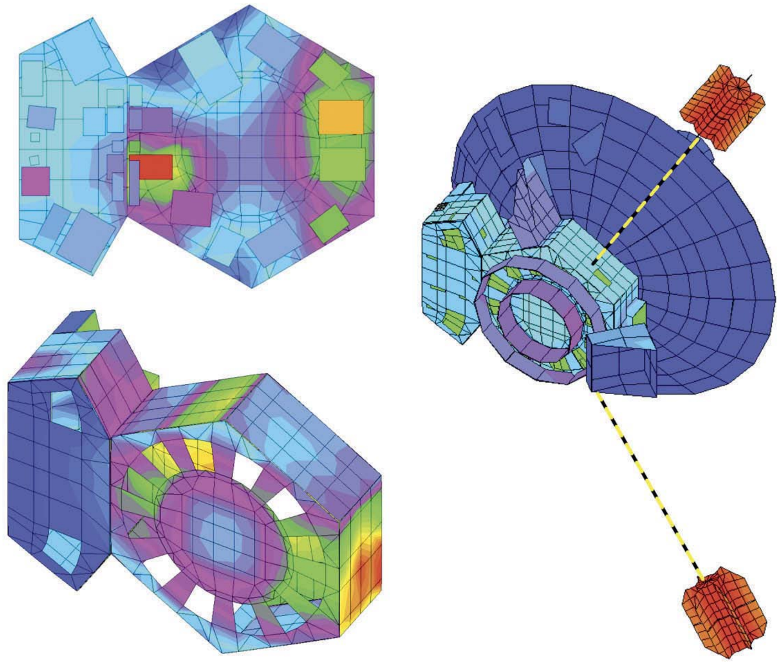
HOW COULD THESE QUESTIONS be answered? With more data and more analysis, of course. We hoped to establish as precisely as possible how much heat these spacecraft really were shedding unevenly and whether the resulting force could explain the peculiar trajectories. For that, we needed two key sets of information: the "housekeeping data" engineers had used to keep tabs on spacecraft operation and the Doppler data, as much as we could find.

As luck would have it, most of the Pioneer 10 and 11 telemetry data had been saved and were available for study. Although there was no requirement that NASA properly archive these records, it turned out that systems engineer Larry Kellogg, a contractor and former Pioneer team member at NASA Ames Research Center, had been informally preserving all the Pioneer data he could get his hands on. Kellogg already had nearly all of the two probes' master data records, binary data files that contained all the Pioneers' science and housekeeping data.

Kellogg had taken care to copy those records, which in total took up just 40 gigabytes of space, from soon-to-be obsolete magneto-optical discs to a laptop hard drive. When we decided to work with the telemetry data in earnest, in 2005, one of us (Toth) had already been in touch with Kellogg, working on new software that could extract useful information from the master data records without the need for an old, decommissioned mainframe.

Procuring additional Doppler data that could help solve the mystery turned out to be a bit trickier. The JPL team had already collected all the radio-science data files that were easy to find and work with, but we knew that we needed more measurements. It took some time, but we were able to find additional files on the hard drives of JPL navigators' computers and the archives of the National Space Science Data Center. We even found magnetic tapes stuffed in cardboard boxes under a staircase at JPL. Some of the files were in a rather sorry state, corrupted while they were converted from one storage format to another over the span of three decades.

To find these files and make them usable, we received financial support from the Planetary Society, a nonprofit space-advocacy organization. We are also grateful to physicist Craig



HOT SPOTS: To see how thermal radiation from the probes themselves may have contributed to small changes in their trajectories, detailed thermal models were constructed. These pictures show how heat was generated and distributed in the spacecraft interiors [cross-section on upper left] and around their exteriors [lower left]. A model of the entire spacecraft [right] shows that the Pioneer radioisotope thermoelectric generators were the greatest source of heat. The colors in the complete spacecraft illustration correspond to temperatures that ranged from −213 °C [blue] to 136 °C [red]. *ILLUSTRATION: NASA*

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BOXED SET: The data collected by navigators on the trajectories of Pioneer 10 and 11 were stored on magnetic tapes. A number ultimately wound up in cardboard boxes that were found in stacks beneath a staircase at NASA's Jet Propulsion Laboratory.
PHOTO: SLAVA G. TURYSHEV

Markwardt at NASA's Goddard Flight Space Center, who helped recover corrupted files and get all the Doppler data into usable condition. In the end, we were able to double the amount of available Doppler measurements, increasing the span of orbital data to 23 years for Pioneer 10 and to more than 10 years for Pioneer 11.

At JPL, veteran navigators Neil Mottinger and Jordan Ellis analyzed the expanded Doppler observations. As with the original orbital analysis, they had to take into account all the information we had on anything that might affect the transmissions. They had to consider Earth's spin, the locations of the receiving antennas, and both terrestrial and solar weather. They also had to factor in the changing communications strategies over the span of time—31 years for Pioneer 10 and 17 for Pioneer 11—during which the probes were capable of sending back signals that could be used for precision navigation. With their completed analysis in hand, we found that the Doppler data were still statistically consistent with a constant deceleration but that a value that decreased over time fitted the data even better.

IF THE EFFECT DIMINISHED slightly over time, we reasoned, maybe the heat generated by the RTGs, which would have slowly decayed, was responsible for the anomaly after all.

To find out, we enlisted the help of a team of engineers at JPL led by Gary Kinsella, who had plenty of experience modeling the thermal behavior of spacecraft, to construct a detailed thermal model of Pioneer 10 and 11. In the absence of computer-aided-design files, which didn't exist 40 years ago, Kinsella's team had to comb through old blueprints and consult with the retired TRW engineers who built the probes in order to reconstruct their 3-D structure.

The team's eventual geometric model divided the surface of each spacecraft into 3300 patches and incorporated documented thermal properties of the materials used to construct the probes. We used the model to show how heat flowed across and radiated off various parts, and with those results, we estimated the magnitude of the thermal recoil force at different times over the course of the Pioneer missions. After matching the model to the Pioneers' temperature and electrical readings, we found that the spacecraft did experience a sizable thermal recoil force, corresponding to an excess of about 60 W even after 20 years in deep space. The magnitude of the force was still tiny by Earth standards—about the same as the backward push your car experiences in reaction to the photons spit out by its high-beam headlights. The team found that a good half of the force came from heat from the RTGs, which bounced off the back of the spacecraft antenna. The other half came from electrical heat from circuitry in the heart of the spacecraft. Most of that heat was radiated through louvers at the back of the probes, which weren't as well insulated as the rest of their bodies, further contributing to the deceleration.

We also calculated the thermal recoil force on the spacecraft using just the Doppler data, by computing the force needed to match the probes' trajectories. When we compared this independent estimate with the one derived from the spacecraft model, we found that the two values matched within 20 percent. Once uncertainties are taken into account, there is no statistically significant difference. Three decades after its discovery, we can now say there is no exotic cause for the Pioneer anomaly: The puzzling deceleration was produced by the asymmetric radiation of waste heat created onboard the spacecraft.

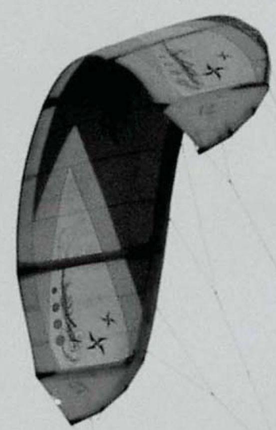
For some, this might seem like a disappointing conclusion to such a long-standing mystery, but accounting for the anomaly actually cements Pioneer 10 and 11's place in history. These spacecraft accomplished something that isn't likely to be repeated anytime soon: They completed a high-precision validation of Einstein's theory of how gravity works, out to twice the distance between Pluto and the sun. No other spacecraft launched since could have been used for such a test (or would show such a subtle anomaly); later spacecraft were too reliant on thrusters, weren't tracked continuously, or just didn't travel far enough. Pioneer 10 and 11 remain our most precisely navigated deep-space probes to date and will probably hold that distinction for many years to come.

These spacecraft also underscore the value of data preservation. In the early days of the Pioneer missions, scientists and engineers often viewed the medium as more valuable than the data it contained. Many considered raw data to be worthless once "useful" scientific and technical information had been extracted. Nowadays data storage may be cheap, but we're still in danger of suffering from shortsightedness when it comes to data custodianship. Every experiment needs a clear plan in place to ensure that a record of the original observations is still available and readable, even decades into the future. It may very well be the only way we'll resolve the next confounding mystery. ❑

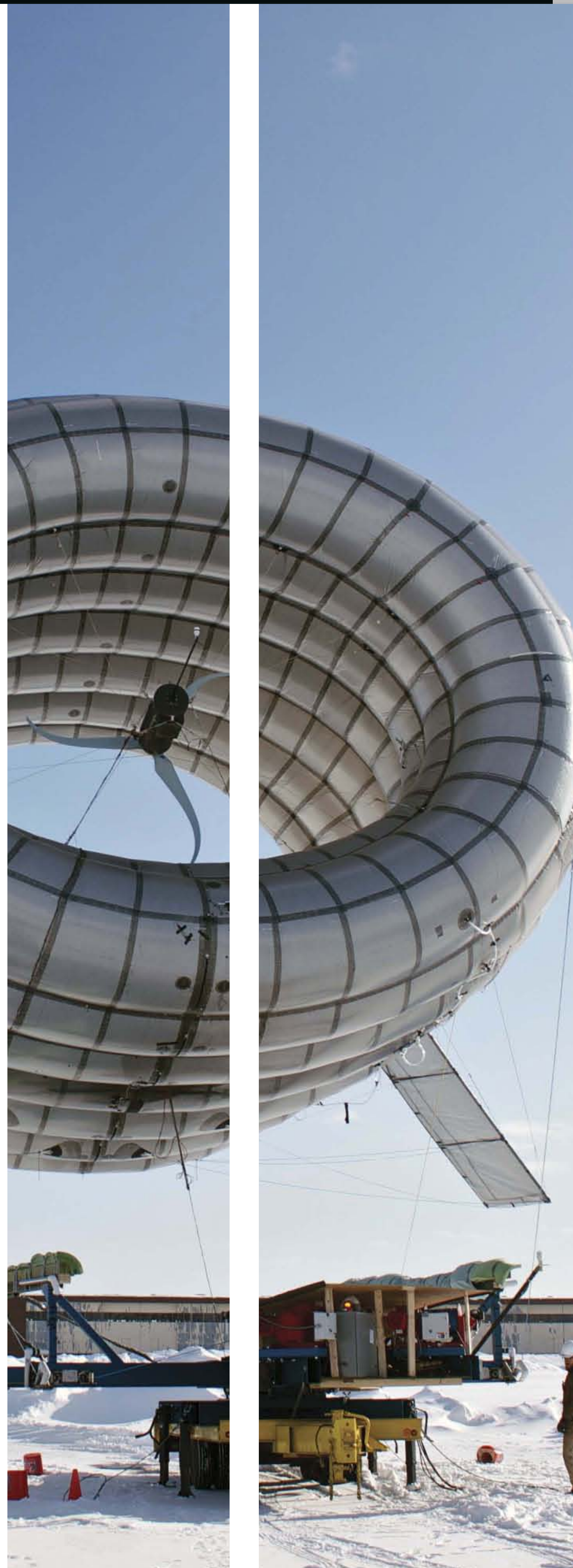
POST YOUR COMMENTS *online at* http://spectrum.ieee.org/pioneer1212

WIND ENERGY INDUSTRY:

Go Fly A



Kite



TOWER-MOUNTED WIND TURBINES DOT THE LANDSCAPE, BUT AIRBORNE SYSTEMS OFFER SOME SURPRISING ADVANTAGES

BY ROBERT CREIGHTON

Raising money to fund product development is never easy, as any tech entrepreneur will tell you. But I've had to grapple with a unique complication: My company, WindLift, is developing a kite-based system that generates electricity. The prototype, designed to put out 12 kilowatts, could save tons of money for some people now using diesel generators. But when I pitch the business to potential investors, it often seems as if all they can remember is their childhood struggles with those cheap stick-and-string fliers, making it impossible for them to envisage what my company aims to achieve.

The problem isn't so much that most people view kites as toys—it's that most people have no idea how sophisticated those toys have become! Take kiteboarding. Since the mid-1990s, a growing number of enthusiasts have been using large kites to enjoy an experience similar to that of waterskiing or skimming over the water on a wakeboard while being pulled by a motorboat. With kiteboarding, you dispense with the boat and are instead pulled across the waves by a good-size kite.

The kites designed for this sport measure up to 20 square meters, almost as big as a small billboard. With them, expert kiteboarders can really fly: In 2010, the world's speed-record holder, Rob Douglas, hit 103 kilometers per hour (64 miles per hour)—faster than the fastest sailboat. And skilled kiteboarders can leap 15 or more meters into the air and then glide back gently to the water's surface.

A kite capable of such feats isn't anything like the ones you played with as a kid—it's an ingeniously engineered airfoil. And by the way, it has high-tech tethers that are 15 times as strong as steel. A lot of research has gone into designing such kites and their rigging so that they can be turned on a dime with a gentle tug on the control lines. They can also be instantly adjusted to reduce the power they deliver, an important feature that allows a kiteboarder to negotiate strong, gusty winds safely.

Given these advances in kite engineering, it should come as little surprise that several companies are now trying to deploy this technology for something more than recreation. A few have attached large kites to cargo ships and motor yachts as a way to reduce their fuel consumption. My company is looking to use these airfoils to offset fuel use, too, but in a different setting—for electrical generators in remote locations where the diesel fuel to run them is a scarce commodity. Diesel in these places is so expensive that supplementing conventional generators with power produced from the wind makes good economic sense.

Mine is just one of several ongoing efforts to use kites to generate electrical power from the wind. Such airborne wind-energy systems offer many advantages over standard wind turbines, most notably that these tethered airfoils can tap the relatively strong and steady winds found higher up. In addition, the area the airfoil can sweep isn't limited by the diameter of the turbine, so these airborne systems are inherently more efficient. Finally, the massive pylon needed to support a very large rotating blade can be eliminated, slashing construction costs and setup times.

Of course, generating electricity with a kite has some challenges you don't have with a standard wind turbine. Turbines can't crash, for example. To avoid such mishaps, you must be able to control the kite so that it crisscrosses the sky in an orderly fashion, despite the vagaries of the wind. You also need to automate this piloting and to make the whole system robust and reliable. So far, nothing that meets all those requirements has emerged on the commercial market, and it will probably be several years at least before anything is available that does.

I view the present situation as being akin to the pioneering days of flight, where nobody knew what configuration of wings and control surfaces would serve best—or whether the whole enterprise would prove practical at all. But if the engineers now working on this technology are persistent and clever enough, using tethered wings to generate electricity from the wind will surely progress just as quickly as early aviation did.

As far back as the early 19th century, some kites were used as a power source—to propel buggies. But the first rigorous technical analysis of kites for generating electricity began in about 1980. Miles Loyd, a researcher at Lawrence Livermore National Laboratory, in California, investigated the physics of the problem, publishing his results in a journal article titled "Crosswind Kite Power."

Loyd showed that by flying a tethered wing back and forth across the wind, you could get considerably more power than you could from a kite that just hovered in one spot. According to Loyd's calculations, if you used a wing as big as the one on a Lockheed C-5A military transport (68 meters long), you could, at least in principle, extract a few megawatts from a 10-meter-per-second wind. That's comparable to what you might get from the biggest of modern wind turbines.

Loyd considered two ways to get electrical energy out of a tethered wing. One is to outfit the wing itself with propeller-like turbine blades that generate power as it zooms through the air. That power would then be sent down an electrically conductive tether. This is now known as the flying-generator, or "flygen," approach. The other technique he considered was to exploit the force that the wing exerts on its tether to generate electricity using equipment on the ground.

Loyd's analysis didn't examine yet another possibility: to generate electricity using turbine blades that serve as both lifting surfaces and energy-harvesting devices. That's the technique Australian engineer Bryan Roberts began experimenting with in 1979—something he calls a gyromill, which he continues to work on with California-based Sky Windpower.

Beginning in the 1990s, other groups around the world also began devising various ways to generate electricity with

PREVIOUS PAGES, FROM LEFT: MAKANI POWER; ALTAEROS ENERGIES; DAVID SCHNEIDER; ALTAEROS ENERGIES kites. But most of their plans involved ambitiously large systems that never materialized despite the many patents filed for them. Perhaps the most influential of these early innovators was Wubbo Ockels, the first Dutch astronaut, who proposed the multikite Laddermill in 1993. Although the Laddermill was never built, Ockels, now a professor of aerospace engineering, has created a well-regarded research and development program in airborne power generation at the Delft University of Technology, in the Netherlands.

Stephan Wrage, one of the founders of Hamburg-based SkySails, is another leading figure in this field, having raised more than US $70 million to develop kites for ship propulsion. The list of people and companies working on airborne wind energy goes on, with many attractive ideas still incubating [see table, "Watts Flying"].

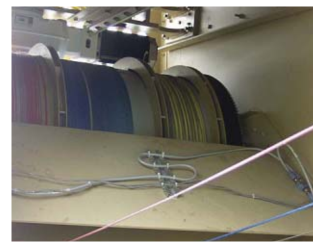
I began thinking about using kites to generate electrical power in 2005. I had just returned from a trip to Honduras, where there is a dire need for affordable power in areas not connected to the grid. Many of the people I met in the country's rural districts relied on diesel generators, but fuel costs limited how often they could run them.

This same problem continues to hold back much of the developing world. Even mobile telephony in such places often depends on running diesel generators constantly, inflating the cost of wireless service. Indeed, the London-based GSM Association estimates that mobile-phone providers spend about $15 billion a year worldwide on diesel fuel for remote base stations.

The scarcity of diesel is also a big issue in war zones, where delivering fuel to mobile generators can cost close to $4 for each kilowatt-hour of electricity generated—tens of times the price

FIELD TESTS: WindLift tests parts of its prototype system, including the airborne telemetry [left], a leading-edge-inflatable kite [two center photos], and a tether-wrapped drum [right].
PHOTOS: DAVID SCHNEIDER (4)

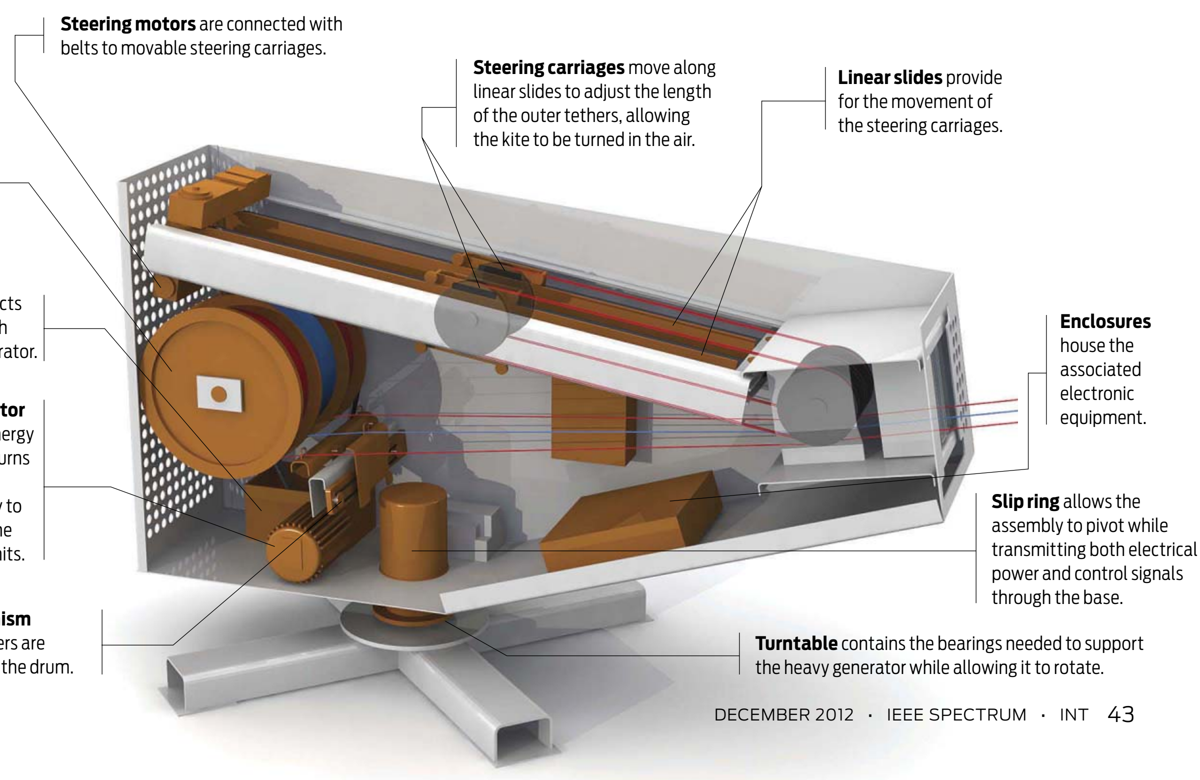


Kite-Power Machine

A look into the inner workings of WindLift's prototype

The author's company, WindLift, built an airborne wind-energy system for engineering tests. It uses a leading-edge-inflatable kite and a ground-based generator, the main components of which are shown here.



JOHN MacNEILL

LIGHT AIRS: The author holds one of the off-the-shelf kiteboarding kites used to test the WindLift generator, waiting for the wind to pick up enough for a good launch.
PHOTO: DAVID SCHNEIDER

that grid-connected consumers typically pay. So if kite power could offset even a fraction of that fuel consumption, there would be considerable savings for the military, both in money and in lives lost protecting resupply lines.

I began exploring ways to use kites to supplement diesel-powered generators while I was a first-year MBA student at the University of Wisconsin–Madison. My initial concepts ran the gamut. Totally ignorant of the earlier efforts in this sphere, I had naive ideas about what would work. Nevertheless, I founded WindLift and began looking for funding for research and development.

My first meeting with a venture capitalist brought in no money, but I got some good advice: He said I should investigate kiteboarding—a sport he had discovered while vacationing in Hawaii. After a quick Internet search, a world of expertise in harnessing the energy of big kites opened up to me. And to be sure I learned all the lessons it had to offer, I took up the sport myself.

The people constructing kites for kiteboarding have roughly the same goals as those designing kite-energy machines—to create maximum tension in the lines, which is why WindLift has been able to use off-the-shelf kiteboarding kites to test its prototype systems, the first of which I built mostly myself. In 2008, I moved my fledgling company from Wisconsin to North Carolina to take advantage of the excellent coastal winds and longer testing season there—the same reasons the Wright brothers went to North Carolina's Kitty Hawk in 1900. Alas, the state's coasts have been highly developed since then, and the lonely dunes over which the Wrights flew are now trampled by millions of tourists each year. So WindLift's engineers and I conduct test flights in open fields several kilometers inland.

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Our current system uses a 90-centimeter-diameter drum, which is connected to a 60-kW motor-generator built originally for a hybrid electric bus. Tension from the kite pulls the tether and turns the drum, thus generating electricity, which is stored in a bank of lead-acid batteries. Control lines attached to the wing are then adjusted to "depower" the kite, reducing the amount of lift it produces. During this phase of the cycle, electricity is fed back into the motor-generator, rotating the drum in the other direction and reeling in the kite.

We constructed our initial prototypes using ram-air wings, which are similar to those found on modern parachutes. We soon realized, though, that some internal structure was needed to stabilize flight during the retract cycle. That's when you want the lift provided by the wing to drop to zero—or even better, to become negative, meaning that the air pushes it downward.

Ram-air wings can't be depowered much without them completely folding up. So we switched to a leading-edge inflatable (LEI) kite, which has a long, slender air bladder at the front of the wing to help it hold its form. Even so, these wings may prove too flexible to execute a reliable retract cycle. We're working now to find ways to reinforce them without making them so stiff that they (or the things they hit) sustain damage on hard landings. If we're not successful, the need to be able to reel in the kite without expending much energy may ultimately force us to adopt completely rigid wings.

So far, we've built two ground stations and have been testing them with LEI kites normally used for kiteboarding. Those wings cannot, however, generate the huge amount of tension we configured our system for. That will soon come from new wings of our own design, which we expect to begin flying next year. In the meantime, with only standard kiteboarding kites attached, our system cannot generate much power. But our experiments with them have allowed us to compare field measurements with our numerical models and also to work on telemetry electronics and automated flight controls.

We're not the only ones getting ready to test the winds. Among our competitors, the most advanced are using rigid wings rather than ones made of fabric. These designs tend to be more expensive, and the wings are prone to damage when they strike the ground. But those rigid airfoils are far more aerodynamic than any fabric wing, allowing them to extract more power from the wind.

Makani Power of Alameda, Calif., is one of the leading companies taking this approach. With $15 million in seed money from Google and a $3 million grant from the U.S. Advanced Research Projects Agency's ARPA-E program, along with other private investment, Makani has built large carbon-composite wings, each outfitted with four propeller-equipped motor-generators. Acting as motors, they provide thrust to launch the wing into the air. After it's in the air, the wing turns to fly across the wind, and the resulting lifting force soon propels the wing forward without assistance. Once the forward thrust from the wind is sufficient to balance the drag from the propellers, now acting as wind-turbine blades, the motor-generators can begin generating electricity. The high velocity of the wing means that Makani's machines don't need gearboxes, which reduces weight and maintenance costs.

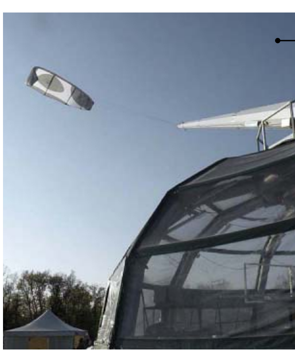
Earlier this year, Makani demonstrated automated flight control of a prototype system rated for 30 kW. The company's engineers have asserted that its power output in different wind conditions matches their expectations, which suggests that Makani will soon have a system that can reliably produce power in the field—a first for any airborne-wind-energy company.

Engineers at Makani hope ultimately to deploy their systems offshore and feed the energy captured into the grid. I suspect that their rigid-wing flygen approach will make economic sense only for larger machines, say, those of 50-kW to 5-MW capacity. But regardless, I admire Makani's impressive technical achievements, which are bringing airborne wind energy that much closer to commercial reality.

If getting power out of a kite still seems, well, blue-sky to you, consider that utility-scale wind turbines also seemed far-fetched 25 years ago. And the world now has more than 238 gigawatts of installed capacity from wind turbines, up by a factor of 10 in just one decade. It's true that those turbines satisfy only a small portion of the world's electricity needs. But that fraction is on the rise, and adding airborne wind energy to the mix should allow it to grow that much faster, further diminishing reliance on fossil fuels.

Success will take considerable inventiveness and a lot more experimentation by all of the groups involved. But the pioneers of aviation experienced exactly the same sorts of challenges and battled similar skepticism, and yet they overcame the obstacles. Now we reap the rewards, getting on planes without reflecting on the many individual technologies that make air travel so safe and routine. The same will happen with airborne wind energy. Future generations will benefit from it without giving much thought to all the failed experiments and countless technical wrinkles that had to be ironed out before this industry could get itself off the ground. ❑

The author wishes to express his condolences to the family, friends, and colleagues of the late Corwin Hardham, the chief executive officer of Makani Power, who died unexpectedly at age 38 just before this article went to press.



FROM TOP: ENERKITE; KITEGEN RESEARCH; SKYSAILS POWER

Watts Flying

COMPANY	COUNTRY	GENERATOR	FLYER
ALTAEROS ENERGIES http://www.altaerosenergies.com	United States	Airborne	Lighter-than-air turbine
AMPYX POWER http://www.ampyxpower.com	Netherlands	Ground-based	Rigid-wing "glider"
ENERKITE http://www.enerkite.com	Germany	Ground-based	Flexible wing
KITEGEN RESEARCH http://www.kitegen.com	Italy	Ground-based	Flexible wing
KITENERGY http://www.kitenergy.net	Italy	Ground-based	Flexible wing
MAGENN POWER http://www.magenn.com	Canada	Airborne	Lighter-than-air turbine
MAKANI POWER http://www.makanipower.com	United States	Airborne	Rigid wing
SKY WINDPOWER http://www.skywindpower.com	United States	Airborne	Multiple sets of rotating blades
SKYSAILS POWER http://www.skysails.com	Germany	Ground-based	Flexible wing
WINDLIFT http://www.windlift.com	United States	Ground-based	Flexible wing

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THE BROADCAST EMPIRE STRIKES BACK

NEW DIGITAL TECHNOLOGIES COULD PUT OVER-THE-AIR TV BACK IN VOGUE

BY LYNN CLAUDY

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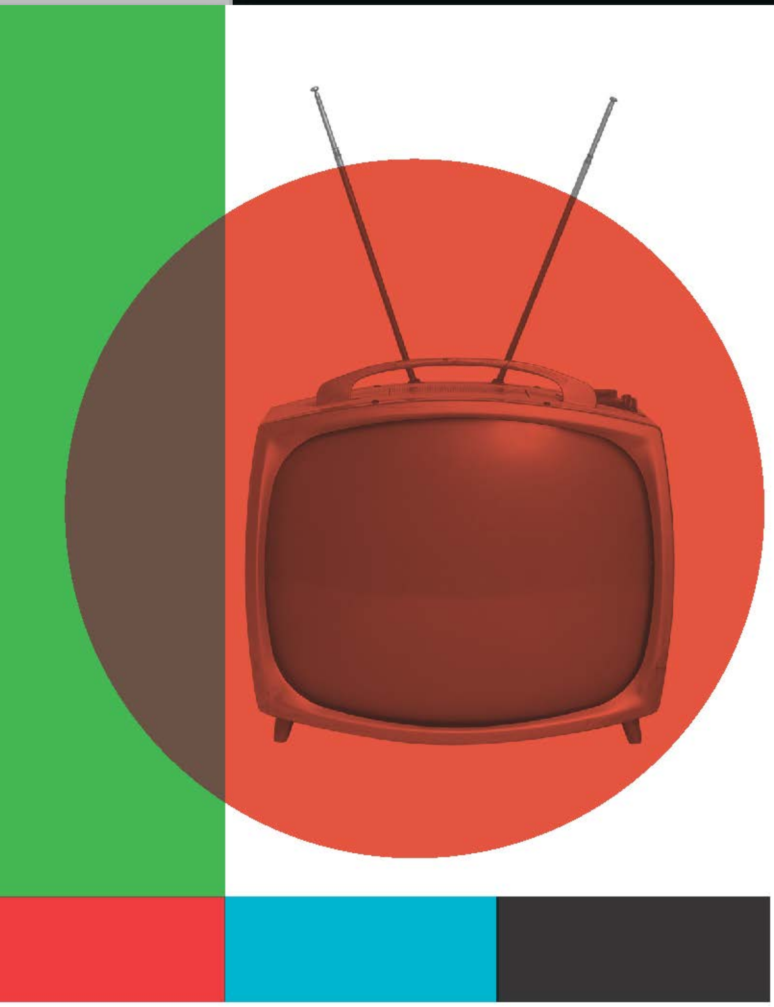

Like most who grew up in the middle of the 20th century, I have fond memories of my family crowded around a snowy, rabbit-eared tube to watch *Bonanza* and *The Ed Sullivan Show* on weekend nights. Back then, broadcast television was king. It was all we had, and we were crazy about it.

By 1960, televisions had found a place in more than three-fourths of homes across the United States. This was just 35 years after Scottish inventor John Logie Baird transmitted the first picture broadcast ever—the moving image of a ventriloquist's dummy—from his laboratory to a room next door. Throughout the 1970s, '80s, and '90s, the average viewer was watching about 3 hours of programming a day, most of it sent on airwaves.

Today, time spent watching TV is at an all-time high. But the 21st century has brought dramatic and permanent changes to the television landscape. And no other entertainment industry has been as deeply affected as broadcasting.

Although broadcast signals still reach almost every American home, fewer than 20 percent depend on them for entertainment. More households now have Internet connections and mobile phones than own HDTV sets. And most of us who do watch television aren't satisfied with only the scheduled programs we get over the air. So we buy subscriptions to cable or satellite services, stream movies online, play Blu-ray discs, download games on tablets and smartphones, browse videos on YouTube, share them on Facebook, and talk about them on Twitter.

As the modern media cornucopia grows ever more bountiful, some people have inevitably begun to ask: Do we really need—or even want—broadcasting anymore?

It's an increasingly urgent question. After all, thousands of broadcast stations worldwide collectively own the rights to vast and immensely valuable swaths of radio spectrum. As demand for mobile data skyrockets and interest in broadcast television merely plateaus, telecom companies have been arguing that they can put that spectrum to better use. They have been pressuring government regulators for years to reclaim some broadcast channels and auction off the corresponding spectrum.

The biggest such reallocation happened in the United States in 2009, when the switch to all-digital broadcasting freed up 18 television channels—about one-fourth of the frequencies previously occupied by broadcasters. But mobile operators are still hungry for spectrum, and the broadcast industry is again vulnerable. The United States' spectrum regulatory agency, the Federal Communications Commission, is now making plans for a new strategy to wrest more spectrum from broadcasters' hands. Through so-called incentive auctions, TV stations could choose to shut down, move to lower, less desirable frequencies, or share channels in exchange for some of the money the U.S. government makes from selling the rights to the spectrum they give up. If the process succeeds, countries in Europe and other spectrum-challenged regions may follow suit.

Television broadcasting will likely never again be the unrivaled entertainment giant it once was. But the technology isn't poised for obsolescence, nor should it be. In many ways that we may have forgotten or simply now take for granted, broadcasting offers an attractive—even preferable—service. For one thing, it is the most direct, most reliable way to get information to massive numbers of people at once, whether that information is a hurricane update or the Olympic Games opening ceremony. Broadcast signals also have a broader reach than cable, broadband, or mobile. And best of all, after you've bought a television set and an antenna, basic programming is *free*.

To stay in the game, however, broadcast technology desperately needs an upgrade. Most broadcasters still use the same digital transmission standards first introduced in the 1990s, when watching television was still something people mostly did at a designated place and time. Meanwhile, consumer preferences have evolved: We want our news and entertainment to be versatile and available anytime, anywhere.

Happily, broadcast engineers are now completing a new generation of digital tools that could turn the industry on its head. Imagine watching the World Cup while sharing statistics on your favorite players in real time. Or traveling from Toronto to Mexico City and immediately picking up local news stations for free on your smartphone. To offer such features, broadcasters will have to adopt new standards, and there's no time like the present. Only new standards can make television cheaper, more dependable, more dazzling, more interactive, and more personalized than it's ever been.

Broadcast TV could be cool again.

Change has never come easily for television broadcasters. Compared with other big tech-based industries such as computing and cellular telephony, broadcasting has adopted new technologies at a notoriously snail-like pace. This is no fault of its engineers or its executives but rather an effect of the highly regulated environment in which broadcasters must operate.

In most parts of the world, radio spectrum is considered a public resource. Like aquifers and forests, this limited resource

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is regulated by government agencies to ensure that it is used in people's best interest. In the early days of radio telecommunications, for example, the U.S. government made a deal with broadcasters: We will let you use some of our spectrum for free, and in return, you must meet certain "public service" obligations.

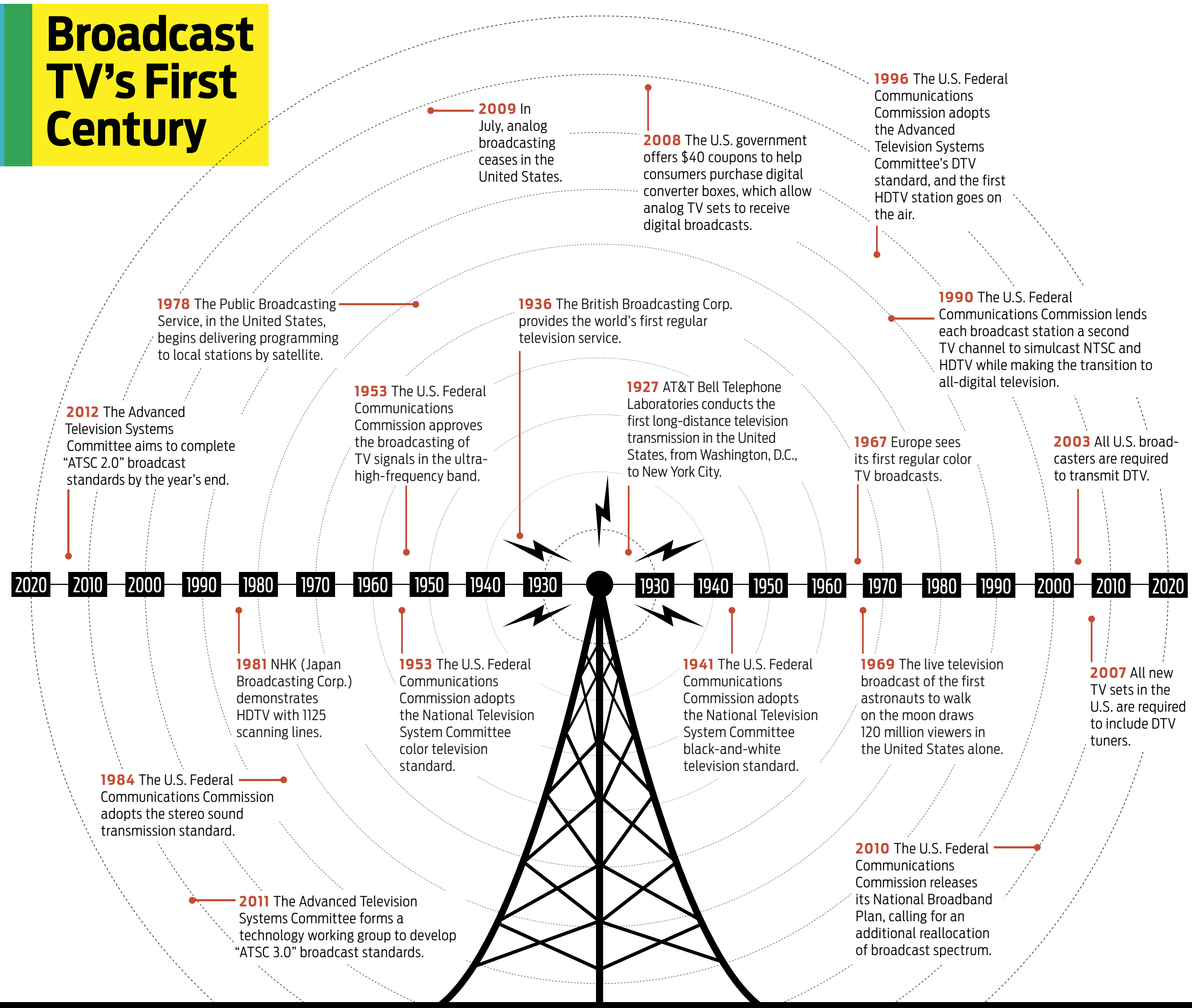
Among the traditional rules, which also include requirements such as censoring profanity and airing at least one program free of charge to all viewers, broadcasters must adhere to a single technical transmission standard. By making all broadcast stations use the same agreed-upon protocols for sending and receiving signals, regulators can assure anyone who buys a TV that it will work anywhere in the country, receive all channels, and won't be obsolete anytime soon. The downside, of course, is that consensus takes time. Consequently, when innovations—color pictures, digital video, and now mobile and online services—grab consumers' attention, the broadcast industry is slow to standardize and adopt them.

For example, the transition from an analog to digital broadcasting standard in the United States took 22 years. The challenge wasn't just selecting and perfecting a single standard from among the more than 20 possible systems proposed in the late 1980s. That took nine years. The longer delay came about because old analog receivers weren't compatible with the new digital transmissions. So for more than a decade, until 2009, broadcasters transmitted both analog and digital signals on separate radio-frequency (RF) channels, waiting for "the last granny" to replace her television set or buy a digital-to-analog converter.

The next evolution of broadcasting technology needs to happen much more quickly, and indeed it is already under way. Many standards groups around the world are developing new technologies that build upon today's basic digital standards. These additions will make digital broadcasting more versatile without totally overhauling it. Old receivers and tuners will continue to read transmissions as they normally would. But broadcasters will also be able to add new features and services aimed at such modern appliances as smartphones and smart TVs.

The Advanced Television Systems Committee (ATSC) in the United States is heading one of the most ambitious initia-

Broadcast TV's First Century



tives. Following similar actions by groups in Asia and Europe, it released in 2009 an enhanced version of its original Digital Television (DTV) standard that permitted the transmission of broadcast-TV signals to moving receivers. Known as Mobile DTV, or MDTV, the technology is just now starting to take hold in the United States, enabling broadcast stations to deliver programming to some cellphones, laptops, and tablets and to television screens in cars, trains, and buses. But that's just the beginning of the next tech-driven shake-up of broadcast TV.

Beyond MDTV, the ATSC is developing further enhancements to DTV, collectively called ATSC 2.0. The new standards will bring to broadcasting all the features modern media consumers have come to expect from their TVs, tablets, and pocketable media players—and maybe even some features they don't yet know they want.

Among other perks, ATSC 2.0 will enable newer receivers to store programs, clips, and movies locally for playback on demand. It will also let viewers subscribe to additional free or paid broadcast channels and personalize the look of their displays as well as the programs and advertising they receive. And there's at least one potential game changer: ATSC 2.0 will take advantage of Internet-connected TVs by enabling broadcasters to integrate online content, such as voting platforms or social networking services, into shows delivered over the air. For instance, viewers could pick, in real time, the winners of contestant game shows, such as "Dancing With the Stars." Or, while watching a broadcast news program, they could read relevant hyperlocal updates on their TV screens, tablets, or phones.

To understand how ATSC 2.0 will make these features possible, you need to first understand the existing DTV standard.

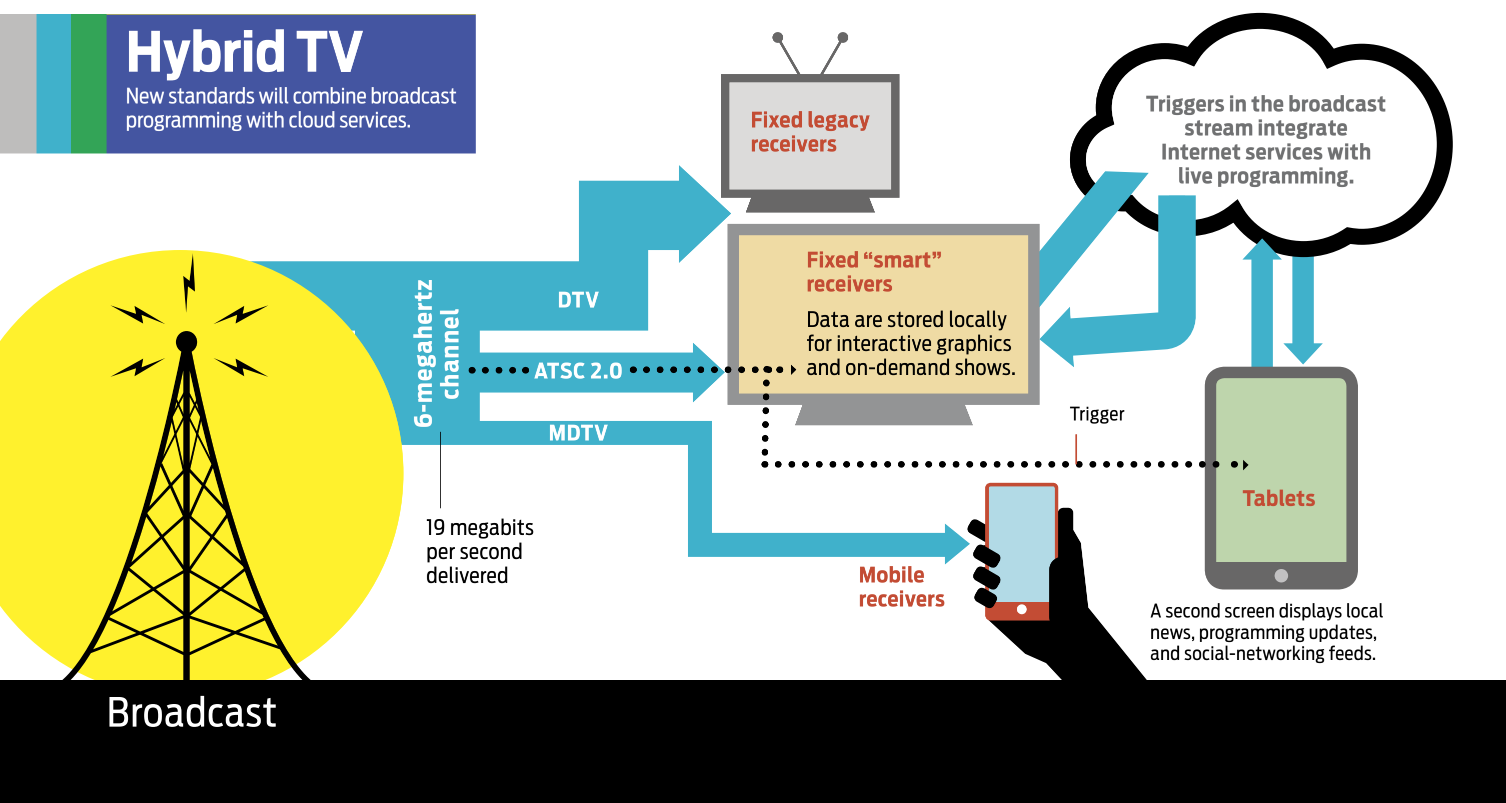
When the ATSC completed the standard in 1995, most mobile phones still had tiny text-only screens and long antennas, and they weighed about as much as a full soft-drink can. The idea of watching television on such a gadget seemed as likely as surfing the Web on a personal computer that fit in your pocket. So the ATSC focused on maximizing benefits for large, stationary screens, which typically experience far less signal distortion and variability than a moving receiver. DTV therefore prioritizes high definition quality over robust signal-repairing schemes.

A DTV signal has a bandwidth of 6 megahertz and is capable of delivering slightly more than 19 megabits per second. Raw high definition video streams at about one gigabit per second, which means that before a high definition program is broadcast, its data must be compressed at a ratio of at least 50 to 1.

After compression, more algorithms at the broadcaster's transmission facility bundle video, audio, and ancillary data (such as closed captioning and program ratings) into packets. Processing equipment at the transmitter then multiplexes the separate packets into a single stream, randomizes them, interleaves them by time, and applies error-correcting codes.

Adding error-correcting bits to the data stream helps assure good television reception. Broadcast signals are disturbed in all sorts of ways: Rain and foliage weaken them, atmospheric conditions distort them, and buildings reflect them, producing multiple delayed copies of the original signal. The resulting damage and interference make it difficult for a receiver to reconstruct the original data stream, causing a disrupted or frozen picture. Error correction increases the chances of recovering the corrupted data.

However, in order to deliver a good picture consistently, even to a stationary receiver, error correction alone isn't sufficient. After the packet stream is error-corrected but before it's broadcast, training sequences are added at distinct intervals. A training sequence is a short segment of pseudorandom data that a receiver already knows. By comparing this known sequence with the received signal, the receiver can estimate changing RF channel conditions and tune its algorithms to best correct for signal impairments, such as multipath, scattering, and power decay.



At this point, the broadcast is nearly ready for transmission. Finally, the digital bit stream is encoded in the RF waveform that will carry the broadcast through the air. The ATSC's DTV system accomplishes the encoding through a modulation scheme known as 8-level vestigial sideband, or 8-VSB. This method maps the binary data onto the waveform by varying its amplitude among eight different levels.

It's worth noting that 8-VSB works very differently from modulation methods employed by other dominant digital television standards, including China's Digital Terrestrial Multimedia Broadcast (DTMB) standard, Japan's Integrated Services Digital Broadcast (ISDB) standard, and the Digital Video Broadcasting (DVB) standard, which was pioneered in Europe. These standards use variations of a modulating technique called orthogonal frequency-division multiplexing (OFDM), which divvies up the bit stream among several thousand carrier waves at different, closely spaced frequencies, each supporting a low data rate. The multiple small-bandwidth carriers are more resistant to signal deterioration—a characteristic that makes OFDM well-suited to mobile television.

But 8-VSB, which uses a single wideband carrier, has the advantage of being able to carry more data. Remember, the ATSC optimized this system to deliver high data rates to fixed receivers. Now, advanced standards such as MDTV and ATSC 2.0 will add to that capacity many more desirable capabilities.

Perhaps the biggest technical challenge to enhancing a digital standard is working within a limited amount of spectrum. The enhanced features—mobile reception, on-demand shows, the integration of online content—require that broadcasters send more data than in a standard DTV-only transmission. Without the possibility of acquiring more spectrum, stations must send the augmented signals in-band—that is, within the RF channel they already use.

Part of the solution is better data-compression algorithms, which reduce the number of bits needed to send the main program. Broadcasters can then use the freed bit capacity to stow additional information in a broadcast signal. Newer receivers will be able to detect and exploit the supplementary data, while older ones will simply ignore those streams they don't understand.

With mobile broadcast TV, the main challenge is overcoming poor reception conditions. In addition to typical disturbances, a signal traveling to a moving receiver is subject to Doppler shift and a constantly changing radio environment, which worsen degradation. The ATSC's MDTV standard solves this problem by using more robust error-correcting codes. It also calls for additional, more closely spaced training sequences—those known data segments that help a receiver adapt to changing RF channel conditions. The extra, longer sequences fine-tune the signal repair process, ensuring a clear picture.

The keystone feature of ATSC 2.0 is its ability to support broadcaster-initiated interactivity between real-time programming and data saved locally at the receiver or retrieved online. The combined broadcast-broadband experience is the broadcasters' ticket to staying competitive in today's connected world. It can be as simple as a one-click product purchase or as stunning as a virtual tour of the winning race car in the Indianapolis 500.

According to the ATSC 2.0 protocol, broadcasters would create these elements by sticking many small bit sequences, called triggers, in the broadcast data stream. A trigger can do several things. For instance, it can announce the availability of interactive content, tell where that content is located locally or online, and signal when it should appear. A trigger can also mobilize more complex application-like objects, which are delivered in a broadcast stream or downloaded from the Internet. These scripted objects act like very simple computer programs in that they control the timing, display, and fetching of various data to produce a personalized, interactive scene.

Advanced digital standards like ATSC 2.0 may be just the key to revitalizing the broadcast industry within the next decade. But technology, like the modern television viewer, never sits still for long. To provide really transformative services in the future, broadcasters will need to completely overhaul digital systems. As receivers get smarter, display sizes grow and shrink, and techniques for packaging, labeling, and modulating data advance, existing digital standards won't be able to sufficiently support them. In anticipation, the ATSC and other standards organizations have already begun work on third-generation standards, which, unlike MDTV and ATSC 2.0, won't be compatible with today's receivers.

Big challenges lie ahead, not just for engineers but also for lawyers, lobbyists, regulators, and policymakers. At the moment, the pitch for a radical change in broadcast standards raises questions we can't yet answer. Perhaps most formidable is how broadcasters will plan the transition from an old standard to a new one without frustrating customers still using legacy systems. Simultaneous broadcasts using both old and new technologies may not be feasible, because broadcasters in the future will likely have even less wiggle room on the radio spectrum than they do today.

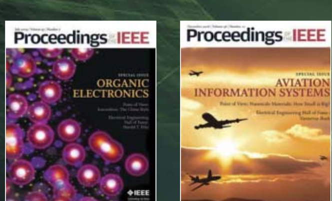
Despite the hurdles, work toward a totally fresh, ultramodern standard invites an alluring possibility. Broadcasters have long dreamed of a single digital standard that works on any television or mobile tablet anywhere in the world. Besides pleasing the world travelers who watch TV on their mobile gadgets, a universal standard could drastically improve economies of scale and drive down the prices of television sets and receivers even lower than they are today.

In the end, an agreement of such international scope may prove too ambitious, and the dream may never become reality. But many broadcast players around the globe are now seriously considering it.

POST YOUR COMMENTS *online at* spectrum.ieee.org/broadcastfuture1212

This past April, 13 television organizations—from Europe, Brazil, Canada, the United States, China, Japan, and South Korea—formed the Future of Broadcast Television (FOBTV) initiative to collaborate on the *next* next generation of broadcast systems worldwide. Already, FOBTV has attracted more than 40 additional members, including production equipment suppliers and consumer electronics manufacturers.

The diverse group may not yet have a technical solution. But when its founders signed the inaugural memorandum of understanding, they at least agreed on one thing: "This is a defining moment for the terrestrial television broadcast industry." ❑



ELECTRICAL *and* COMPUTER ENGINEERING
TEXAS A&M UNIVERSITY

DEPARTMENT HEAD

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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 Electrical and Computer Engineering (**http://www.ece.tamu.edu**).

Candidates must possess a Ph.D. or equivalent in electrical engineering or a closely related field, and must qualify as a tenured full professor in the department. The candidate must have notable accomplishments and experience in research, academic or industry leadership, teaching, and scholarship. The college seeks a visionary with ability to increase the rate of advancement the department has achieved in recent years. The preferred start date for this position is on or before September 1, 2013. Remuneration and other perquisites will be highly competitive.

The department's 65 faculty members have considerable expertise and international recognition in the areas of analog and mixed signal systems; biomedical imaging and genomic signal processing, computer engineering and systems; control and optimization; electromagnetics; networking; photonics; power electronics; power systems; solid state electronics; and telecommunications. The department faculty has 19 IEEE Fellows, two members of the National Academy of Engineering, two recipients of the Presidential Early Career Award (PECASE), and 18 recipients of NSF CAREER Awards, the Office of Naval Research (ONR) Young Investigator Awards and the Air Force Office of Scientific Research (AFOSR) Young Investigator Awards.

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. Approximately 20 percent of the engineering students are graduate students. U.S. News & World Report ranks the engineering graduate program seventh and the undergraduate program eighth among 181 Ph.D.-granting U.S. universities. 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 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 state and federal agencies, private organizations, partners and collaborators, and key industry groups; and 5) providing leadership for continued acquisition of internal and external resources.

Interested persons with nationally recognized academic and research 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 vice chancellor and dean of engineering and TEES director.

Applicants should submit a letter of application and a copy of their latest curriculum vitae. This search is an ongoing process; applicants will be considered until the position is filled.

For additional information or submission of applications contact:

Dr. César O. Malavé
Industrial and Systems Engineering
Texas A&M University
3131 TAMU
College Station, TX 77843-3131
(979) 845-5535
DHSearch@ece.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.

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BAYLOR UNIVERSITY

The Electrical and Computer Engineering Department of Baylor University

seeks faculty applicants for two Tenure-Track Assistant/Associate Professor Positions in all areas of electrical and computer engineering, with preference in the areas: embedded systems, computer/network security, software engineering, sensor networks, power, and energy. Applicants seeking a more senior position must demonstrate a record of sustained research funding. All applicants must have an earned doctorate and a record of achievement in research and teaching. The ECE department offers B.S., M.S., M.E. and Ph.D. degrees and is poised for rapid expansion of its faculty and facilities, including access to the Baylor Research and Innovation Collaborative (BRIC), a newly-established research park minutes from the main campus.

Chartered in 1845 by the Republic of Texas, Baylor University is the oldest university in Texas. Baylor has an enrollment of approximately 18,000 students and is a member of the Big XII Conference. Baylor's mission is to educate men and women for worldwide leadership and service by integrating academic excellence and Christian commitment within a caring community. The department seeks to hire faculty with an active Christian faith; applicants are encouraged to read about Baylor's vision for the integration of faith and learning at **www.baylor.edu/profuturis/**.

Application reviews are ongoing and will continue until both positions are filled; however, applications received by January 1, 2013 will be assured of full consideration.

Applications must include:

1) a letter of interest that identifies the applicant's anticipated rank,
2) a complete CV,
3) a statement of teaching and research interests,
4) the names and contact information for at least four professional references.

Additional information is available at **www.ecs.baylor.edu**. Send materials via email to Dr. Robert J. Marks II at *Robert_Marks@baylor.edu*. Please combine all submitted material into a single pdf file.

Baylor is a Baptist University affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Employment Opportunity employer, Baylor encourages candidates with an active Christian faith who are minorities, women, veterans, and persons with disabilities to apply.

Electrical Engineering Faculty Positions at King Abdullah University of Science and Technology

The Electrical Engineering (EE) program invites applications for faculty positions at King Abdullah University of Science and Technology (KAUST) for Assistant, Associate, and Full Professor positions beginning in the fall of 2013.

The EE program currently has 13 full time faculty and is recognized for its vibrant research programs and collaborative environment. EE research is strongly supported by KAUST's international research collaboration networks and KAUST's advanced research facilities, including the Nanofabrication, Imaging and Characterization, and the Supercomputing Core Facilities. More information about the EE academic programs and research activities are available at http://ee.kaust.edu.sa.

The disciplines of EE critically support KAUST's interdisciplinary research initiatives in water, food, energy, and the environment, especially by advancing green technology, and energy efficient computers and communication systems through the use of novel nano, bio, info, and opto device technologies. To accelerate these initiatives, the EE program seeks to work with other programs and centers in KAUST to aggressively strengthen synergies with the Geometric Modeling and Scientific Visualization Research Center, Computational Bioscience Research Center, and the Solar Energy and Photovoltaic Engineering Center as well as research clusters in Microsystems and Nanoelectronics, Communication and Signal Processing, Electromagnetics, and Photonics. Priority will be given to candidates with research interests in areas that may enhance and complement the above centers and clusters, including, but not limited to:

- **Circuits and Solid-State Devices**
- **Signal Processing and Information Theory for Bioinformatics**
- **Photonic and Optical Devices and Systems**
- **Visualization and Imaging**

All candidates should have the ability to pursue a high impact research program and have a commitment to teaching at the graduate level. Applicants should apply at **http://apptrkr.com/283531**. You will be required to complete a brief application form and upload a single pdf file including a complete curriculum vitae with a list of publications, a research plan, a statement of teaching interests, and the names and affiliation of potential referees for Associate Professor and Full Professor positions. Applications received by January 15, 2013 will receive full consideration and positions will remain open until filled.

About KAUST

King Abdullah University of Science and Technology (KAUST) is an international, graduate research university dedicated to advancing science and technology through interdisciplinary research, education, and strategic collaborations with leading centers around the world. Located on the shores of the Red Sea in Saudi Arabia, KAUST offers superb research facilities, generous assured research funding, and internationally competitive salaries, attracting top international faculty, scientists, engineers, and students to conduct fundamental and goal-oriented research to address the world's pressing scientific and technological challenges.

ASSISTANT PROFESSOR
(Multiple Postings/Tenure-Track)
Division of Electrical and Computer Engineering
Louisiana State University

LSU

Seeking candidates for tenure-track faculty positions starting August 2013 or earlier in: **i.** experimental area in processing of electronic materials, semiconductor device fabrication including MEMS, micro and nanostructures; **ii.** area of digital signal processing (DSP) with focus on DSP hardware including but not limited to high-performance computing with DSP hardware, novel DSP architectures, and hardware/software co-design; or **iii.** area of cyber security including but not limited to secure hardware architectures, software vulnerability analysis, network security and cyber warfare.

Responsibilities: Teach undergraduate and graduate level courses with clarity and high quality. Examine and grade student performance. Develop a research program. Disseminate knowledge via technical papers and conferences. Prepare and submit proposals for grant/contract funds. Direct M.S. and Ph.D. students. Participate in university service, committee activities, supervision of teaching/research assistants and student advising. Maintain professional standards and level of competence.

Required Qualifications: Earned Ph.D. or equivalent degree in Electrical Engineering or a closely related field; demonstrated potential for excellence in teaching at graduate and undergraduate levels, conducting quality research, and obtaining research sponsorship. ABD candidates will be considered. **Additional Qualifications Desired:** Applications must identify one of the three areas listed above, contact information of at least three referees, statement of teaching and research interest along with detailed curriculum vita.

An offer of employment is contingent on a satisfactory pre-employment background check. Application deadline is January 15, 2013 or until a candidate is selected. Women and minorities are encouraged to apply. Apply online and view a detailed ad: **https://lsusystemcareers.lsu.edu Position #005978**

LSU IS AN EQUAL OPPORTUNITY/EQUAL ACCESS EMPLOYER

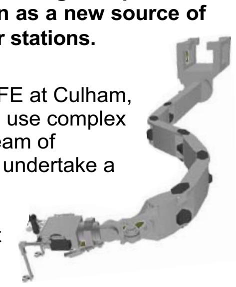
Quick link at ad URL:
https://lsusystemcareers.lsu.edu/applicants/Central?quickFind=55345

United Kingdom Atomic Energy Authority

MOTION CONTROL ENGINEER

Salary £25,686 - £46,005 plus benefits
Culham, Oxfordshire

Nuclear fusion, the process that powers the Sun, can play a big part in our carbon-free energy future. CCFE is one of the world's leading fusion research laboratories. Our scientists and engineers are working with partners around the globe to develop fusion as a new source of clean energy for tomorrow's power stations.



To maintain the JET Tokamak at CCFE at Culham, the Remote Handling Unit engineers use complex systems and tools developed by a team of engineers to enter the Tokamak and undertake a wide variety of tasks.

To assist in the ongoing improvement of these systems, an enthusiastic Motion Control Engineer is being sought to cover both maintenance of the control systems currently in use and to develop innovative yet practical proposals for enhanced systems for future fusion projects like ITER and DEMO. Skills should include C and C++ programming and real time motion control, from concept through analysis to hands on implementation.

If you are interested in this position, please send a full CV, quoting reference number CCFE/L66/12 to alanna.o'connor@ccfe.ac.uk
Further details are available from:
www.ccfe.ac.uk** or **www.uk-atomic-energy.org.uk

Positions Open

Toyota Technological Institute

TOYOTA TECHNOLOGICAL INSTITUTE 豊田工大

Toyota Technological Institute has two openings for "Principal Professor" positions in its School of Engineering. For more information, please refer to the following website:
http://www.toyota-ti.ac.jp/bosyu/index_E.html

Research fields:
1. Advanced Energy Technology and Related Sciences
This field covers fundamental studies and applied research on advanced energy technology, including new concepts and systems for the generation, storage, and utilization of energy as well as innovative propulsion mechanisms. It also covers basic and applied studies of materials and their functions for advanced energy technology.

2. Science and technology for advanced instrumentation and/or information processing This field covers new devices and systems for advanced information processing and/or communication technology, including quantum information technology and leading instrumentation technology for ultra-sensitive measurements and/or bio-medical studies and diagnosis. It also covers large-scale computation in cyber-physical space and related technology for advanced sensor networks.

Qualifications: A successful candidate must have a Ph. D. degree or the equivalent in a relevant field; he/she must possess outstanding competence to promote world-class research program(s) as well as to conduct excellent teaching and research supervision for graduate and undergraduate students, so as to fulfill his/her mission as a superb leader in research and education.

The "Principal Professor" will serve as the head of a "unit laboratory", that consists of the Principal Professor, one associate professor, and two research assistants, i.e., one assistant professor and one post-doctoral fellow. Alternatively, two post-doctoral fellows can be hired in place of an assistant professor. All the expenses for hiring these unit members will be covered by TTI. A start-up grant of about one hundred million Japanese yen (ca. one million US dollars) is available. In addition, a research budget of about ten million Japanese yen (ca. one hundred thousand US dollars) will be given each year to promote research programs for a period of five years. At the end of this five-year term, the principal professor will be given a formal evaluation, as described on our web page.

Start date: Fiscal year 2013 (on the date of the earliest convenience)
Documents: (1) A curriculum vitae
(2) A list of publications
(3) Copies of 5 representative papers
(4) An outline of research and educational accomplishments (about 3-pages) and a future plan of educational and research activities (about 3- pages)
(5) Names of two references, including phone numbers and e-mail addresses
(6) An application form (available on our website)

Deadline: March 31, 2013
Inquiries: Search Committee Chair, Vice President Dr. Shuji Tanaka
(Phone) +81-52-809-1775 (E-mail) ***tanaka_mat@toyota-ti.ac.jp***

The above documentation should be sent to:
Mr. Takashi Hirato
Toyota Technological Institute
2-12-1, Hisakata, Tempaku-ku
Nagoya, 468-8511 Japan

Please write "Application for Principal Professorship in (the field of your choice)" on the return envelope.

LAFAYETTE COLLEGE

Lafayette College *is a selective, private, liberal arts college of 2,400 undergraduates. Our 110-acre campus is located one and a half hours from both New York City and Philadelphia. Degree programs are offered in the liberal arts, sciences and engineering.*

Lafayette College is currently seeking applicants for 2 positions available within our Department of Electrical and Computer Engineering for the 2013-2014 Academic Year.

Visiting Faculty Position – Electronics

The successful candidate will teach undergraduate electrical and computer engineering courses primarily in the electronics area, but ability to teach semiconductor physics preferred. Applicants should possess a Ph.D. degree in Electrical and Computer Engineering or closely related field and must demonstrate a strong commitment to undergraduate education and research.

Tenure-Track Faculty Position – Computer Engineering and Embedded Systems

Applicants should possess a Ph.D. degree in Electrical or Computer Engineering and must demonstrate a strong commitment to undergraduate teaching, mentoring, and research along with potential for multidisciplinary collaboration. The successful candidate will teach courses covering digital systems, microcontrollers, FPGAs, embedded systems, computer organization/architecture, and other courses that contribute to the College's Common Course of Study. Exceptionally qualified candidates may be considered at the Associate Professor level.

Lafayette College's ABET-accredited ECE program features small class sizes, hands-on laboratory experiences, and strong faculty-student interaction. **Applications should include a cover letter, curriculum vitae, and the names of three references and should be submitted by email (preferred) at ecesearch12@lafayette.edu. Consideration of applications will begin in January 2013.**

Lafayette College is committed to creating a diverse community: one that is inclusive and responsive, and is supportive of each and all of its faculty, students, and staff. All members of the College community share a responsibility for creating, maintaining, and developing a learning environment in which difference is valued, equity is sought, and inclusiveness is practiced. Lafayette College is an equal opportunity employer and encourages applications from women and minorities.

University of Minnesota Duluth

Jack Rowe Endowed Chair in Electrical Engineering

The Department of Electrical Engineering at the University of Minnesota Duluth is seeking candidates for the tenured position of Jack Rowe Endowed Chair. The Chair holder is expected to teach courses at both undergraduate and graduate levels, develop an externally funded research program, and establish a strong relationship with communities and industries of the region. A Ph.D. in Electrical Engineering or Electrical and Computer Engineering from a regionally accredited institution with a minimum of 10 years of combined research and teaching experience in academia and/or industry in the areas of Power, Energy, and Control is required. The candidates must have a distinguished national and/or international reputation in research or education with a strong record of obtaining external funding. Experience in working with students, staff, and faculty from diverse communities and cultures is highly desired.

Please apply online via the Employment System at **https://employment.umn.edu/applicants/Central?quickFind= 181509**

Completed applications should include a letter of application, a research plan, a complete resume, and contact information of three professional references.

Applications will be accepted until the position is filled. University of Minnesota Duluth is an equal opportunity and affirmative action educator and employer and welcomes applications from women and minorities. For further information, please contact Search Chair Dr. Taek Kwon at ***tkwon@d.umn.edu*** or 218-726-8211.

The Faculty of Applied Sciences, Simon Fraser University, announces a tenure-track position in the area of Power Electronics at the rank of Assistant or Associate Professor beginning on July 1, 2013. The appointment will be in the School of Mechatronic Systems Engineering (MSE). Research areas of interest for the position include a range of applications including, but not limited to, electric vehicles, modern transportation systems, industrial electronics, smart grid, and alternative energy. Applicants must have a PhD and undergraduate degrees in Electrical or a related discipline in Engineering, have demonstrated excellence or have strong potential in teaching, and possess a strong commitment to research and scholarship, as reflected in refereed publications. Industrial experience will be an asset.

All qualified candidates are encouraged to apply; however, Canadians and permanent residents will be given priority. The University is committed to employment equity. For further details see: **http://www.sfu.ca/vpacademic/faculty_openings/applied_sciences.html**

To apply, send a curriculum vitae including a statement of career objectives, names, addresses, email addresses, and phone numbers of three referees to

Dr. John Jones, Acting Director
School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, B.C., Canada V5A 1S6
phone: (778)782-3119
Fax: (778) 782-4951
email: jones@sfu.ca

York University's Lassonde School of Engineering empowers creative minds to change the world. At Lassonde we are incorporating the concept of Renaissance Engineering™ that we are pioneering into our new-wave engineering learning experience through co-operative education and industry partnerships, entrepreneurship and leadership opportunities, and global learning and study abroad. The new Lassonde School of Engineering builds on York University's existing fully accredited and innovative programs in Computer Engineering, Geomatics Engineering and Space Engineering, as well as new programs in Software Engineering and Electrical Engineering (***lassonde.yorku.ca/our-point-of-view/***).

The Lassonde School of Engineering is a unique opportunity for both senior and junior faculty to help lead the creation of innovative teaching and research programs that integrate the diverse areas of engineering, law, business, sciences and humanities within Canada's leading interdisciplinary research and teaching university.

TENURE-STREAM POSITIONS IN ELECTRICAL ENGINEERING We seek two outstanding candidates at the Assistant or Associate Professor level in Electrical Engineering with an emphasis on power engineering and/or energy systems, including (but not limited to): high power electronics, power systems, energy storage/generation/transmission, smart grid, renewable energy sources.

Candidates for the above position must hold earned undergraduate and PhD degrees in the relevant Engineering field, or a closely related discipline. Successful candidates will have a demonstrated track record of technical, academic (teaching and scholarly research) and professional achievement appropriate to the level of their appointment. Successful candidates must be eligible for prompt appointment to the Faculty of Graduate Studies. Successful candidates shall demonstrate commitment to the engineering profession by being licensed as a Professional Engineer in Ontario, or by becoming licensed soon after appointment.

Positions will commence **July 1, 2013**, subject to budgetary approval. Applications must be received by **January 4, 2013**. Applicants should visit **lassonde.yorku.ca/new-faculty** for full position details and to complete the online application process, ensuring that they provide all of the information required.

York University is an Affirmative Action Employer. The Affirmative Action Program can be found on York's website at www.yorku.ca/acadjobs or a copy can be obtained by calling the affirmative action office at 416.736.5713. All qualified candidates are encouraged to apply; however, Canadian citizens and permanent residents will be given priority.

YORK U
UNIVERSITÉ
UNIVERSITY
redefine THE POSSIBLE.

Power Electronics vacancies in the newly established **National Center for Power Electronics and Energy:** Sun Yat-Sen University, Guangzhou, China announces openings of Associate Professor, Assistant Professor, Post-doc, and one-year Visiting positions. Candidates with background in all fields of power electronics are looked for, including power supplies on chip, power electronics for alternative sources of energy, for medical equipment, and for TV sets. Besides scholarly record, industrial experience in companies or participation at industrial projects will be an advantage. Competitive salary based on qualifications. Submit CV either to: ioinovici@gmail.com or Glenda Nie, issrs@mail.sysu.edu.cn.

University of São Paulo
School of Engineering of São Carlos
Electrical and Computer Engineering Department
Brazil

The Electrical and Computer Engineering Department of the School of Engineering of São Carlos, University of São Paulo, seeks faculty applicants for three tenure-track assistant professor positions. Qualified individuals are considered for the research areas of antennas and propagation; electrical machines; microprocessors and microelectronics. Candidates must have a Ph.D. degree and will be expected to carry out research and teaching activities at the graduated and undergraduated levels.

USP is a public research university and it is consistently the top Brazilian institution of higher learning in international rankings. The city of Sao Carlos, located 235 km from Sao Paulo, is home to the School of Engineering.

Initial activities can be conducted in English but successful applicants are expected to teach in Portuguese within a 2-year timeframe. Starting salary, including benefits, is around US$ 65,000.00/year.

For further information and details on the selection process, please contact Prof. Murilo A Romero, the Department Head, at murilo.romero@usp.br, including a letter of interest with teaching and research statements, as well as a complete CV.

QUEEN'S UNIVERSITY AT KINGSTON

Mathematics – Applied Math/ Mathematical Biology

The Department of Mathematics and Statistics at Queen's University is seeking outstanding candidates for a tenure-track position in Applied Mathematics at the Assistant Professor level, with a starting date of July 1, 2013, pending budgetary approval. Although applications in all areas of Applied Mathematics are invited, priority will be given to candidates able to contribute to the Mathematics and Engineering program or to the Mathematical Biology program.

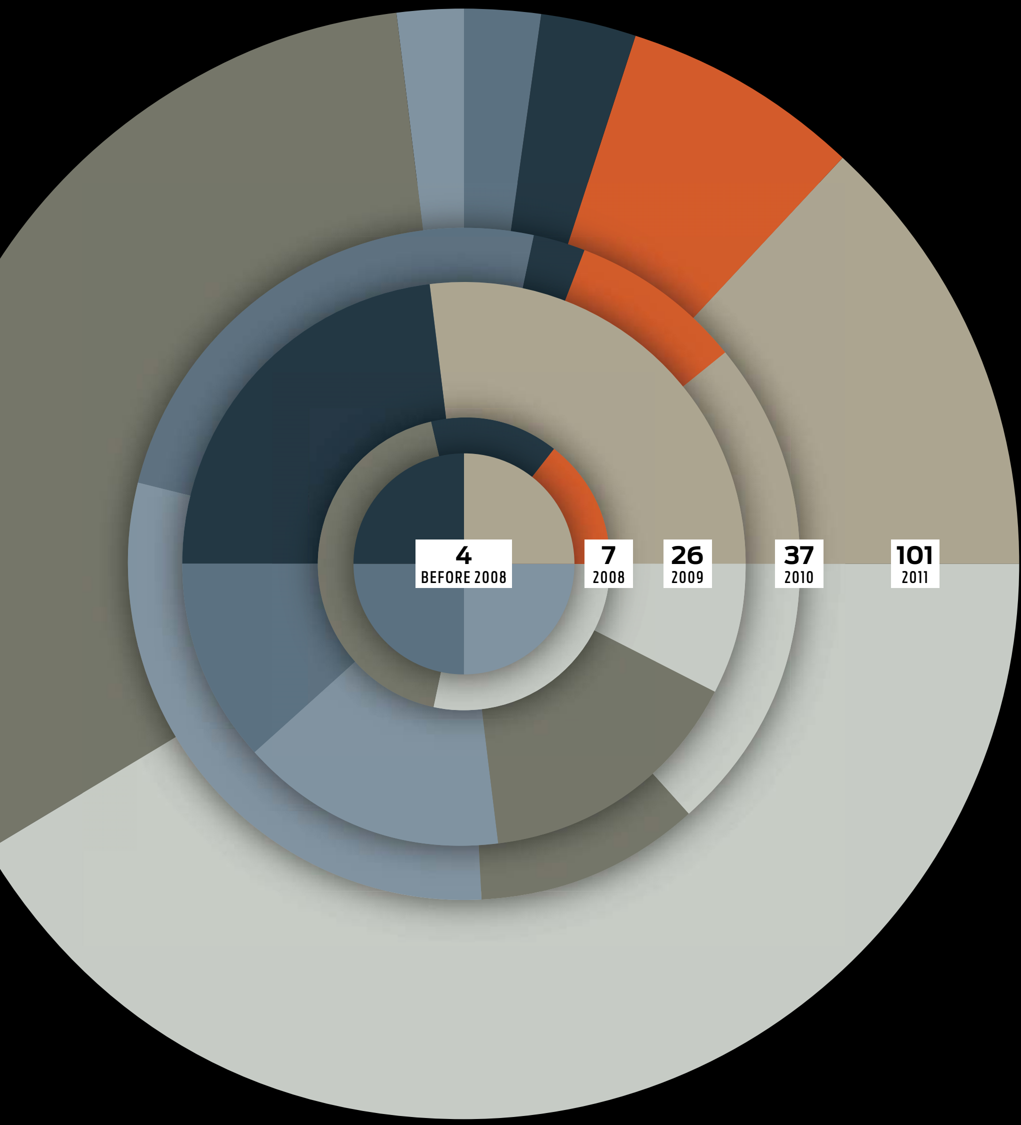
For complete ad and information on how to apply go to: **http://www.mast.queensu.ca/positions/**

Application materials should be submitted through **http://www.mathjobs.org** .

Contact: e-mail
position@mast.queensu.ca .

Deadline: January 15, 2013.

the data



CLOUD SECURITY THREATS

- Insecure interface & APIs
- Data loss or leakage
- Hardware failure
- Poor infrastructure planning
- Nefarious use of cloud computing
- Unknown risk profile
- Other

7 2008 Bold numerals represent total number of incidents with known causes per year

INCIDENTS WITH UNKNOWN CAUSES, BY YEAR

BEFORE 2008

2008

2009

2010

2011

TOTAL KNOWN INCIDENTS, BY CATEGORY

Suggested new categories are in orange

INSECURE INTERFACE & APIs

DATA LOSS OR LEAKAGE

HARDWARE FAILURE

POOR INFRASTRUCTURE PLANNING

NEFARIOUS USE OF CLOUD COMPUTING

UNKNOWN RISK PROFILE

CLOUD-RELATED MALWARE

SHARED TECHNOLOGY ISSUES

NATURAL DISASTERS

CLOSURE OF CLOUD SERVICE

MALICIOUS INSIDER

ACCOUNT OR SERVICE HIJACKING

A complete white paper describing these results is planned for release in January 2013.

BRANDON PALACIO

Understanding Cloud Failures

TO MANY, cloud computing kicked off in 2008, with the rapid proliferation in the use of Amazon.com's Web and storage services. A new type of computing has inevitably led to new problems. Working under the auspices of the Nanyang Technological University and the Cloud Security Alliance, both in Singapore, and the University of Waikato in New Zealand, we set out to categorize these problems. We studied 11 491 articles from 39 news sources published from 2008 to 2012 that reported on cloud-computing outages, identifying 172 unique incidents. We could not assign a cause for all (although the proportion of unexplained incidents is declining, providers are still cautious with information). But our analysis of the 75 percent of incidents for which a cause was given revealed that the current list of the top seven threats proposed by the international Cloud Security Alliance is insufficient. We recommend five more categories: hardware failure, natural disaster, service closure, cloud-related malware, and inadequate infrastructure planning. In particular, hardware failure is one of the top three threats, responsible for 10 percent of incidents.

There is clearly an urgent need for the industry to address these threats and to agree to mandatory reporting of cloud outages and their causes. *—Ryan K.L. Ko, Stephen S.G. Lee & Veerappa Rajan*

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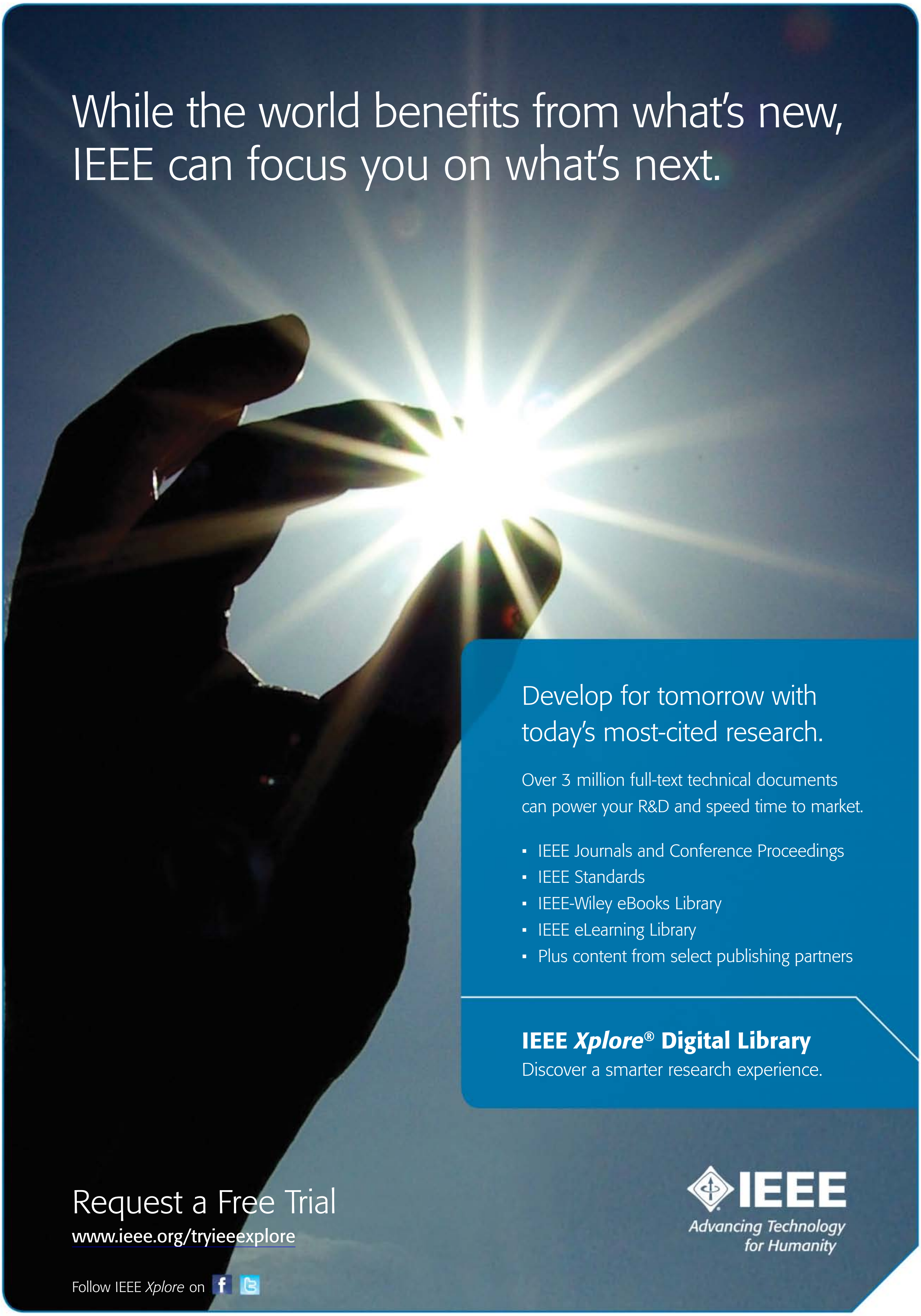
While the world benefits from what's new,
IEEE can focus you on what's next.
Develop for tomorrow with today's most-cited research.
Over 3 million full-text technical documents can power your R&D and speed time to market.
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▪ IEEE Standards
▪ IEEE-Wiley eBooks Library
▪ IEEE eLearning Library
▪ Plus content from select publishing partners
IEEE Xplore® Digital Library
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