Research Horizons

A Publication of the Georgia Institute of Technology *Summer 2014*

ENCOURAGING ENTREPRENEURSHIP

Georgia Institute of Technology

- *Flashlight in the Body*
- *High-Energy Rocket Fuel*
- *Silicon Speed Record*
- *Wireless Chemical Sensor*
- *Hot Polymers*

CROSSTALK

MOVING INNOVATION TO MARKET

Georgia Tech was created in 1885 to develop technical leaders to support industry and economic development in the Southeastern United States. Today, it is recognized as one of the top research universities in the world and still holds true to that original vision.

In this issue of Research Horizons, you'll learn more about Georgia Tech's unique approach to pursuing grand challenges, engaging with industry, and inspiring the next generation of research and industry leaders.

The cover story about Georgia Tech's InVenture Prize shares the exciting activities of students taking part in the faculty-led innovation competition. You'll see how their ideas come to life, while they compete for a cash prize, patent filing and the additional support needed to help them develop their own startup companies.

This issue also includes a feature story about Georgia Tech's Advanced Technology Development Center (ATDC), which is one of the oldest and most highly-regarded university-based startup incubators in the country. Each year ATDC works with more than 300 companies and has played a key role in launching over 150 ventures that have attracted $2.5 billion in investment and created over 5,500 jobs.

Finally, you will find a feature about Georgia Tech's role in the National Science Foundation (NSF) I-Corps program, which is focused on identifying commercialization opportunities and providing entrepreneurship training for those conducting NSF-funded research.

At Georgia Tech, our research strategy focuses on talented faculty and creative students doing powerful research that stretches beyond the lab and into the real world. As the center of a vibrant innovation ecosystem, we work hard to facilitate transformative opportunities, strengthen collaborative partnerships, and maximize the economic and societal impact of all we do.

Stephen E. Cross
Executive Vice President for Research
July 2014

Georgia Tech *Research Horizons* Magazine

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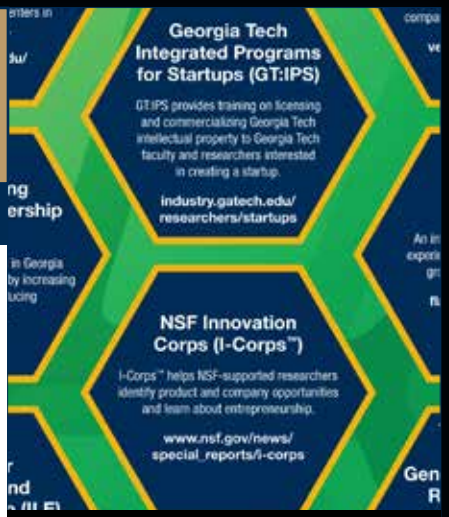

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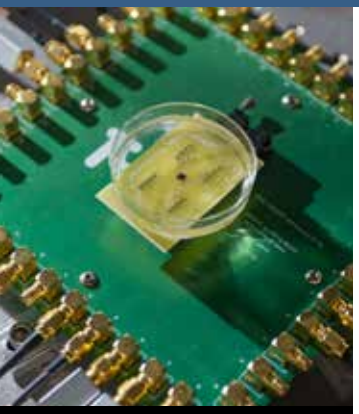

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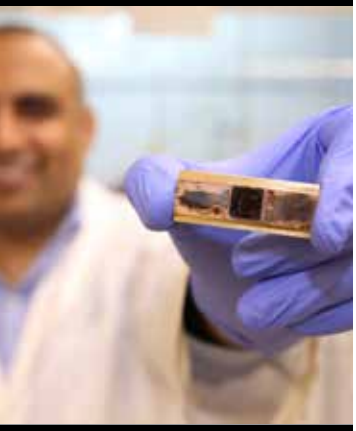

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Cover: Georgia Tech's InVenture Prize allows students to experience what it's like to be an entrepreneur. Shown are (l-r) Jasmine Burton, Brandie Banner, and Erin Cobb of Team Sanivation, which developed an inexpensive mobile solution to help the nearly 2.6 billion people worldwide who don't have access to hygienic bathrooms.

A new catheter-based imaging device would provide forward-looking, real-time, three-dimensional imaging from inside the heart, coronary arteries, and peripheral blood vessels. The device could better guide surgeons working in the heart, potentially allowing more clogged arteries to be cleared without major surgery.

Flashlight in the Body:

Single-Chip Device Provides Real-Time 3-D Images from Inside the Heart

By John Toon

Photo: Rob Felt

A single-chip catheter-based device that would provide forward-looking, real-time, three-dimensional imaging from inside the heart, coronary arteries and peripheral blood vessels is shown on the tip of a finger.

Researchers have developed the technology for a catheter-based device that would provide forward-looking, real-time, three-dimensional imaging from inside the heart, coronary arteries, and peripheral blood vessels. With its volumetric imaging, the new device could better guide surgeons working in the heart, potentially allowing more clogged arteries to be cleared without major surgery.

The device integrates ultrasound transducers with processing electronics on a single 1.4 millimeter silicon chip. On-chip processing of signals allows data from more than 100 elements on the device to be transmitted using just 13 tiny cables, permitting it to easily travel through circuitous blood vessels. The forward-looking images produced by the device would provide significantly more information than existing cross-sectional ultrasound.

Researchers have developed and tested a prototype able to provide image data at 60 frames per second, and plan next to conduct studies that could lead to commercialization of the device.

"Our device will allow doctors to see the whole volume that is in front of them within a blood vessel," said F. Levent Degertekin, a professor in the George W. Woodruff School of Mechanical Engineering at Georgia Tech. "This will give cardiologists the equivalent of a flashlight so they can see blockages ahead of them in occluded arteries. It has the potential for reducing the amount of surgery that must be done to clear these vessels."

Details of the research were published in the February 2014 issue of the journal *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*. Research leading to the device development was supported by the National Institute of Biomedical Imaging and Bioengineering (NIBIB), part of the National Institutes of Health.

Degertekin explained that most of the devices currently available for doctors to see what is going on inside the arteries and heart provide only cross-sectional images.

"If you have an artery that is totally blocked, for example, you need a system that tells you what's in front of you. You need to see the front, back, and sidewalls altogether," Degertekin said. "That kind of information is basically not available at this time."

The single chip device combines capacitive micromachined ultrasonic transducer (CMUT) arrays with front-end CMOS electronics technology to provide three-dimensional intravascular ultrasound (IVUS) and intracardiac echography (ICE) images. The dual-ring array includes 56 ultrasound transmit elements and 48 receive elements. When assembled, the donut-shaped array is just 1.5 millimeters in diameter, with a 430-micron center hole to accommodate a guide wire.

Power-saving circuitry in the array shuts down sensors when they are not needed, allowing the device to operate with just 20 milliwatts of power, reducing the amount of heat generated inside the body. The ultrasound transducers operate at a frequency of 20 megahertz.

Imaging devices operating within blood vessels can provide higher resolution images than devices used from outside the body because they can operate at higher frequencies. But operating inside blood vessels requires devices that are small and flexible enough to travel through the circulatory system. They must, of course, also be able to operate in blood.

Doing that requires a large number of elements to transmit and receive the ultrasound information. Degertekin and his collaborators miniaturized the elements and use them to carry out some of the processing on the probe itself.

Based on their prototype, the researchers expect to conduct animal trials to demonstrate the device's potential applications. They ultimately expect to license the technology to an established medical diagnostic firm to conduct the clinical trials necessary to obtain FDA approval.

For the future, Degertekin hopes to develop a version of the device that could guide interventions in the heart under magnetic resonance imaging (MRI).

In addition to Degertekin, the research team included Jennifer Hasler, a professor in the School of Electrical and Computer Engineering; Mustafa Karaman, a professor at Istanbul Technical University; Coskun Tekes, a postdoctoral fellow in the Woodruff School of Mechanical Engineering; Gokce Gurun and Jaime Zahorian, recent graduates of the School of Electrical and Computer Engineering; and Georgia Tech Ph.D. students Toby Xu and Sarp Satir. rh

This research was supported by award number R01EB010070 from the National Institute of Biomedical Imaging and Bioengineering (NIBIB), part of the National Institutes of Health (NIH). The content of this article is solely the responsibility of the authors and does not necessarily represent the official views of the NIBIB or NIH.

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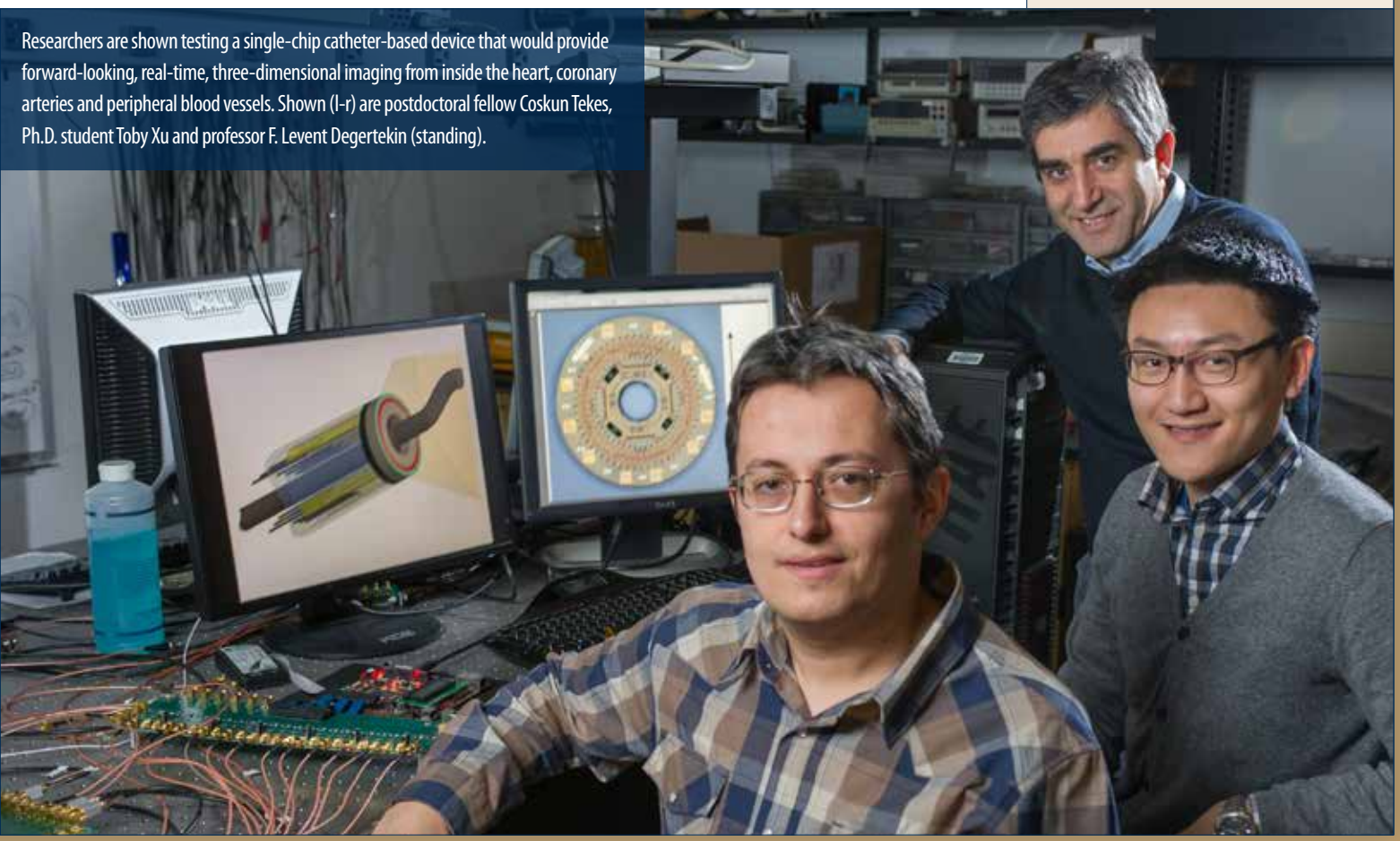
"Our device will allow doctors to see the whole volume that is in front of them within a blood vessel. This will give cardiologists the equivalent of a flashlight so they can see blockages ahead of them in occluded arteries. It has the potential for reducing the amount of surgery that must be done to clear these vessels."

— F. Levent Degertekin, professor in the George W. Woodruff School of Mechanical Engineering



Researchers are shown testing a single-chip catheter-based device that would provide forward-looking, real-time, three-dimensional imaging from inside the heart, coronary arteries and peripheral blood vessels. Shown (l-r) are postdoctoral fellow Coskun Tekes, Ph.D. student Toby Xu and professor F. Levent Degertekin (standing).

Photo: Rob Felt

Georgia Tech has long been a leader in supporting the launch and development of technology companies. Beginning with the Advanced Technology Development Center (ATDC), Georgia Tech has established an integrated set of initiatives designed to build a community of innovators and entrepreneurs.

Launching Technology Companies:

Integrated Set of Initiatives Helps Build a Community of Innovators and Entrepreneurs

By John Toon

Photo: Gary Meek

Among the successes of Georgia Tech's initiatives for launching technology-based startup companies is CardioMEMS, which was recently sold to St. Jude Medical Inc. Shown is the company's first implantable sensor product.

In the late 1970s, a group of Georgia Tech alumni convinced the Institute's president, Georgia's governor, and the state's General Assembly to fund an initiative aimed at helping entrepreneurs launch and build new companies based on technology. The goal was to create new jobs and economic activity around Georgia Tech, which was then emerging as a national and international research and education powerhouse.

That initiative has grown into the Advanced Technology Development Center (ATDC), now the nation's largest and most respected university-based technology incubator. Over 34 years, ATDC has helped launch more than 150 companies that, together, have provided thousands of new jobs and attracted more than $2 billion in funding.

And it has helped create a technology community and entrepreneurship culture that's among the nation's most active.

Encouraged by the success of ATDC, Georgia Tech has created an integrated set of initiatives designed to encourage student entrepreneurship, help researchers form companies based on the technology developed in Georgia Tech labs, and accelerate the growth of new firms. The success of these efforts led the National Science Foundation (NSF) to make Georgia Tech one of the first nodes in its Innovation Corps program, which helps NSF-funded researchers turn their research into new ventures, new products, and new jobs.

This section of Research Horizons highlights three components of that entrepreneurship community: the InVenture Prize, NSF I-Corps, and the ATDC. The major components of this community are represented in the graphic on the opposite page. Other components will be featured in upcoming issues of this magazine. rh

Advanced Technology Development Center (ATDC)

Georgia Tech's technology incubator, with a 34-year history, helps Georgia entrepreneurs launch and build techology companies. Affiliation with Georgia Tech is not required.

atdc.org

Corporate Innovation Groups

Georgia Tech provides an attractive environment for corporate innovation groups wanting to locate near students and faculty. AT&T, NCR, Panasonic, and ThyssenKrupp have such centers in Technology Square.

b.gatech.edu/1myo0lU

Georgia Tech VentureLab

Helps Georgia Tech faculty, researchers, and students identify opportunities for commercialization and create startup companies based on research results.

venturelab.gatech.edu

Georgia Tech Integrated Programs for Startups (GT:IPS)

GT:IPS provides training on licensing and commercializing Georgia Tech intellectual property to Georgia Tech faculty and researchers interested in creating a startup.

industry.gatech.edu/researchers/startups

Georgia Manufacturing Extension Partnership (GaMEP)

GaMEP helps manufacturers in Georgia improve their competitiveness by increasing top-line growth and reducing bottom-line cost.

gamep.org

Flashpoint

An intense four-month accelerator experience for competitively selected groups of startup companies.

flashpoint.gatech.edu

NSF Innovation Corps (I-Corps™)

I-Corps™ helps NSF-supported researchers identify product and company opportunities and learn about entrepreneurship.

www.nsf.gov/news/special_reports/i-corps

Institute for Leadership and Entrepreneurship (ILE)

ILE enhances leadership and entrepreneurship for socially responsible value creation.

www.ile.gatech.edu

Technological Innovation: Generating Economic Results (TI:GER)

TI:GER teaches students about the non-technological hurdles to commercializing university research. Multidisciplinary teams are made up of science/engineering Ph.D. candidates, MBA and law students.

tiger.gatech.edu

InVenture Prize

This competition is a faculty-led innovation experience for undergraduate students; students work individually or in teams to develop and present innovations.

inventureprize.gatech.edu

Graphic: Rhys Black

The technical aspects of engineering new products come naturally for many students, but they often lack business savvy. Georgia Tech's InVenture Prize allows students to experience what it's like to be an entrepreneur. The initiative is helping change the culture at Georgia Tech.

InVenture Prize:

Competition Encourages Students to Invent and Become Entrepreneurs

By Laura Diamond

Jasmine Burton, Brandie Banner and Erin Cobb (l-r) display the prizes they won as Team Sanivation, which developed an inexpensive mobile solution to help the nearly 2.6 billion people worldwide who don't have access to hygienic bathrooms.

Photo: Rob Felt

After Partha Unnava broke his ankle playing pickup basketball, he spent a summer walking with uncomfortable crutches that left him with pain and fatigue. Unnava, a student in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University, knew he could invent something better.

So along came The Better Walk Crutch, a device he created with the help of two other students. The team has already raised $160,000 for the invention and attracted attention from orthopedic surgeons.

Team Better Walk was among the finalists for the 2014 InVenture Prize, Georgia Tech's annual contest that rewards students with cash prizes and free patents for big innovations that aim to solve the world's problems. The competition exposes students to multiple aspects of entrepreneurship.

"InVenture is part of the changing culture at Georgia Tech where we are getting students to think more like entrepreneurs," said Chris Reaves, director of undergraduate research and student innovation, and one of InVenture's organizers.

The InVenture first-place prize is $20,000 plus a spot in Flashpoint, Georgia Tech's startup accelerator program. Second-place finishers go home with $10,000. The winners receive free U.S. patent filings by Georgia Tech's Office of Technology Licensing.

"Students want to build their own business and have a positive impact on society," Reaves said.

Student Interest Grows

InVenture started in 2009 and is expanding beyond Georgia Tech. The University of Florida held its own version earlier this year, and other colleges have requested more information.

Nearly 560 Georgia Tech students signed up for this year's contest – the largest number ever. Over the course of several months, the group was narrowed to six teams that competed in the finale on March 26.

Judges considered a variety of factors such as innovation, marketability, and probability of success.

Team Sanivation won with their invention of an inexpensive mobile solution to help the nearly 2.6

billion people worldwide who don't have access to hygienic bathrooms.

Their Safi Choo (Swahili for "clean toilet") is meant to replace the pit latrines often found in the developing world and in refugee camps. The device has received preliminary support from the U.S. Centers for Disease Control and Prevention (CDC).

The all-female team left for Kenya soon after the end of the spring semester to test the toilet, which allows users to sit or squat while a filtration system reduces the spread of sanitation diseases. The device includes several large drawers that separate liquid and solid waste for removal and disposal.

"We want to have a positive impact on humanity," said Team Sanivation member Erin Cobb, a student in the School of Industrial Design. "We're happy we've been able to get some people to talk about a taboo topic."

InVenture's second-place team invented the Sucette Smart Soother, a modernized pacifier that fits more naturally with a baby's mouth and growing dental structure. It even changes color when the baby has a fever.

The three-member Sucette Smart Soother team, made up of biomedical engineering majors, read studies showing how today's pacifiers are associated with some dental, skeletal, and speech deformities.

"We realized there are so many problems with existing pacifiers and parents have no clue," said team member Rachel Ford.

The team went through multiple rounds of prototyping before settling on the final prototype, which features a concave inner portion so the tongue is positioned to allow for proper development of the bones surrounding the mouth.

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"We've spent so much time in our engineering classes that it's exciting to apply what we've learned in the real world. To have people willing to write a check to support something you invented is an amazing feeling."

— Partha Unnava, a student in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University

Developers of The Better Walk Crutch demonstrate its advantages at the InVenture Prize competition on March 26, 2014. The group has already attracted significant funding. Shown (l-r) are Partha Unnava, Andrew Varghese, and Frankie Swindell.

Photo: Rob Felt

InVenture Finalists

Nearly 560 students signed up for this year's contest – the largest number ever. Over the course of several months the group was narrowed to six teams. Their designs were:

- The Better Walk Crutch. Modernized crutches to help people get around more confidently and comfortably while going through rehabilitation for lower leg injury.
- The Enlighten Music Trainer. A tool to eliminate the frustration some people feel when learning to play the guitar. Songs are placed in an SD card slot and the trainer programs notes to show on LED lights on a removable sleeve.
- Sleepwell Sleepwear. A nightshirt that reduces snoring and symptoms of sleep apnea. The garment senses when people are sleeping on their backs and uses automated positional therapy to move them to a healthier position.
- The Safi Choo Toilet. An inexpensive, mobile toilet to replace the pit latrines often used in the developing world and in refugee camps.
- The Sucette Smart Soother. A modernized pacifier designed to fit more naturally with a baby's mouth and growing dental structure.
- Upsadazy. A baby stroller that safely and quickly climbs stairs without the risk of tipping over and harming the child.

The Process

Competitors spent months – if not years – designing prototypes, reading research and medical journals, and interviewing experts, patients, and others who could benefit from the inventions.

Members of team Better Walk, for instance, talked with more than 50 physical therapists, orthopedic surgeons, and other experts about their redesigned crutch.

As a result, their product offers forearm support to reduce fatigue, and the design removes direct stress from the wrist. There is also a side-piece that provides additional stability.

They've already raised $160,000 for their invention, and about two dozen physicians asked to buy the device when a version was shown at a conference of orthopedic surgeons.

"We've spent so much time in our engineering classes that it's exciting to apply what we've learned to the real world," Unnava said. "To have people willing to write a check to support something you invented is an amazing feeling."

After Graduation

Students continue working on their innovations after they graduate.

Patrick Whaley won InVenture in 2010 for weighted exercise clothing that can be worn without joint damage or any limitations on movement. He turned his invention into Titin Tech, a Georgia-based company operating out of Alpharetta, an Atlanta suburb. Players in the NFL and NBA, and clients around the world wear his weighted compression gear.

Erika Tyburski won second place in 2013 for AnemoCheck, an inexpensive and disposable test that would allow self-testing for anemia. Since then, she has worked with the Atlanta-based Global Center for Medical Innovation and has finished clinical testing and prototyping the device. She hopes to form a company later this year.

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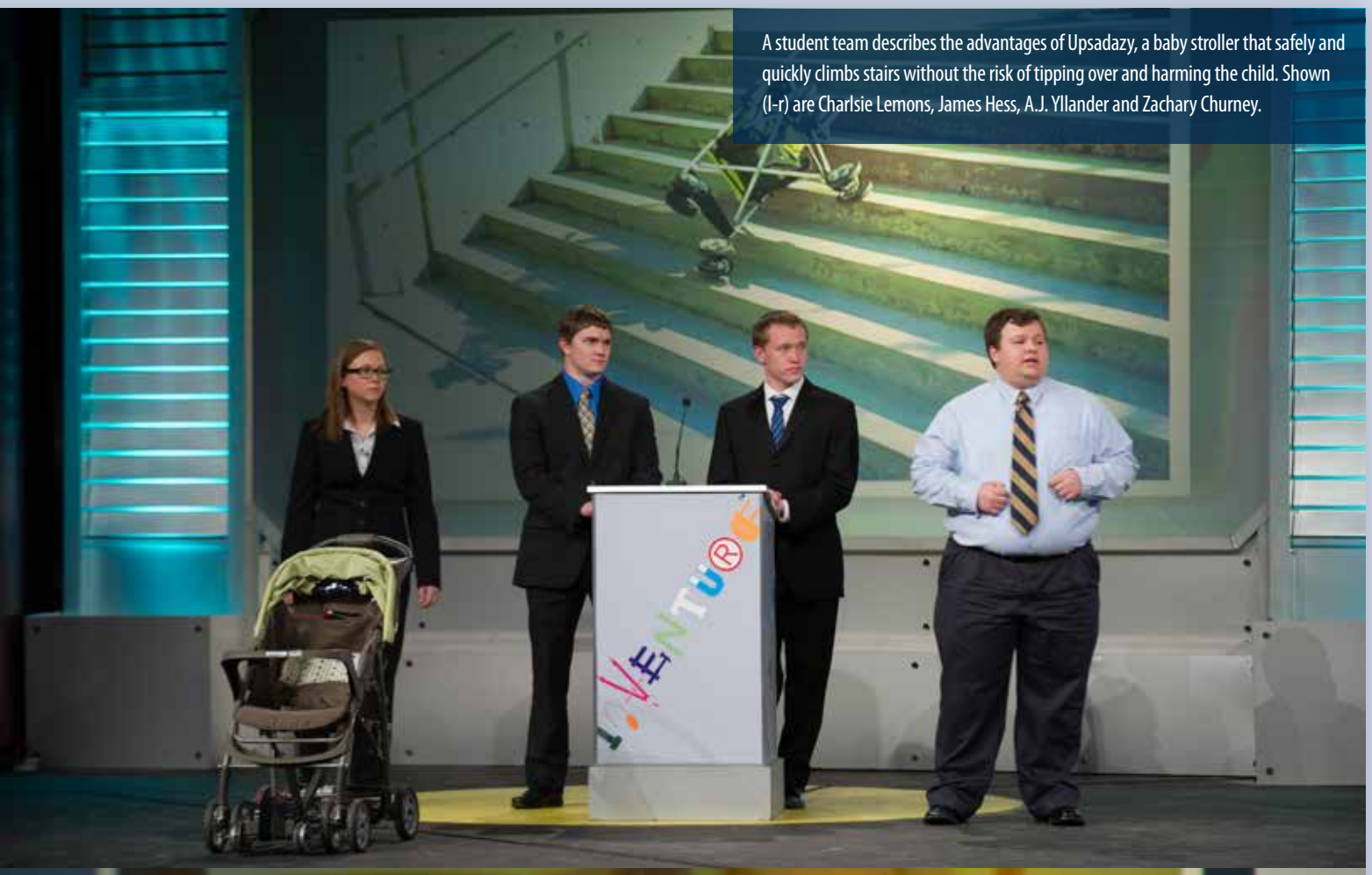
What's Next?

The next InVenture Prize finale is scheduled for April 1, 2015. Learn more about the competition here: (inventureprize.gatech.edu).

Photo: Rob Felt



A student team describes the advantages of Upsadazy, a baby stroller that safely and quickly climbs stairs without the risk of tipping over and harming the child. Shown (l-r) are Charlsie Lemons, James Hess, A.J. Yllander and Zachary Churney.

Students demonstrate the Sucette Smart Soother, a modernized pacifier designed to fit more naturally with a baby's mouth and growing dental structure. The device also indicates when a child has a fever. Shown (l-r) are Will McAllister and Esteban Ongini.

Photo: Rob Felt

The National Science Foundation's Innovation Corps (I-Corps™) program helps NSF-funded researchers learn about starting up a company. This includes helping participants determine whether there's really a market for what they've developed. Georgia Tech was one of the first nodes in the I-Corps network, and a dozen Georgia Tech researchers have gone through the program so far.

Photo: Maxwell Guberman

Professor Ayanna Howard has launched a company to commercialize an interface device, technology developed through an NSF grant. The technology allows disabled children to use tablet computers by connecting a wide range of specialized input devices.

Innovation Corps:

Initiative Helps Turn Research Discoveries into New Companies

By John Toon

Ayanna Howard has a heart for children with disabilities. So when a National Science Foundation (NSF) grant led to development of an input device that would allow kids with disabilities to operate tablet computers, she wanted to commercialize the technology to get it into the hands of the children.

But after talking with more than a hundred potential users of the device, she learned the real need was for a generic interface system able to connect a wide range of input devices – big button switches, joysticks, sip-and-puff straws and others – to the tablet computers. And it turned out that the market was much larger than Howard imagined, extending to adults with disabilities and potentially even persons with Alzheimer's.

A professor in the Georgia Tech School of Electrical and Computer Engineering, Howard has now launched a company, Zyrobotics, to commercialize the device. Run by a former graduate student, the company will help disabled children do what all kids want to do: play video games and interact with computers.

Assistance with refining the device came through the Innovation Corps (I-Corps™), an NSF program that helps researchers funded by the Foundation learn about starting up a company – and by talking to potential customers – to determine whether there's really a market for what they've developed.

"Without I-Corps, I wouldn't have thought to pursue this," said Howard, who holds the title of Motorola Foundation Professor. "They showed us how to talk about the technology in terms that the general public could understand. And I-Corps made us take a step back and ask if what we had developed was really of value to potential customers."

I-Corps Innovation

A dozen Georgia Tech teams – each composed of a faculty member, entrepreneurial lead, and industry mentor – have now gone through the six-week I-Corps program. About a third of them have, like Howard, revised their plans and decided to move forward with forming a company and creating a product based on the results of NSF-supported research. The program is part of a national effort to turn research discoveries into new companies and new products, supporting economic development and building understanding of what it means to be an entrepreneur.

"Through the Innovation Corps, NSF seeks to accelerate the development of new technologies, products, and processes that arise from fundamental research," said Rathindra (Babu) DasGupta, the NSF's program director for I-Corps. "The goals of I-Corps are to spur translation of fundamental research, to encourage collaboration between academia and industry, and to train students to understand innovation and entrepreneurship."

The program provides mentoring and funding designed to move the results of NSF-supported research through the early stages of company formation. "NSF investments strategically strengthen the nation's innovation ecosystem by addressing the challenges inherent in the early stages of the innova-

tion process," DasGupta added.

I-Corps at Georgia Tech

Because of its long experience with forming companies from university research, Georgia Tech was selected in July 2012 to be among the first institutions to become "nodes" teaching the I-Corps curriculum. The program is basically a boot camp that shows what it's like to form a startup company, and it helps ensure that there's a real market for a fledgling company's proposed product. About 25 teams from universities around the country participate each time the program is taught at one of the I-Corps nodes, including Georgia Tech's.

"The I-Corps process is very similar to the scientific method, which scientists and engineers are familiar with," explained Keith McGreggor, who directs the I-Corps program at Georgia Tech. "We use this process to turn fiction – what you might think is true – into fact by doing experiments and testing hypotheses in the real world with customers instead of in the laboratory."

I-Corps puts faculty members and graduate students through a pressure cooker environment that simulates a real startup. Not everyone is cut out for entrepreneurship, McGreggor noted. Faculty members often have a skill-set – collaborating with other researchers, teaching students, and publishing papers – that's different from the skills needed to produce products and services that non-researchers are willing to buy.

The centerpiece of the program is "customer discovery" in which the teams must talk with at least 100 potential customers about their proposed product. This interaction with the real world almost inevitably leads to what I-Corps staff call "the pivot," which occurs when the teams, based on customer feedback, realize they've been developing a product for which there isn't a market. In many cases, that realization leads to new, and successful, directions for the technology.

"Everyone starts out with one idea about what they want to do, and they almost always change to something else that they are also ca-

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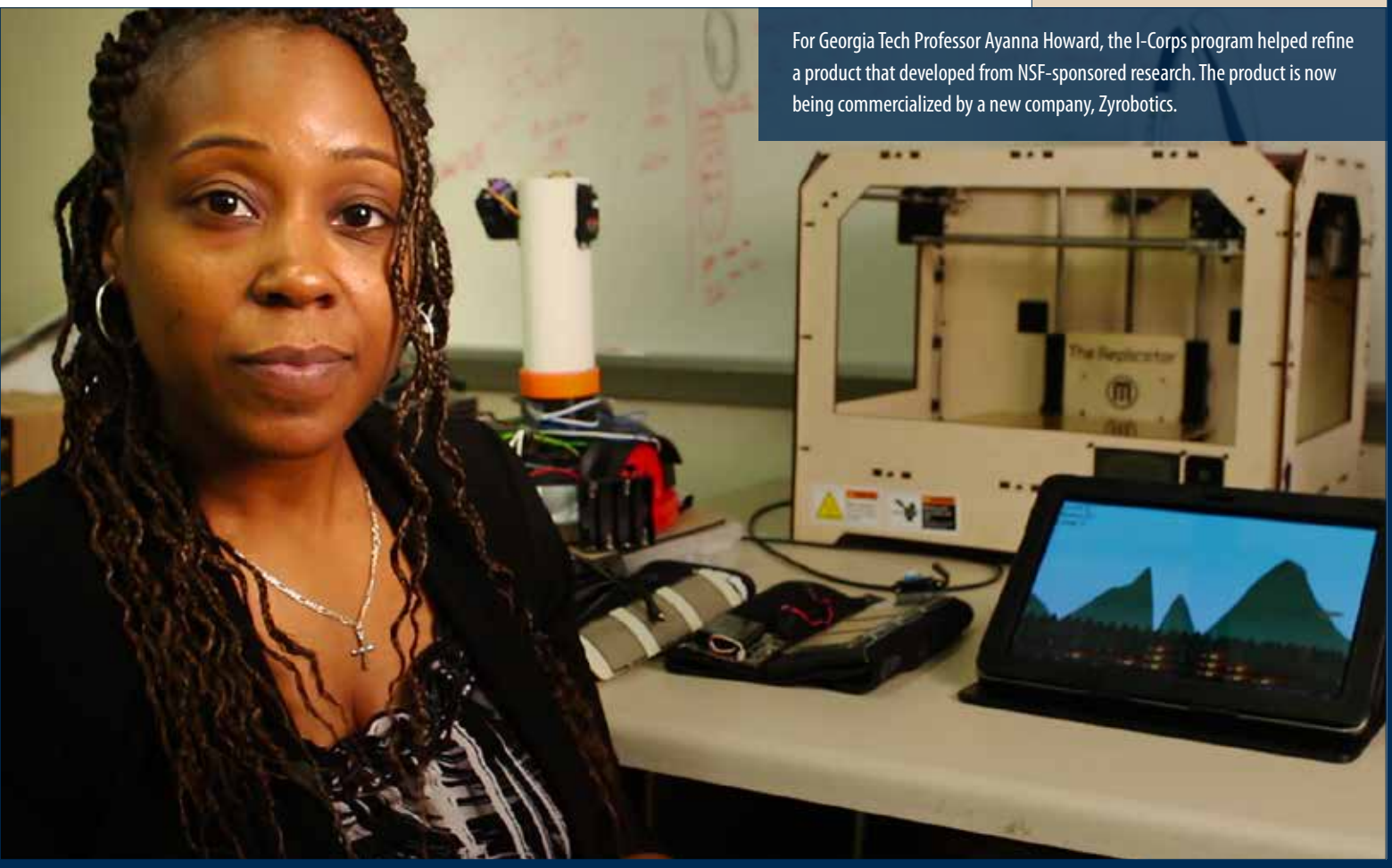
"The I-Corps process is very similar to the scientific method, which scientists and engineers are familiar with. We use this process to turn fiction – what you might think is true – into fact by doing experiments and testing hypotheses in the real world with customers instead of in the laboratory."

— Keith McGreggor, director of the I-Corps program at Georgia Tech



For Georgia Tech Professor Ayanna Howard, the I-Corps program helped refine a product that developed from NSF-sponsored research. The product is now being commercialized by a new company, Zyrobotics.

Photo: Maxwell Guberman

Keith McGreggor, who directs the I-Corps program at Georgia Tech, addresses one of the first groups of commercialization teams to go through the program. I-Corps helps faculty understand how to turn research results into new products and companies.

Photo: Gary Meek

pable of doing," McGreggor said. "It can be difficult for people to switch gears, but what's beautiful about this program is that they do switch."

At the end of the six weeks, the teams decide whether or not to go forward with their idea. For Georgia Tech teams, fledgling companies that emerge from the process can join VentureLab, a program that helps researchers form companies, create prototypes, bring in experienced management, and obtain early-stage funding. VentureLab companies can go on to be members of the Advanced Technology Development Center (ATDC), Georgia Tech's incubator program that helps entrepreneurs launch and build successful companies. Many also participate in Flashpoint, an accelerator program open to technology companies in Georgia.

Marketing MOFs

Krista Walton and David Sholl used the I-Corps process to confirm the market need for metal-organic frameworks (MOFs), a new materials technology with a broad range of potential market applications. With NSF support, the researchers had developed a way to scale up the synthesis of MOFs, a class of nanomaterials. But they weren't sure what direction to take next – a classic problem for technologies that have many possible applications.

"By talking with more than 100 potential customers, we went through numerous refinements in our understanding of how we can create a sustainable business with our technology," said Sholl, chair of Georgia Tech's School of Chemical and Biomolecular Engineering. "We saw over and over again that the issues that obsess researchers doing fundamental research and the issues that matter to customers are often not the same."

Talking with the customers required a large investment of time, but Sholl – who is also a Georgia Research Alliance (GRA) Eminent Scholar in Energy Sustainability – was pleased with the level of interest in the technology. The potential customers he and Walton interviewed also identified applications they had never considered.

As a result of the process, Sholl and Walton – an associate professor in the School of Chemical and Biomolecular Engineering – formed Inmondo Tech, and are working with several initial customers to develop a first product.

Smartphone Questions

For Gregory Abowd, the benefits of I-Corps were different. A serial entrepreneur with a record of launching successful companies, Abowd felt he knew how to commercialize technology he developed that helps connect young patients with their doctors

I-Corps requires a large investment of time, something that can be difficult if faculty members aren't prepared for it. At least one member of the team has to be available nearly full-time during the six-week program.

Photo: Gary Meek

through handheld devices. But he wanted to apply I-Corps' systematic process to starting a new company.

"I've had some successful and unsuccessful startup efforts, but I really didn't understand what the important elements of the successful ones were," said Abowd, who is a Regents' Professor and Distinguished Professor in Georgia Tech's School of Interactive Computing. "I was intrigued with the idea of being a little more structured going into this one, because I had learned there are an infinite number of ways to make mistakes in the business world."

The company, established as L.S.Q. LLC in Georgia, will provide a way to ask questions of smartphone users at times when they aren't actively using their handheld devices. Building on the original purpose of the technology, which was to boost interaction with children who have chronic diseases, Abowd sees many possible applications, including surveys designed for the small screens of mobile devices.

"We'll ask questions at a point when people are interacting with their phones, but at a point of pause," he explained. Abowd has assembled a team and is talking with potential customers. He expects to form a joint venture with a market research firm and develop a product quickly.

Advice to Others

What advice do the teams give faculty members and graduate students thinking about participating in I-Corps?

"There is a growing network to help with commercialization, both at Georgia Tech and around the country," noted Abowd. "A successful startup requires a lot of effort, and it's more than a full-time job. I-Corps gives you a six-week exposure to help you determine whether this is right for you."

I-Corps requires a large investment of time, something that can be difficult if faculty members aren't prepared for it, Howard noted. To be successful, at least one member of the team has to be available nearly full-time during the six-week program.

"I would recommend this 100 percent, and have already talked with other faculty members about I-Corps," Howard said. "This process is very different from what we normally do in research and teaching, and it has changed the way I think about what I do. It was a great experience for us."

I-Corps teams follow a rigorous application process designed to determine whether team members are truly committed to launching and building a startup, McGreggor noted. That can be daunting.

"I-Corps simulates a startup, so it puts a lot of heat on the team to see if they are going to stay together when they get into a company,"

David Sholl, chair of Georgia Tech's School of Chemical and Biomolecular Engineering, is co-founder of startup company Inmondo Tech. The company is commercializing metal-organic framework materials.

Photo: Billy Howard

he said. "We challenge the researchers in ways that they have probably not been challenged since they were graduate students. It is exquisitely uncomfortable for some people."

Broader Impacts

I-Corps has also changed the way Georgia Tech approaches startup companies. Customer discovery and early pivoting to serve the marketplace, for instance, are now at the core of Georgia Tech's VentureLab program, which serves all students, faculty, and researchers, McGreggor said.

"Faculty members are forced to look into the face of a world that may not want what they have produced," he said. "What we've learned is that when entrepreneurs get it wrong, it's usually because they are building something that nobody really wants. This has really changed our approach to doing things in VentureLab."

The I-Corps focus on the role of graduate students in the startup process aligns well with the practice of VentureLab, as faculty members may not have the time or flexibility to commit to the demanding needs of a growing startup.

VentureLab recognizes that the graduate students involved in developing a technology may be the right team members to go forward as part of the new company. That makes creating a startup a real alternative to traditional post-graduation opportunities.

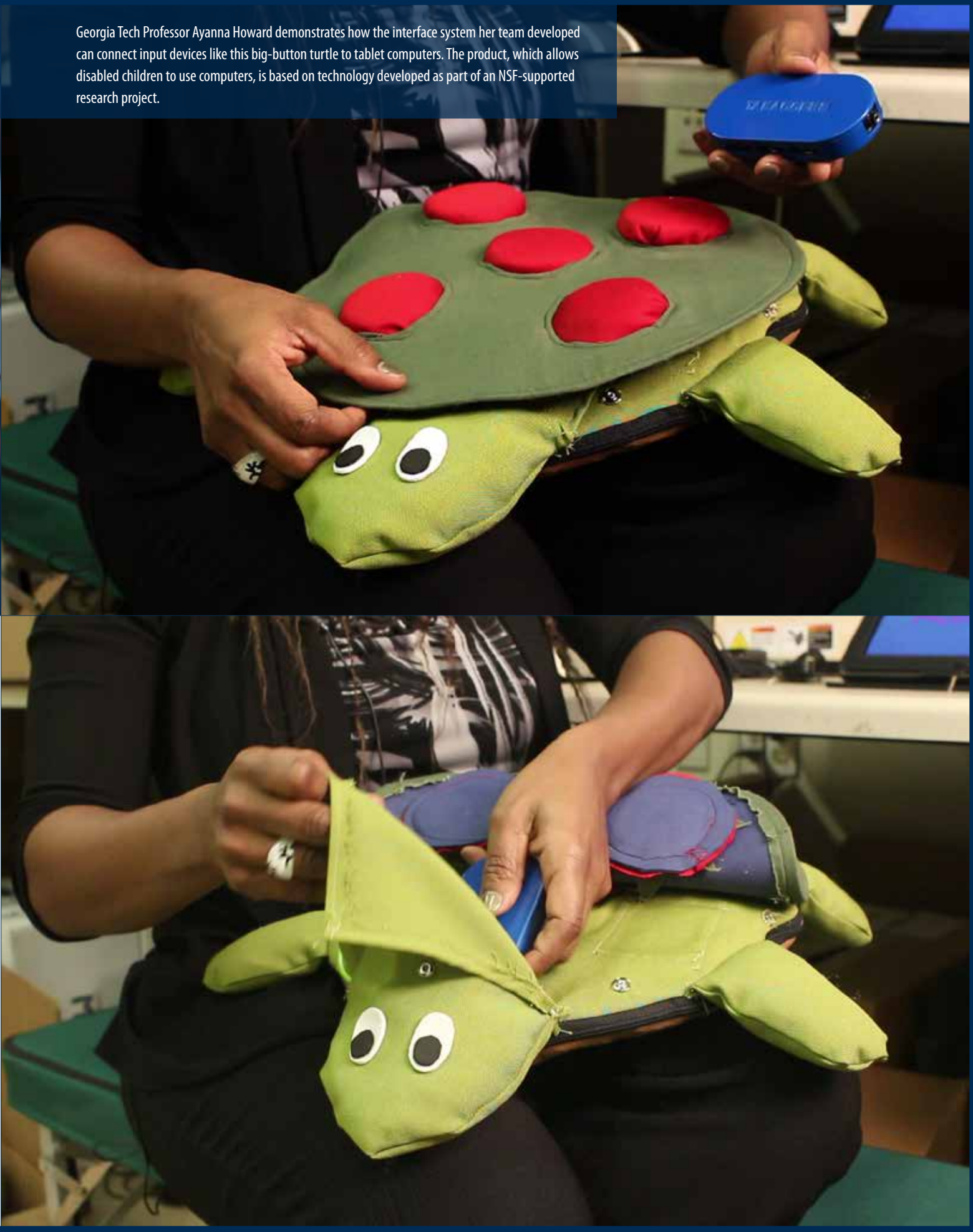
Beyond the new enterprises begun, the I-Corps program is having a larger impact on the universities whose faculty members have participated.

"Additional successes of the program have been far-reaching," said the NSF's DasGupta. "Faculty are taking what they learned in I-Corps about innovation and technology transfer back to their universities and training their students differently. The participation of students and postdoctoral fellows in I-Corps has also had favorable impacts: They report that their employability is enhanced by their participation in I-Corps."

The program was launched in 2011, and continues to evolve as NSF tracks the results. In addition to its teams of researchers, entrepreneurs, and mentors, I-Corps is also focusing on nodes and sites to bring the concepts to a larger group of NSF researchers.

"We continue to explore ways to expand the program's impact nationally, and at the state and local levels," DasGupta added. rh

Photos: Maxwell Guberman



Georgia Tech Professor Ayanna Howard demonstrates how the interface system her team developed can connect input devices like this big-button turtle to tablet computers. The product, which allows disabled children to use computers, is based on technology developed as part of an NSF-supported research project.

The Advanced Technology Development Center (ATDC) is Georgia Tech's technology incubator, which helps entrepreneurs launch and build companies. The nation's oldest and most successful university-based incubator, ATDC graduated three companies in March 2014. This article highlights how ATDC assisted them.

Launching and Building Companies:

Georgia Tech's Advanced Technology Development Center is a Startup Powerhouse

By John Toon

Photo: Rob Felt

Georgia Tech's Advanced Technology Development Center (ATDC) is headquartered in Technology Square. ATDC has helped make Midtown Atlanta a center for startup technology companies in Georgia.

When he enrolled as a Ph.D. student in Georgia Tech's College of Computing five years ago, Vijay Balasubramaniyan never expected to become the CEO of one of Atlanta's hottest young information security companies.

But, today, the phone call fingerprinting technique he developed provides the foundation for Pindrop Security, a three-year-old company that has attracted $12 million in investment from Andreessen Horowitz, one of Silicon Valley's most prestigious venture capital firms. Pindrop counts top U.S. companies among its customers; these include two of the nation's five largest banks.

From an office in Midtown, near Georgia Tech's Technology Square, the company is building a business to help battle the multi-billion dollar problem of fraud committed using the telephone.

As Pindrop's CEO, Balasubramaniyan handles duties that are vastly different from those of his Ph.D. days. He's meeting with marketing and engineering staff, dashing off to customer meetings on the West Coast, and glancing at a large computer screen that monitors potentially fraudulent calls going into the call centers of Pindrop's customers.

On March 27, Pindrop became one of three companies to graduate from the Advanced Technology Development Center (ATDC), Georgia Tech's startup incubator. ATDC was established 34 years ago to create technology jobs and economic growth for the state of Georgia.

The three graduate companies – Pindrop, MessageGears and SalesLoft – show ATDC's technology diversity.

Pindrop Security: Flagging Fraudulent Calls

Each type of handset and each telephone network has its own unique audio characteristics. Caller ID can be spoofed to indicate that a request for a new credit card or wire transfer of money is coming from Atlanta. But if the call is really coming from a Skype phone in Nigeria, Pindrop Security can tell.

"We are trying to bring trust back to the telephone," said Balasubramaniyan, who co-founded Pindrop in 2011. "We extract about 147 different features from the audio of the call. These features

Vijay Balasubramaniyan

uniquely identify the phone as well as what type of device is making the call and where in the world that call is coming from. That allows us to differentiate what is a legitimate call and what is a fraudulent call."

Banks, financial institutions, retailers, and others now attempt to verify calls by asking for personal information: a caller's hometown, mother's maiden name, or high school attended. In the old days, this information was known only to the callers, but thanks to the Internet and services such as Facebook, such personal data can be readily available to fraudsters.

Large companies are fighting these fraudsters by capturing their voiceprints and maintaining lists of bad phone numbers. But those work only after the first fraudulent call and can be defeated if the fraudsters can alter their voices.

In the fall of 2010, at a major computer security conference, Balasubramaniyan presented the concept of "acoustic fingerprinting" phone calls. He was joined by Mustaque Ahamad, then director of the Georgia Tech Information Security Center, and Patrick Traynor, an associate professor in the Georgia Tech School of Computer Science. The presentation ignited a frenzy of media coverage, which attracted a flood of inquiries from banks and financial services companies.

Balasubramaniyan was then invited to present at a major financial services conference, which heightened the interest. "At that point, we knew we had a technology that could be commercialized," he recalled.

Balasubramaniyan partnered with Paul

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"We are all about supporting entrepreneurs. It isn't just about space. It isn't just about coaching or mentoring. It isn't just about investors or customers. We have all the things that an entrepreneur needs at ATDC."

— K.P. Reddy, interim general manager of the ATDC

The "Wall of Fame" at ATDC headquarters highlights graduates of the startup accelerator. More than 150 companies have gone through the ATDC program, and they have created thousands of new jobs.

Photo: Rob Felt

Judge, a repeat entrepreneur who holds a Georgia Tech Ph.D., to co-found Pindrop. "Atlanta has good ideas and technical geniuses who deserve a global stage," said Judge. "My focus is working to turn a good idea into a great company."

Pindrop worked with Georgia Tech's VentureLab program, which helps faculty members and research staff commercialize technology developed in research labs. It also got assistance with a proposal to the National Science Foundation for a Small Business Innovation Research (SBIR) grant, which provided early funding to help develop the technology. More assistance came from the Georgia Research Alliance (GRA), which offered seed funding, and Flashpoint, a Georgia Tech program that accelerates the growth of technology companies.

The success path led to ATDC, which helped connect Pindrop to a broad range of resources.

"ATDC has constantly helped us to be bigger than we actually are," said Balasubramaniyan. "When you are dealing with really large banks, you want great conference rooms and office space. You want a great look and feel for when you bring customers to your offices. ATDC has helped significantly with that."

Balasubramaniyan previously worked for several leading technology companies. At those companies, he helped build network management software and other commercially important applications following a clear solution map.

"When I came to Georgia Tech, I was working on purely hard problems, really difficult problems for which the solutions weren't clear," he said. "At Pindrop, we have this unique opportunity to work on problems that are not only hard, but also meaningful. To hear our customers talk about situations where we have protected somebody's life savings or somebody's retirement account, on a day-to-day basis, that is what makes this job really meaningful."


Dan Roy

MessageGears: Meeting Email Customization Challenges

Sophisticated companies carefully tailor their email marketing campaigns based on what they know about their customers. But the information needed to produce custom campaigns usually resides in databases behind secure firewalls, while the emails themselves must be sent from a "software-as-service" (SAS) system located outside the firewall.

MessageGears, another 2014 graduate of Georgia Tech's ATDC, has developed a product that allows companies to have the best of both these worlds.

"The challenge for the kinds of customers we are selling to is that they have lots of data they need to use in the messages to personalize the messages," said Dan Roy, CEO of the company. "What we have done with our technology is split the challenge in half. The delivery system is an SAS-based component, and we manage deliverability for our customers. But the software itself runs on premise and connects directly to our customers' databases."

Founded in 2010, the company now has about 50 customers, including such names as GEICO and Activision.

"We measure our success by our growth in message volume," said Roy. "We are sending more than 100 million messages a month now, and our goal is to get to a billion messages by the end of next year."

MessageGears connected to ATDC through friends who were familiar with the organization. Roy had worked for a Silicon Valley startup, so he had heard of the organization. But MessageGears was his first time as a CEO.

"This was new territory with me, and I just wanted to get immersed into a community of other entrepreneurs to learn the ropes," he said. "Every entrepreneur has to think about funding and fundraising from the very beginning. We had some seed funding when we started the company, but we knew that was going to run out pretty quickly before we built a customer base and started getting revenue."

ATDC helped explain fundraising and provided information that Roy and the company's co-founders needed to interact with the investor community and consider their choices.

"It was very valuable to us, and I'm not even sure where we would be without the support of ATDC," he added. "The formal ATDC organization is great, but just being in a community of other entrepreneurs, people who are in a similar situation to us, is very helpful."


Kyle Porter

SalesLoft: Finding Prospects Using the Internet

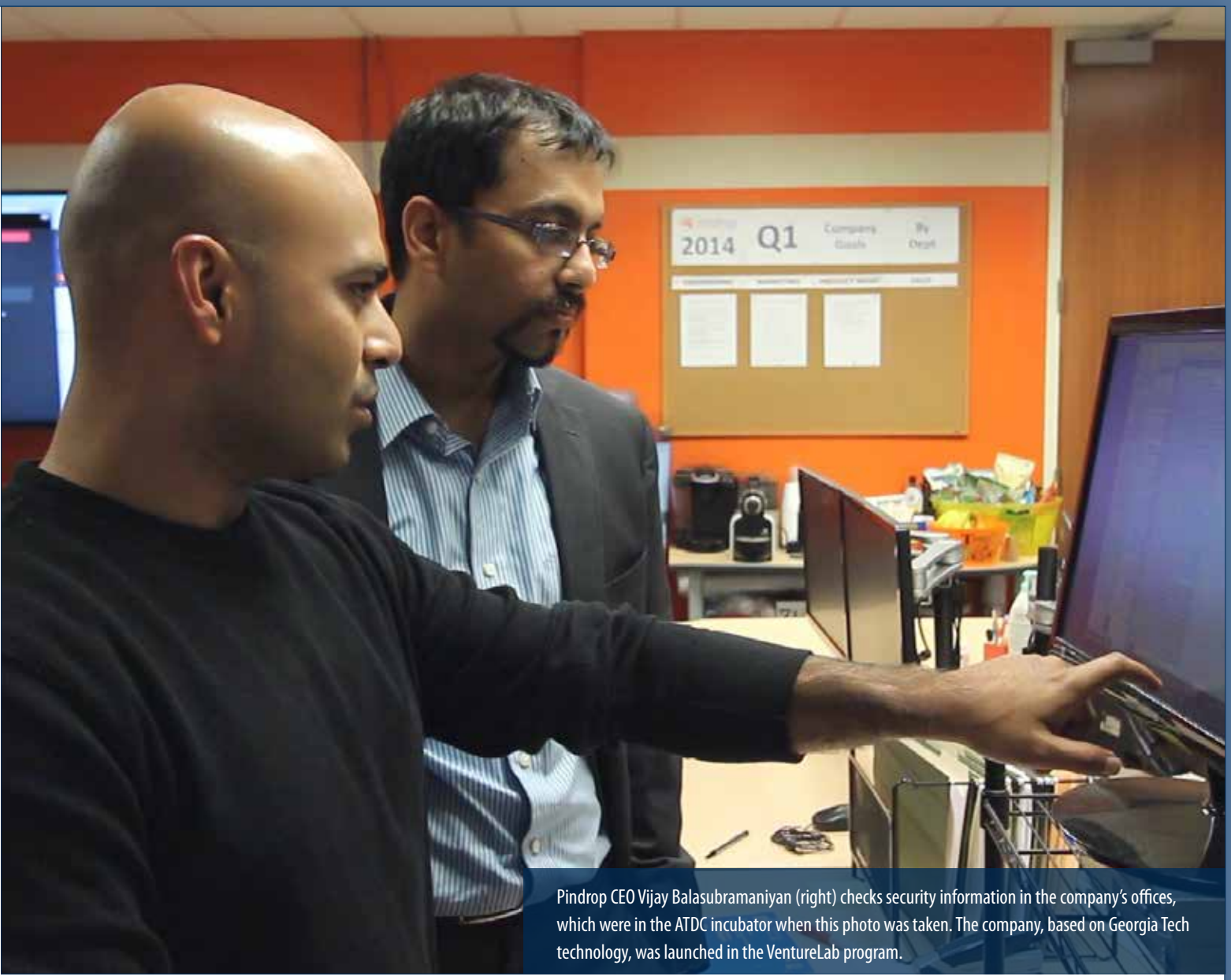
Finding appropriate sales prospects can be one of a company's greatest challenges. Manually searching the Internet is one way. SalesLoft is a better way, said Kyle Porter, the company's CEO – and a Georgia Tech graduate.

"SalesLoft builds a platform that gives marketers, sales professionals, and prospectors the ability to build accurate and targeted lists of leads just using information on the Internet," he explained. "Someone can come onto SalesLoft and say, 'I want to talk with VPs of manufacturing in the Boston area with company sizes between 50 and 200 employees.'"

"Our software allows them to collect all that information on the Web, adds in a bunch of demographic fields, finds phone numbers and email addresses, then synchs to popular CRM systems."

Porter and co-founder David Cummings started SalesLoft in late 2011. By 2012, SalesLoft was recognized as one of the top 10 most innovative companies in Georgia by the Technology Association of Georgia. In the last year, they've added 12,000 new users.

Photo: Maxwell Guberman



Pindrop CEO Vijay Balasubramaniyan (right) checks security information in the company's offices, which were in the ATDC incubator when this photo was taken. The company, based on Georgia Tech technology, was launched in the VentureLab program.

Porter credits Rob Forman and Tim Dorr – also a Georgia Tech graduate – for building a great product.

SalesLoft's path to the ATDC began with a delivery accident. In 2004, Porter had partnered on a real estate investment with Lloyd Solomon, then CEO of ATDC member company Quellan. One day, a package addressed to Quellan was accidentally delivered to Porter. While dropping the package off to Solomon at ATDC's Centergy headquarters, Porter received a tour of the incubator and was bitten by the startup bug.

He took a job with a human resources company in the building and spent the next five years developing a network of CEOs, entrepreneurs, service providers, and investors.

"When we started SalesLoft in 2011, we immediately joined ATDC as a select member and have had a ton of value from the Industry Connect program," Porter said. "We have been able to address a lot of our business challenges. For me as a first-time CEO, there were a lot of the things that I had never dealt with before, and these guys have been able to walk me through and help with those challenges. It has been awesome to have them almost like an extra founder on the team."

ATDC: Building a Technology Ecosystem

"These three companies demonstrate the kind of diversity that we have in the ATDC," said K.P. Reddy, an entrepreneur, author, and Georgia Tech graduate who serves as the incubator's interim general manager. "If you look at any ecosystem – and we are part of a larger technology ecosystem – diversity like this is what drives its health."

ATDC assists companies spinning out of Georgia Tech, those headed up by Georgia Tech alumni, and companies that have no direct Georgia Tech connection. The common denominator is a fit with the ATDC program.

ATDC emphasizes coaching, support from a community of entrepreneurs, and connections to a broad range of resources. The

Georgia Tech's Advanced Technology Development Center (ATDC) operates its incubator on an entire floor of the Centergy Building in Technology Square. At any given time, as many as 30 companies are operating in the facility.

Photo: Rob Felt

companies receive access to Georgia Tech resources: students, faculty, and research facilities. Additionally, they can connect to industry giants such as AT&T, which recently located one of its Foundry product development centers in Technology Square to be close to the startup community there.

"We are not trying move the needle 5 percent or 10 percent," Reddy explained. "We are trying to make orders of magnitude differences for startup companies. We are able to help companies do much more than they could on their own."

Each of the 2014 graduates cites a different benefit from ATDC, which isn't surprising, said Reddy.

"We are all about supporting entrepreneurs," he explained. "It isn't just about space. It isn't just about coaching or mentoring. It isn't just about investors or customers. We have all the things that an entrepreneur needs at ATDC."

Among the newest programs are Industry Connect and Campus Connect. Industry Connect brings in representatives from Atlanta's largest corporations to learn about startups that may have solutions to the challenges they face. In 2013, ATDC's Industry Connect program facilitated more than 20 contracts between ATDC startups and Global 1000 companies.

Campus Connect helps ATDC companies leverage Georgia Tech resources, connecting them to one of the nation's top 10 publicly supported universities, with a science and engineering research program that is among the largest in the United States.

"There is a lot of brain power and a lot of talent at Georgia Tech, and we are leveraging that," said Reddy. "Being connected to a top university really makes a difference."

And, the Georgia Tech connections extend beyond faculty and research assistance. A recent career fair held with the Georgia Tech College of Computing and School of Electrical and Computer Engineering attracted 150 students, who learned about opportunities at 25 startups. Internships and new hires will likely result, Reddy said.

ATDC companies tend to fall into two categories: those with high market risk and low technical risk – such as social media companies – and those with high technical risk and low market risk, including many of the science-based startups spinning out of Georgia Tech. Those two groups help one another, and build a robust ecosystem.

"Our scientists have to learn how to market, and our marketers have to learn about science," Reddy noted. "That's where the ecosystem gets really strong."

Reddy believes ATDC has a great reputation, one that should make it top of mind for any technology entrepreneur in Georgia.

"If I'm looking for hash browns, I go to Waffle House," he added. "If I'm going to start a company, I go to ATDC." rh

Staff members of ATDC graduate company MessageGears pose in the company's offices in Midtown Atlanta. The company helps marketers customize their email campaigns.

Photo: Maxwell Guberman

Scientists have engineered a bacterium to synthesize pinene, a hydrocarbon produced by trees that could potentially replace high-energy fuels, such as JP-10, in missiles and other aerospace applications. With improvements in process efficiency, the biofuel could supplement limited supplies of petroleum-based JP-10.

Tree Power:

Engineered Bacteria Produce Biofuel Replacement for High-Energy Rocket Fuel

By John Toon

Could tree enzymes help power the rockets of the future?

Researchers at Georgia Tech and the Joint BioEnergy Institute in California have engineered a bacterium to synthesize pinene, a hydrocarbon produced by trees that could potentially replace high-energy fuels, such as JP-10, in missiles and other aerospace applications. With improvements in process efficiency, the biofuel could supplement limited supplies of petroleum-based JP-10 – and might also facilitate development of a new generation of more powerful engines that could use the fuel.

By inserting enzymes from trees into the bacterium, first author and Georgia Tech graduate student Stephen Sarria, working under the guidance of Georgia Tech assistant professor Pamela Peralta-Yahya, boosted pinene production six-fold over earlier bioengineering efforts. Though a more dramatic improvement will be needed before pinene dimers can compete with petroleum-based JP-10, the scientists believe they have identified the major obstacles that must be overcome to reach that goal.

Funded by the U.S. Department of Energy's Office of Science and by Georgia Tech startup funds awarded to Peralta-Yahya's lab, the research was reported February 27, 2014, in the journal *ACS Synthetic Biology*.

"We have made a sustainable precursor to a tactical fuel with a high energy density," said Peralta-Yahya, an assistant professor in the School of Chemistry and Biochemistry and the School of Chemical and Biomolecular Engineering. "We are concentrating on making a 'drop-in' fuel that looks just like what is being produced from petroleum and can fit into existing distribution systems."

Fuels with high energy densities are important in applications where minimizing fuel weight is important. The gasoline used to power automobiles and the diesel used mainly in trucks both contain less energy per liter than the JP-10. The molecular arrangement of JP-10, which includes multiple strained rings of carbon atoms, accounts for its higher energy density.

The amount of JP-10 that can be extracted from each barrel of oil is limited, and sources of potentially comparable compounds such as trees can't provide much help. The limited supply drives the price of JP-10 to around $25 per gallon. That price point gives researchers working on a biofuel alternative a real advantage over scientists working on replacing gasoline and diesel.

"If you are trying to make an alternative to gasoline, you are competing against $3 per gallon," Peralta-Yahya noted. "That requires a long optimization process. Our process will be competitive with $25 per gallon in a much shorter time."

While much research has gone into producing renewable ethanol and bio-diesel fuels, comparatively little work has been done on replacements for the high-energy JP-10.

Photo: Rob Felt

By placing colonies of E. coli engineered to produce pinene into test tubes containing glucose, researchers were able to determine which enzyme combinations produced the hydrocarbon most efficiently.

Peralta-Yahya and collaborators set out to improve on previous efforts by studying alternative enzymes that could be inserted into the E. coli bacterium to produce fuel from sugars. They settled on two classes of enzymes – three pinene synthases and three geranyl diphosphate synthases – and experimented to see which combinations produced the best results.

Their results were much better than earlier efforts, but the researchers were puzzled, because for a different hydrocarbon, similar enzymes produced more fuel per liter. So they tried an additional step to improve their efficiency. They placed the two enzymes adjacent to one another in the E. coli cells, ensuring that molecules produced by one enzyme would immediately contact the other. That boosted their production to 32 milligrams per liter – much better than earlier efforts, but still not competitive with petroleum-based JP-10.

Peralta-Yahya believes the problem now lies with built-in process inhibitions that will be more challenging to address. To be competitive, the researchers will have to boost their production of pinene 26-fold. Peralta-Yahya says that's within the range of possibilities for bioengineering the E. coli.

Theoretically, it may be possible to produce pinene at a cost lower than that of petroleum-based sources. If that can be done – and if the resulting biofuel operates well in these applications – that could open the door for lighter and more powerful engines fueled by increased supplies of high-energy fuels. Pinene dimers have already been shown to have an energy density similar to that of JP-10.

Co-authors from the Joint BioEnergy Institute included Betty Wong, Hector Garcia Martin, and Professor Jay D. Keasling, co-corresponding author of the paper. rh

CITATION: Stephen Sarria, et al., "Microbial Synthesis of Pinene," (ACS Synthetic Biology, 2014). (http://dx.doi.org/10.1021/sb4001382).

This work was started at the DOE Joint BioEnergy Institute (JBEI) and finished at Georgia Tech. The work at JBEI was funded by the U.S. Department of Energy's Office of Science, Office of Biological and Environmental Research through contract DE-AC02-05CH11231 between Lawrence Berkeley National Laboratory and the U.S. Department of Energy (DOE). The work at Georgia Tech was funded by startup funds awarded to the Peralta-Yahya laboratory. Any opinions expressed are those of the authors and do not necessarily represent the official views of the DOE.

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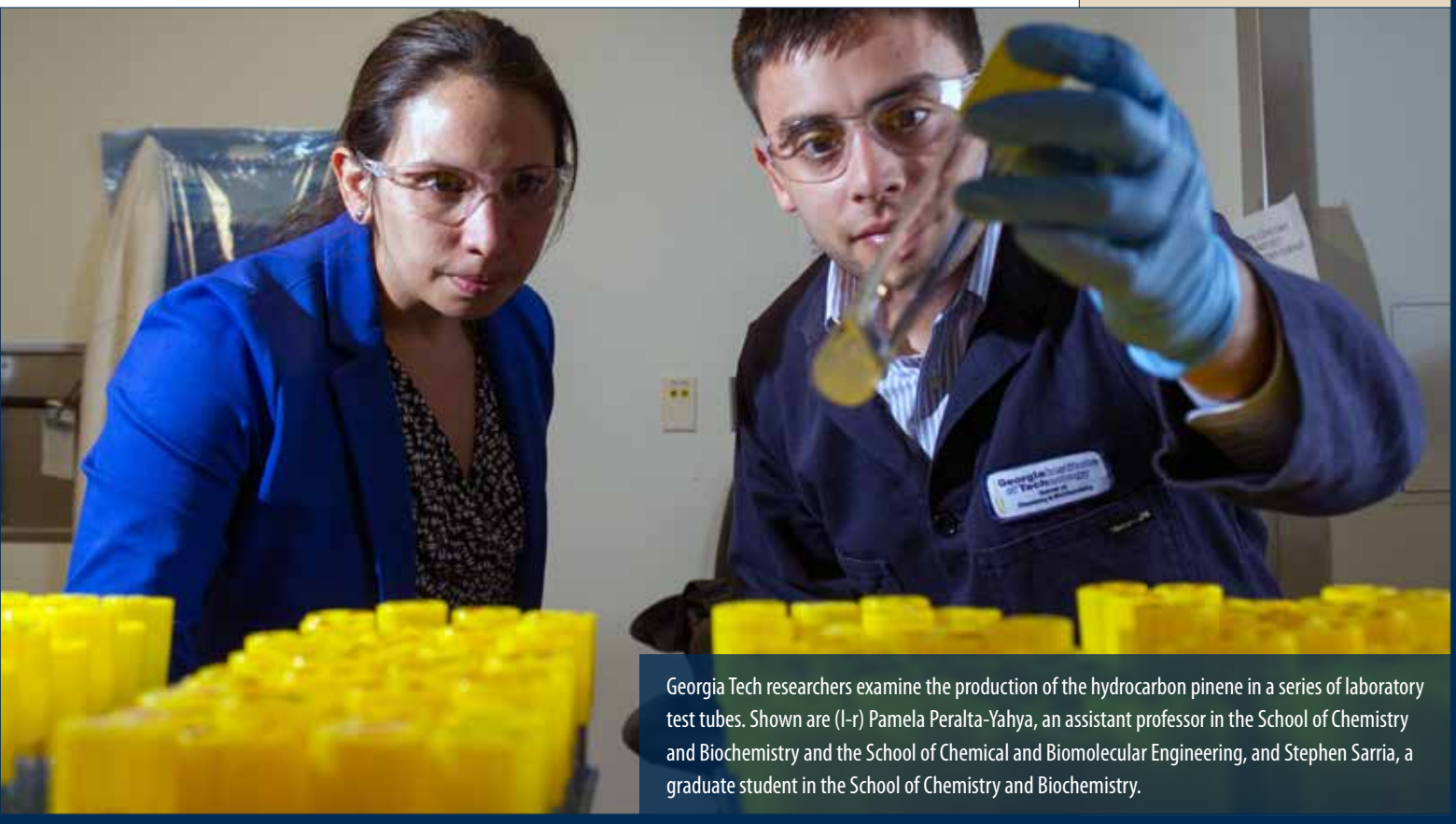
"We have made a sustainable precursor to a tactical fuel with a high energy density. We are concentrating on making a 'drop-in' fuel that looks just like what is being produced from petroleum and can fit into existing distribution systems."

— Pamela Peralta-Yahya, assistant professor in the School of Chemistry and Biochemistry



Georgia Tech researchers examine the production of the hydrocarbon pinene in a series of laboratory test tubes. Shown are (l-r) Pamela Peralta-Yahya, an assistant professor in the School of Chemistry and Biochemistry and the School of Chemical and Biomolecular Engineering, and Stephen Sarria, a graduate student in the School of Chemistry and Biochemistry.

Photo: Rob Felt

A collaboration of engineers from two continents has demonstrated the world's fastest silicon-based device to date. The investigators operated a silicon-germanium (SiGe) transistor at 798 gigahertz (GHz) f_MAX, exceeding the previous speed record for silicon-germanium chips by about 200 GHz.

Speedy Transistors:

Silicon-Germanium Chip Sets New Speed Record

By Rick Robinson

Photo: Rob Felt

Professor John Cressler (left) and graduate student Partha Chakraborty work at a cryogenic probe station at Georgia Tech to analyze the operation of the new silicon-germanium chip.

A research collaboration consisting of IHP-Innovations for High Performance Microelectronics in Germany and Georgia Tech has demonstrated the world's fastest silicon-based device to date. The investigators operated a silicon-germanium (SiGe) transistor at 798 gigahertz (GHz) f_MAX, exceeding the previous speed record for silicon-germanium chips by about 200 GHz.

Although these operating speeds were achieved at extremely cold temperatures, the research suggests that record speeds at room temperature aren't far off, said professor John D. Cressler, who led the research for Georgia Tech. Information about the research was published in February 2014 by the journal *IEEE Electron Device Letters*.

"The transistor we tested was a conservative design, and the results indicate that there is significant potential to achieve similar speeds at room temperature – which would enable potentially world-changing progress in high data rate wireless and wired communications, as well as in signal processing, imaging, sensing, and radar applications," said Cressler, who holds the Schlumberger Chair in Electronics in the School of Electrical and Computer Engineering. "Moreover, I believe that these results also indicate that the goal of breaking the so-called 'terahertz barrier' – meaning achieving terahertz speeds in a robust and manufacturable silicon-germanium transistor – is within reach."

Meanwhile, Cressler added, the tested transistor itself could be practical as is for certain cold-temperature applications. In particular, it could be used in its present form for demanding electronics applications in outer space, where temperatures can be extremely low.

IHP, a research center funded by the German government, designed and fabricated the device, a heterojunction bipolar transistor (HBT) made from a nanoscale SiGe alloy embedded within a silicon transistor. Cressler and his Georgia Tech team, including graduate students Partha S. Chakraborty, Adilson S. Cardoso, Brian R. Wier and Anup P. Omprakash, performed the exacting work of analyzing, testing, and evaluating the novel transistor.

"The record low temperature results show the potential for further increasing the transistor speed toward terahertz (THz) at room temperature. This could help enable applications of silicon-based technologies in areas in which compound semiconductor technologies are dominant today. At IHP, B. Heinemann, H. Rücker, and A. Fox were supported by the whole technology team working to develop the next THz transistor generation," said Bernd Tillack, who is leading the technology department at IHP in Frankfurt (Oder), Germany.

Silicon, a material used in the manufacture of most modern microchips, is not competitive with other

materials when it comes to the extremely high performance levels needed for certain types of emerging wireless and wired communications, signal processing, radar, and other applications. Certain highly specialized and costly materials – such as indium phosphide, gallium arsenide, and gallium nitride – presently dominate these highly demanding application areas.

But silicon-germanium changes this situation. In SiGe technology, small amounts of germanium are introduced into silicon wafers at the atomic scale during the standard manufacturing process, boosting performance substantially.

The result is cutting-edge silicon-germanium devices such as the IHP Microelectronics 800 GHz transistor. Such designs combine SiGe's extremely high performance with silicon's traditional advantages – low cost, high yield, smaller size, and high levels of integration and manufacturability – making silicon with added germanium highly competitive with the other materials.

Cressler and his team demonstrated the 800 GHz transistor speed at 4.3 kelvins (452 degrees below zero, Fahrenheit). This transistor has a breakdown voltage of 1.7 volts, a value that is adequate for most intended applications.

The 800 GHz transistor was manufactured using IHP's 130-nanometer BiCMOS process, which has a cost advantage compared with today's highly scaled CMOS technologies. This 130-nanometer SiGe BiCMOS process is offered by IHP in a multi-project wafer foundry service.

The Georgia Tech team used liquid helium to achieve the extremely low cryogenic temperatures of 4.3 kelvins in achieving the observed 798 GHz speeds. "When we tested the IHP 800 GHz transistor at room temperature during our evaluation, it operated at 417 GHz," Cressler said. "At that speed, it's already faster than 98 percent of all the transistors available right now." rh

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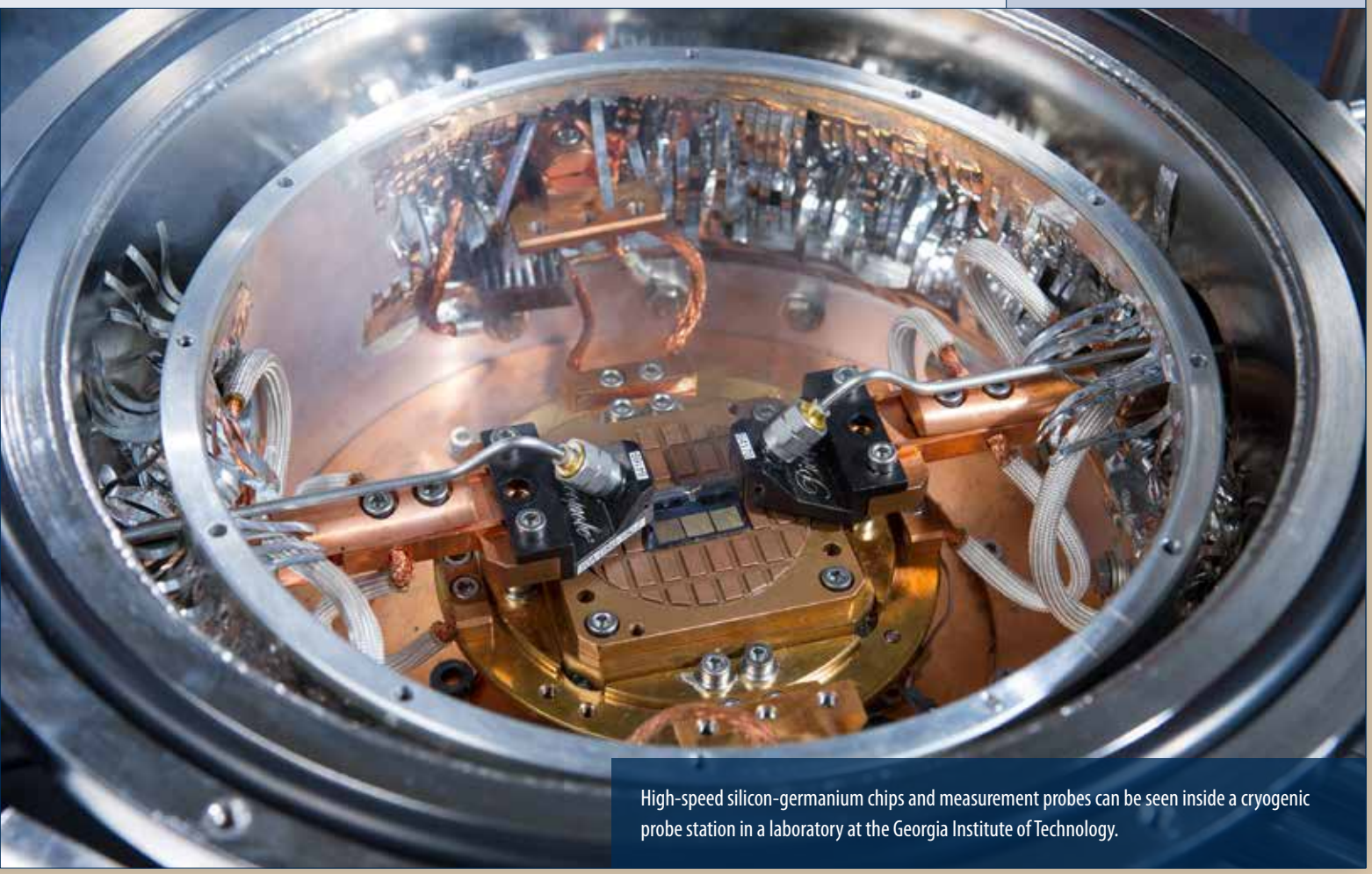
— John Cressler, professor in the School of Electrical and Computer Engineering



High-speed silicon-germanium chips and measurement probes can be seen inside a cryogenic probe station in a laboratory at the Georgia Institute of Technology.

Photo: Rob Felt

Georgia Tech researchers are part of an international team of scientists using the IceCube observatory at the South Pole to study neutrinos zipping through the Earth from outer space. These subatomic particles normally pass through the Earth as easily as light passes through a pane of glass.

Unlocking a Mystery:

Observatory Catches Neutrinos in a South Pole Block of Ice

By John Toon

Photo: Ignacio Taboada

This "selfie" by Georgia Tech Associate Professor Ignacio Taboada shows the kind of gear necessary to venture out on snow at the South Pole.

Scientists are using a one cubic kilometer block of ice at the South Pole to help unravel one of the great scientific mysteries of our time.

The block is part of IceCube, an observatory built in one of the most inhospitable parts of the world to study neutrinos zipping through the Earth from outer space. These subatomic particles normally pass through the Earth as easily as light passes through a pane of glass. But a few of them crash into the ultra-clear ice of IceCube. When they do, they produce secondary particles that can create a faint bluish light called Cherenkov radiation.

Scientists like Ignacio Taboada, an associate professor in the Georgia Tech School of Physics, are using information from that glow to learn more about these neutrinos – including, perhaps, where in the universe they came from. Between May 2010 and May 2012, IceCube had measured 28 neutrinos that likely originated outside our solar system, the first time such very-high-energy cosmic neutrinos have been observed.

As the IceCube Neutrino Observatory celebrated the third anniversary of the end of construction on December 18, 2013, it received the "Breakthrough of the Year" award from the British journal *Physics World* for observing these cosmic visitors.

"We now know that neutrinos from outside our planet are there, and we saw roughly as many as we had expected," said Taboada, who has been part of the IceCube Collaboration team for 14 years and was a co-author of the November 22, 2013, paper in the journal *Science* that reported the neutrino findings. "We have learned some things about neutrinos, but there are still other things that we don't understand."

The centerpiece of IceCube is a matrix of 86 strings of basketball-sized optical detectors placed one and a half kilometers beneath the Antarctic snow. Each string includes 60 optical detectors that are so sensitive they can register a single photon. Dug into the ice by a special hot-water drill, the strings are arranged in a pattern designed to use the Cherenkov radiation to map the path of neutrinos through the ice.

By observing the path of the particles through the ice block, scientists had hoped to learn where the particles originated in space. But from the 28 neutrino events observed so far, that hasn't been possible.

"So far, we are not seeing individual sources for the neutrinos," said Taboada. "We are not seeing any place in the sky that we can point to and say that we see even three or four of the neutrinos coming from. It is very diffuse. It may be that the sources are very weak, or that we have a detector that is not large enough."

Neutrinos are nearly massless particles that carry no electrical charge and originate from a variety of sources, including radioactive decay, our own sun, cosmic rays and events such as exploding stars.

Built with funds from the National Science Foundation and scientific organizations from three

European countries, IceCube was also designed to measure cosmic rays, which accompany the formation of neutrinos. The existence of cosmic rays has been known for more than a hundred years, but their sources are also unknown.

"This is essentially the birth of a new branch of astrophysics," said Taboada. "We've observed the universe with photons, and now we can observe using neutrinos."

IceCube is also facilitating Taboada's own research on gamma ray bursts, which is being conducted with Ph.D. students James Casey and Jacob Daughhetee.

"Gamma ray bursts are gigantic explosions that last for only a few seconds," Taboada said. "Over those few seconds, they are so bright that they can outshine the rest of the universe combined. They are brief, but they are very powerful while they last."

Scientists believe that there are at least two kinds of gamma ray bursts: those associated with supernovas that eject jets of matter and radiation, and neutron stars that spiral together and eventually merge. Neutrinos from gamma ray bursts can also be detected by IceCube.

IceCube was built at the South Pole to take advantage of the very clear ice available there and the darkness within the ice. "We used Antarctic ice because we needed a highly transparent material to observe the Cherenkov radiation," explained Taboada. "The ice allows us to see evidence of these secondary particles."

Basic science done in facilities like IceCube is really all about human curiosity – which often ends up having a more practical benefit.

"Basic science is not always about finding a cure for cancer," Taboada said. "But if you look at the last 400 years of basic scientific discovery, research and basic science have time and again resulted in a better life for humans. Satisfying that human curiosity often turns out to be a very long-term, very high-risk and very high-payoff investment. That's a basic reason to do science." rh

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"This is essentially the birth of a new branch of astrophysics. We've observed the universe with photons, and now we can observe using neutrinos."

— Ignacio Taboada, associate professor in the School of Physics

The IceCube Observatory at the Amundsen-Scott South Pole Station, in Antarctica, hosts the computers collecting raw data. Due to satellite bandwidth allocations, only certain data can be sent to the University of Wisconsin-Madison for further analysis.

Photo: Sven Lidstrom

Researchers are developing a micro gas chromatograph (GC) that would measure gases emitted from crops to detect diseases in time to prevent damage. About the size of a 9-volt battery, the technology's portability could help farmers increase yield and profits by reducing crop losses.

Boosting Crop Yield:

Miniature Gas Chromatograph Could Help Farmers Detect Crop Diseases Earlier

By Angela Colar

Photo: Rob Felt

Milad Navaei, a graduate research assistant, holds the micro gas chromatograph, which is being developed by GTRI researchers for early detection of diseases in crops.

Researchers at the Georgia Tech Research Institute (GTRI) are developing a micro gas chromatograph (GC) for early detection of diseases in crops. About the size of a 9-volt battery, the technology's portability could give farmers just the tool they need to quickly evaluate the health of their crops and address any possible threats immediately, potentially increasing yield and profits by reducing crop losses.

"It's estimated that each year U.S. farmers lose 12 percent of their crops to pests and another 12 percent to diseases," said Gary McMurray, division chief of GTRI's Food Processing Technology Division.

To identify potential threats to crop health, farmers typically look for physical symptoms of disease, such as discolored or wilting leaves. However, in many cases, by the time these symptoms are visible, the plant is already dead or dying. And the culprit pathogen may have already spread to nearby plants, threatening the health of the entire crop.

"The key is to give farmers the ability to get early diagnostic results, which allows them to take action before it's too late," added McMurray.

GTRI's micro gas chromatograph is a GC-on-chip device. Its separation column, where the gas interacts with the polymer coated on the interior walls, is about the size of a quarter, and the thermal conductivity detector is about half the size of a penny. When the two are combined, the device itself is about the size of a 9-volt battery.

McMurray said the goal is to be able to fit dozens of micro GCs on a ground robot that a farmer could then use in crop fields to take samples from plant to plant and get results in minutes.

"The idea is to have the robot be a mobile chemical laboratory that provides real-time data to the farmer. The robot provides a simple way to collect the data in an unstructured environment like a farm," said McMurray.

Because all plants and pathogens emit volatile organic compounds (VOCs), these emissions can be used as chemical markers for rapid detection. Building the micro GC was the easy part, said Jie Xu, a GTRI senior research scientist. The challenge now, she explained, is correlating the VOCs emitted from plants to their health status.

"It's relatively easy to detect VOCs, but we still have a long way to go to interpret changes in plant VOC mixtures," said Xu.

The difficulty lies in understanding how plants react to local environmental conditions. For example, changes in temperature, humidity, and soil moisture and nutrient levels, all have an effect on VOC emissions.

To determine if the emissions are due to a pathogen, a chemical signature has to be established by

studying VOCs released under these different environmental conditions.

Researchers next plan to conduct field tests using a benchtop model of the micro GC. Working with colleagues at the USDA's Agricultural Research Service, they will test peach trees for peach tree root rot disease at the Southeastern Fruit and Tree Nut Research Laboratory in Byron, Georgia. The goal is to collect air and soil samples that can be analyzed to identify the disease's chemical signature.

McMurray said a portion of the collected samples will be retained for additional laboratory tests with a traditional gas chromatograph-mass spectrometer to confirm the effectiveness of the micro GC. The team will then pursue efforts to integrate the device into an autonomous robotic platform for crop field sampling and VOC data analysis.

"Real-time data from sensing technologies like the micro GC, when used in conjunction with other data collected on the farm, could revolutionize the ability of farmers to identify sick plants before any physical symptoms appear," said McMurray.

Earlier detection also means earlier intervention, which could ultimately translate into a boon for America's farmers. "If we could cut in half the 12 percent of crop losses due to diseases, farmers could potentially realize billions of dollars more in revenue each year," McMurray added.

In addition to agricultural applications, the micro GC could potentially be used for homeland security monitoring to detect chemical threats, such as gases in subways and dangerous explosives in vehicles.

The micro GC project is being conducted in collaboration with researchers at GTRI, Georgia Tech's George W. Woodruff School of Mechanical Engineering and the Parker H. Petit Institute for Bioengineering and Bioscience, the Department of Plant Pathology in the University of Georgia's College of Agricultural and Environmental Sciences, and the USDA's Agricultural Research Service. rh

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Photo: Rob Felt

A GTRI research team has produced an advanced Web-based tool that lets physically separated participants collaborate on model-based systems engineering projects. Known as the Framework for Assessing Cost and Technology (FACT), the program utilizes open-source components to visualize a system's potential expense alongside its performance, reliability and other factors.

Online Design:

Collaborative Software Helps Systems Engineers Link Performance and Cost

By Rick Robinson

Photo: Gary Meek

A new advanced Web-based tool known as the Framework for Assessing Cost and Technology (FACT) lets physically separated participants collaborate on model-based systems engineering projects.

Today's modeling and simulation (M&S) software provides indispensable tools for systems engineering challenges. Such programs allow investigators to experiment with "what-ifs" by adjusting design parameters and examining potential outcomes.

A Georgia Tech Research Institute (GTRI) team has produced an advanced Web-based tool that lets physically separated participants collaborate on model-based systems engineering projects. Known as the Framework for Assessing Cost and Technology (FACT), the program utilizes open-source software components to allow users to visualize a system's potential expense alongside its performance, reliability and other factors.

The research is sponsored by the U.S. Marine Corps Systems Command (MCSC) and reported in March 2013 in the *Proceedings of the 11th Conference on Systems Engineering Research*.

The FACT tool enables users to pull all aspects of a project into a single M&S process, explained Tommer Ender, a GTRI senior research engineer who co-leads the effort.

"The FACT framework lets multiple users work together online to create entire systems, including complex technology systems," Ender said. "All they need is access to a Web browser."

FACT's features include:

- Capacity to weigh cost along with performance factors.
- Adaptability to a wide range of systems engineering problems.
- Ability to track the entire collaborative process.
- Advanced security and configurability features.
- Collaboration among many systems engineering platforms with Web access.

FACT is currently in use at the GTRI field office in Quantico, Virginia, located on the Quantico Marine Corps Base. There, senior research engineers Jim Bertoglio and Ron Smith are working with Marine Corps personnel to maximize the software's effectiveness.

Inside the GTRI facility, a dedicated conference room, with six large high-definition screens, provides highly reconfigurable work areas. The screens function individually or together, while notes handwritten on a linked screen can instantly become electronic text that supports the online collaboration.

M&S software, Ender explained, has traditionally been used to address performance issues. For instance, M&S tools allow researchers to investigate the capabilities of air or ground vehicles, or radar systems' effectiveness against hostile action.

"These tools do an excellent job of answering the 'how fast, how well' questions, but we rarely see them working in either collaborative or cost-aware environments," he said.

With FACT, online users can take advantage of a technique called trade-space analysis, which allows them to juggle performance, cost, and other factors, said Daniel Browne, a research engineer who leads the project for GTRI. For example, users examining vehicle convoy logistics could investigate the complex interrelationship of vehicles, personnel, supplies, and cost to pinpoint optimal combinations.

"We can select parameters for each component down to the desired level of detail, and then experiment with trade-offs at the attribute level," Browne said. "Suppose I use FACT to adjust the number of convoy personnel per HUMVEE to increase fuel efficiency. I can then turn around and look at how that change affects the number of convoys I can field and what the ultimate cost savings is."

FACT's collaborative capabilities include security and usability functions that are highly configurable, he said. If, for instance, a given user is responsible only for budgetary considerations, administrators could limit that person to just the model's cost portions.

Users can create entire technical models outside the FACT framework, and then introduce those models into the collaborative arena for team-wide consideration. In all cases, administrators can go back and trace each part of the work, including where it came from and what happened after it came into the system.

Ender said that FACT's modeling capabilities can be applied to many different types of projects. The GTRI development team has already used it to address systems engineering questions relating to ships, satellites, and ground vehicles.

"In the past, it's been very challenging to reuse modeling and simulation tools," he said. "You could build a big beautiful tool for a customer, but when the customer came in with a different problem, you had to start again from scratch."

A major factor in FACT's portability is that its building blocks are both flexible and familiar. They're based on open-source software standards and recognized approaches to systems engineering processes.

For instance, the FACT toolkit utilizes the Systems Modeling Language (SysML), an open-source modeling language widely used in systems engineering applications. SysML supports design, analysis, and validation of many different kinds of systems development.

The FACT tool itself will likely be limited to military use, Browne said. But software frameworks similar to FACT offer promise for future applications that could support both academic and commercial systems engineering needs. rh

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"The FACT framework lets multiple users work together online to create entire systems, including complex technology systems. All they need is access to a Web browser."

— Tommer Ender, GTRI senior research engineer

The Georgia Tech Research Institute (GTRI) team that developed the Framework for Assessing Cost and Technology (FACT) includes (left to right, standing) Tommer Ender, Daniel Browne, Santiago Balestrini-Robinson, (seated) Aaron Hansen, Jennifer DeLockery.

Photo: Gary Meek

New sonar research could help improve the Navy's ability to find sea mines deep under water. The underlying technology, known as synthetic aperture sonar (SAS), uses advanced computing and signal processing power to create fine-resolution images of the seafloor based on reflected sound waves.

Protecting Ships:

Synthetic Aperture Sonar to Help Navy Hunt Sea Mines

By Brett Israel

Since World War II, sea mines have damaged or sunk four times more U.S. Navy ships than all other means of attack combined, according to a Navy report on mine warfare. New sonar research being performed by the Georgia Tech Research Institute (GTRI) could improve the Navy's ability to find sea mines deep under water.

The underlying technology, known as synthetic aperture sonar (SAS), uses advanced computing and signal processing power to create fine-resolution images of the seafloor based on reflected sound waves. Thanks to the long-term vision and a series of focused efforts funded by the Office of Naval Research spanning back to the 1970s, SAS is becoming a truly robust technology. When it transitions to the fleet, SAS will dramatically improve the Navy's ability to carry out the mine countermeasures mission.

"The Navy wants to find sea mines," said Daniel Cook, a GTRI senior research engineer. "There are systems that do this now, but compared to SAS, the existing technology is crude."

The SAS research is funded by a grant from the Office of Naval Research and is conducted in collaboration with the Applied Research Laboratory at the Pennsylvania State University. In the past year, the group has made strides in improving the ability to predict and understand sonar image quality and has published and presented its work at conferences.

Sonar systems emit sound waves and collect data on the echoes to gather information on underwater objects. The Navy uses torpedo-shaped autonomous underwater vehicles (AUVs) to map swaths of the seafloor with sonar sensors. The AUVs zigzag back and forth in a "mowing the lawn pattern," Cook said. These AUVs can map at a range of depths, from 100 to 6,000 meters.

SAS is a form of side scanning sonar, which sends pings to the port and starboard sides of the AUV and records the echoes. After canvassing the entire area, data accumulated by the sensor is processed into a mosaic that gives a complete picture of that area of the seafloor.

SAS has better resolution than real aperture sonar (RAS), which is currently the most widespread form of side scanning sonar in use. RAS transmits pings, receives echoes, and then paints a strip of pixels on a computer screen. RAS repeats this pattern until it has an image of the seafloor. This technology is readily available and relatively cheap, but its resolution over long ranges is not good enough to suit the Navy's mine-hunting needs.

RAS sensors emit acoustic frequencies that are rel-

Synthetic aperture sonar produced this image of a World War II airplane that crashed into the ocean.

Image Courtesy of U.S. Navy

atively high and are, therefore, quickly absorbed by the seawater. SAS uses lower frequency acoustics, which can travel farther underwater. Upgrading to SAS improves the range at which fine-resolution pictures can be produced.

"RAS can give you a great-looking picture but it can only see out 30 to 50 meters," Cook said. "For the same resolution, SAS can see out to 300 meters."

SAS does not create a line-by-line picture of the seafloor like RAS. Instead, SAS pings many times while recording the echoes on a hard drive for post-processing. The data is analyzed by computers in a complex signal processing effort. The processing converts the pings into a large fine-resolution image of the seafloor. The commonly accepted measure for fine resolution is a pixel size of 1 inch by 1 inch, which is what SAS can achieve.

Tests of SAS in AUVs have produced fine-resolution images of sunken ships, aircraft, and pipelines. But when looking at an image of the seafloor from above, operators might have difficulty discerning the identity of simple objects.

For example, certain mines have a circular cross section. When looking at a top-down image, an operator might not be able to tell the difference between a mine and a discarded tire. To discern if that circular-shaped object is a threat, operators consider the shadow that an object casts in the sonar image. A mine will cast a shadow that is easy to distinguish from that of clutter objects such as tires. The shadow contrast research will be used to help ensure that this distinction is as clear as possible.

"Predicting contrast has been a challenging problem for the sonar community," Cook said. "We have developed a compact model that allows us to compute contrast very quickly."

This research is supported by the Office of Naval Research under grant numbers N00014-12-1-0085 and N00014-12-1-0045. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Office of Naval Research.

CITATION: D. Cook, et al. "Synthetic aperture sonar contrast, in 1st International Conference and Exhibition on Underwater Acoustics," June 2013, pp. 143–150.

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"The Navy wants to find sea mines. There are systems that do this now, but compared to SAS [synthetic aperture sonar], the existing technology is crude."

— Daniel Cook, GTRI senior research engineer

Torpedo-shaped autonomous underwater vehicles (AUVs) are used to map swaths of the sea floor with sonar sensors.

Photo Courtesy of U.S. Navy

A research team has developed a small electronic sensing device that can alert users wirelessly to the presence of chemical vapors in the atmosphere. The technology is aimed at military, commercial, environmental, healthcare, and other applications.

RFID Chip:

Tiny Wireless Sensing Device Alerts Users to Telltale Vapors Remotely

By Rick Robinson

Photo: Rob Felt

This close-up image shows a functionalized nanomaterial-based chemical sensor, inside a flow-cell test chamber.

A research team at the Georgia Tech Research Institute (GTRI) has developed a small electronic sensing device that can alert users wirelessly to the presence of chemical vapors in the atmosphere. The technology, which could be manufactured using familiar aerosol-jet printing techniques, is aimed at military, commercial, environmental, healthcare, and other applications.

The current design integrates nanotechnology and radio-frequency identification (RFID) capabilities into a small working prototype. An array of sensors uses carbon nanotubes and other nanomaterials to detect specific chemicals, while an RFID integrated circuit informs users about the presence and concentrations of those vapors at a safe distance wirelessly.

Because it is based on programmable digital technology, the RFID component can provide greater security, reliability, and range – and much smaller size – than earlier sensor designs based on non-programmable analog technology. The present GTRI prototype is 10 centimeters square, but further designs are expected to squeeze a multiple-sensor array and an RFID chip into a one-millimeter-square device printable on paper or on flexible, durable substrates such as liquid crystal polymer.

"Production of these devices promises to become so inexpensive that they could be used by the thousands in the field to look for telltale chemicals such as explosives and ammonia," said Xiaojuan (Judy) Song, a GTRI senior research scientist who is principal investigator on the project. "This remote capability would inform soldiers or first responders about numerous hazards before they encountered them."

Wireless sensors could also be valuable for identifying and understanding air pollution, she said. Inexpensive sensors that detect ammonia and nitrogen oxides could be fielded in large numbers, giving scientists increased knowledge of the location and intensity of pollutants.

The availability of such chips might also help companies detect food spoilage. Healthcare facilities may benefit, too, as the presence of telltale chemicals could inform caregivers of patient conditions and needs.

The present prototype contains three sensors along with an RFID chip. Future devices for field use might contain a much larger number of sensors based on various functionalized nanomaterials – including carbon nanotubes, graphene, and molybdenum disulfide – depending on the types of chemicals to be detected.

"In general, having an extensive sensing array is the best approach," Song said. "For real-world applications, a variety of sensors offers better functionality, because they can work together to produce a more detailed and reliable picture of the chemical environment."

The RFID component in the GTRI device makes use of the 5.8 gigahertz (GHz) radio frequency. The advantage of 5.8 GHz technology is that it will allow for RFID tags to be made extremely small – in the area of one centimeter square, said Christopher Valenta, a GTRI research engineer who is co-principal investiga-

tor on the project. He explained that the digital transmission of data from RFID-based sensors does a much better job than earlier analog techniques based on interpretation of radio-frequency waveforms.

Specifically, digital signaling with 5.8 GHz RFID offers:

- Greater security due to digital techniques that prevent unauthorized access to the wireless data stream.
- Increased resistance to interference from materials such as metals that can cause false readings.
- Digital-logic readings of chemical concentrations that are more precise and easier to interpret than analog approaches.
- Potential longer-range communication capability.

The GTRI team is currently gearing up to design a very small 5.8 GHz RFID component. After fabrication and testing, the chip could be manufactured in large numbers inexpensively.

The GTRI team successfully tested its prototype sensing system in a demonstration designed to resemble an airport checkpoint. The sensor array detected the targeted chemical despite immersion in a complex chemical environment, and the RFID component was able to transmit the sensors' readings.

The present GTRI prototype is semi-passive, so it requires a battery to power the sensor and on-board electronics. However, the prototype communicates passively, without transmitting any data. It uses backscatter communication, which reflects the incoming signal back to the remote reading device. The team is continuing to work on the important tasks of developing pattern-recognition software that will support effective functioning of the sensor array, and enabling the prototype to work without batteries.

"The prototype 5.8 GHz wireless sensing system promises to be flexible and highly scalable," said Valenta, a Ph.D. candidate in the School of Electrical and Computer Engineering. "An advanced design might include an array of 10 or more different sensors, with electronics that could utilize those sensors to perform 25 different jobs, and yet still be tiny, robust, and inexpensive." rh

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— Xiaojuan (Judy) Song, GTRI senior research scientist

The RFID Enabled Sensing Testbed (R.E.S.T.) shown here allows rapid prototyping of RFID-enabled sensors and RF technology. A carbon nanomaterial-based sensor board can be seen on the right, along with a 5.8 GHz two-state RF modulator.

Photo: Rob Felt

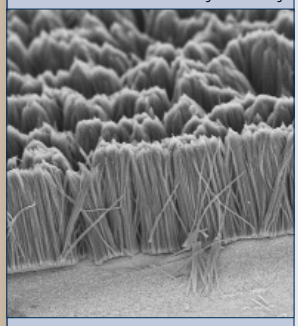
By harnessing an electropolymerization process to produce aligned arrays of polymer nanofibers, researchers have developed a thermal interface material able to conduct heat 20 times better than the original polymer. The modified material can reliably operate at temperatures of up to 200 degrees Celsius, and could be used to draw heat away from electronic devices.

Thermal Interface:

Heat-Conducting Polymer Cools Electronic Devices at 200 Degrees Celsius

By John Toon

Image: Virendra Singh



This scanning electron microscope image shows vertical polythiophene nanofiber arrays grown on a metal substrate. The arrays contained either solid fibers or hollow tubes, depending on the diameter of the pores used to grow them.

Polymer materials are usually thermal insulators. But by harnessing an electropolymerization process to produce aligned arrays of polymer nanofibers, researchers have developed a thermal interface material able to conduct heat 20 times better than the original polymer. The modified material can reliably operate at temperatures up to 200 degrees Celsius.

The new thermal interface material could be used to draw heat away from electronic devices in servers, automobiles, high-brightness LEDs, and certain mobile devices. The material is fabricated on heat sinks and heat spreaders and adheres well to devices, potentially avoiding the reliability challenges caused by differential expansion in other thermally conductive materials.

"Thermal management schemes can get more complicated as devices get smaller," said Baratunde Cola, an assistant professor in the George W. Woodruff School of Mechanical Engineering at Georgia Tech. "A material like this, which could also offer higher reliability, could be attractive for addressing thermal management issues. This material could ultimately allow us to design electronic systems in different ways."

The research, which was supported by the National Science Foundation, was reported March 30, 2014, in the advance online publication of the journal *Nature Nanotechnology*. The project involved researchers from Georgia Tech, the University of Texas at Austin, and the Raytheon Company. Virendra Singh, a research scientist in the Woodruff School, and Thomas Bougher, a Ph.D. student in the Woodruff School, are the paper's co-first authors.

Amorphous polymer materials are poor thermal conductors because their disordered state limits the transfer of heat-conducting phonons. That transfer can be improved by creating aligned crystalline structures in the polymers, but those structures – formed through a fiber-drawing process – can leave the material brittle and easily fractured as devices expand and contract during heating and cooling cycles.

The new interface material is produced from a conjugated polymer, polythiophene, in which aligned polymer chains in nanofibers facilitate the transfer of phonons – but without the brittleness associated with crystalline structures, Cola explained. Formation of the nanofibers produces an amorphous material with thermal conductivity of up to 4.4 watts per meter Kelvin at room temperature.

"Polymers aren't typically thought of for these applications because they normally degrade at such a low temperature," Cola explained. "But these conjugated polymers are already used in solar cells and electronic devices, and can also work as thermal materials. We are taking advantage of the fact that they have a higher thermal stability because the bonding is stronger than in typical polymers."

The structures are grown in a multi-step process that begins with an alumina template containing tiny pores covered by an electrolyte containing monomer precursors. When an electric potential is applied to the template, electrodes at the base of each pore attract the monomers and begin forming hollow nanofibers. The amount of current applied

and the growth time control the length of the fibers and the thickness of their walls, while the pore size controls the diameter. Fiber diameters range from 18 to 300 nanometers, depending on the pore template.

After formation of the monomer chains, the nanofibers are cross-linked with an electropolymerization process, and the template removed. The resulting structure can be attached to electronic devices through the application of a liquid such as water or a solvent, which spreads the fibers and creates adhesion through capillary action and van der Waals forces.

"With the electrochemical polymerization processing approach that we took, we were able to align the chains of the polymer, and the template appears to prevent the chains from folding into crystals, so the material remained amorphous," Cola explained. "Even though our material is amorphous from a crystalline standpoint, the polymer chains are highly aligned – about 40 percent in some of our samples."

Samples of the new material have been tested to 200 degrees Celsius through 80 thermal cycles without any detectable difference in performance. While further work will be necessary to understand the mechanism, Cola believes the robustness results from adhesion of the polymer rather than a bonding.

"We can have contact without a permanent bond being formed," he said. "It's not permanent, so it has a built-in stress accommodation. It slides along and lets the stress from thermal cycling relax out."

In addition to those already mentioned, co-authors of the paper included Professor Kenneth Sandhage, Research Scientist Ye Cai, Assistant Professor Asegun Henry, and Graduate Assistant Wei Lv of Georgia Tech; Professor Li Shi, Annie Weathers, Kedong Bi, Micheal T. Pettes and Sally McMenamin in the Department of Mechanical Engineering at the University of Texas at Austin; and Daniel P. Resler, Todd Gattuso and David Altman of the Raytheon Company. rh

CITATION: Virendra Singh, et al., "High thermal conductivity of chain-oriented amorphous polythiophene," (Nature Nanotechnology, 2014). http://www.dx.doi.org/10.1038/nnano.2014.44

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— Baratunde Cola, assistant professor in the George W. Woodruff School of Mechanical Engineering

Assistant Professor Baratunde Cola, from the George W. Woodruff School of Mechanical Engineering at Georgia Tech, and Ph.D. student Tom Bougher, show photoacoustic test equipment used to measure heat conductance of a new polymer material developed for thermal management.

Photo: Candler Hobbs

Researchers are helping to improve the capabilities of the nation's Multi-Disciplinary Intelligence (Multi-INT) system, which monitors incoming data produced by intelligence, surveillance, and reconnaissance (ISR) sensors. The effort could help human analysts better review the data to identify possible threats.

Actionable Intelligence:

MINT Program Helps Pinpoint Threats Contained in Intelligence Data

By Rick Robinson

Every day, U.S. military and security units receive vast amounts of data collected by intelligence, surveillance, and reconnaissance (ISR) sensors. Human analysts constantly review this data, searching for possible threats.

To aid this effort, researchers from the Georgia Tech Research Institute (GTRI) are helping to improve the capabilities of the nation's Multi-Disciplinary Intelligence (Multi-INT) system, which monitors incoming data.

A key to improving the U.S. Multi-INT system involves bringing "actionable intelligence" – information that could require immediate response – to the attention of human analysts as quickly as possible, explained Chris Kennedy, a research program analyst who leads the MINT effort in GTRI. But finding actionable intelligence is a challenge; it must be identified from myriad raw data gathered by intelligence sources, which include optical and radar sensors, communications sensors, measurements and signatures intelligence (MASINT) and others.

"The number of analysts is limited, and they can only perform a certain number of actions," said Kennedy. "So out of a huge set of information, which could involve millions of data points, you need to find the most valuable pieces to prioritize for investigation and possible action."

GTRI's work addresses two related Multi-INT challenges:

- Network bandwidth and workstation processing power sometimes can't keep up with incoming data sets that contain terabytes or even petabytes of raw information.
- Human analysts need to stay on top of incoming data by concentrating on the most significant information.

Metadata are small amounts of information that contain the key elements of a data point, which is an individual piece of data. For example, in the case of a car moving down a road, its metadata might consist of the make/model/color, location, speed, and number of passengers. Those attributes are highly informative, yet much easier to transmit and process than, say, a video of the car, which would involve large amounts of data.

The GTRI approach creates metadata fields, or utilizes existing ones, thereby characterizing each data point with minimal overhead. Then only the metadata is transmitted to the main system for immediate processing; the rest of the raw data is retained in an archive in case it's needed later.

The metadata technique results in much smaller amounts of information being relayed from ISR sources to computers. That reduces processing loads, helping computers and networks keep up with incoming data. The raw data is also stored and can be examined if necessary.

"Obviously under this data-reduction approach there are information losses that could affect how our program makes decisions, which is why our system is only a tool for – and not a replacement for – the human analyst," Kennedy said.

Photo: Gary Meek

GTRI researchers are helping to improve the capabilities of the nation's Multi-Disciplinary Intelligence system.

The second challenge – supporting human analysts – is addressed by methods that improve the system's ability to identify, compare, and prioritize different types of information.

First, the gathered metadata is converted into a single uniform format. By creating one format for all incoming metadata, data points from many different sources can be more readily identified and manipulated. This uniform format is independent of the data source, so different types of ISR data can be processed together.

Then, utilizing the identity-bearing metadata tags, GTRI researchers use complex machine-learning algorithms to find and compare related pieces of information. Powerful concurrent-computing techniques allow problems to be divided up and computed on multiple processors. That helps the system perform the complex task of determining which data points have been previously associated with other data points.

Metadata approaches have been used in the past, Kennedy explained, but only for a single intelligence technology, such as a text-recognition program that identifies keywords in voice-to-text data. The GTRI approach differs because it integrates metadata from a variety of intelligence disciplines into a single technology that prioritizes corroborative relationships from multiple sources.

Under GTRI's integrated approach, one set of potentially significant signals could be quickly compared to others in the same vicinity to form an in-depth picture. For example, in a disaster relief scenario, one aircraft-mounted ISR sensor might detect information indicating abandoned vehicles. But if another sensor detected a functioning communications device in one of the vehicles, that would indicate a higher likelihood of finding a survivor, prompting a rescue reconnaissance.

The MINT team is improving the program's capacity to process many data points quickly. They're using three primary sets of testing data involving thousands or millions of data points over lengthy time spans. The researchers' goal is to achieve real-time or near-real-time processing capability, so analysts can be alerted to abnormal information almost instantly.

"We want to get to the point where, as the latest data is coming in, it's being correlated against the data we already have," Kennedy said. "We need to able to say to the analyst, 'OK you've got a million data points, but look at these 10 first.'" rh

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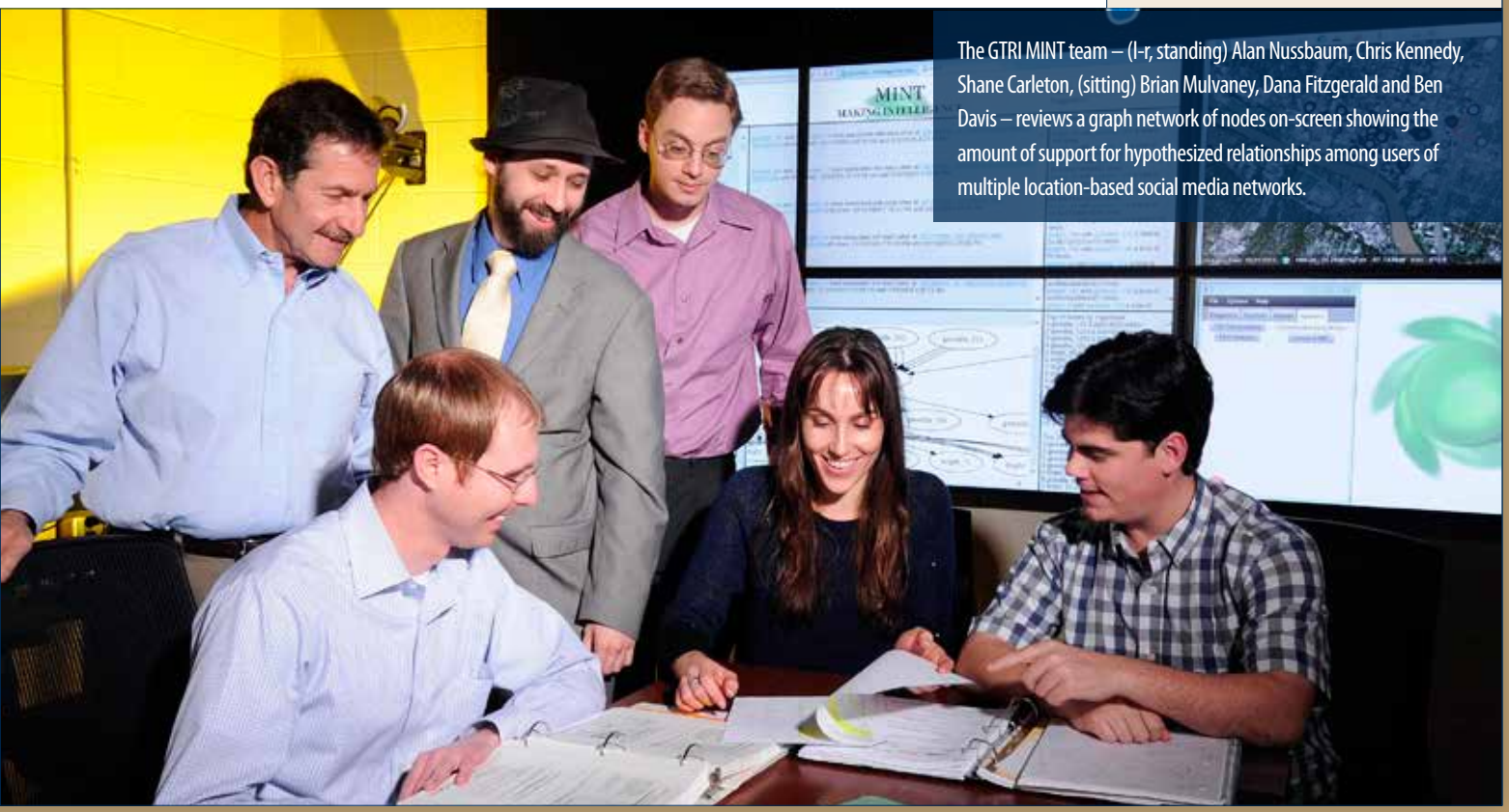
"The number of analysts is limited, and they can only perform a certain number of actions. So out of a huge set of information, which could involve millions of data points, you need to find the most valuable pieces to prioritize for investigation and possible action."

— Chris Kennedy, research program analyst in GTRI



The GTRI MINT team – (l-r, standing) Alan Nussbaum, Chris Kennedy, Shane Carleton, (sitting) Brian Mulvaney, Dana Fitzgerald and Ben Davis – reviews a graph network of nodes on-screen showing the amount of support for hypothesized relationships among users of multiple location-based social media networks.

Photo: Gary Meek

"Waviness" Explains Low Stiffness in Nanotube Forests

Photo: Rob Felt

Georgia Tech Ph.D. student Wei Chen, Professor Suresh Sitaraman and Ph.D. student Nick Ginga (l-r) examine a carbon nanotube sample against a backdrop of scanning electron microscope images of carbon nanotubes.

A new study has found that "waviness" in forests of vertically aligned carbon nanotubes dramatically reduces their stiffness, answering a long-standing question surrounding the tiny structures. Instead of being a detriment, however, the waviness may make the nanotube arrays more compliant and, therefore, useful as thermal interface material for conducting heat away from future high-powered integrated circuits.

Measurements of nanotube stiffness, influenced by a property known as modulus, had suggested that forests of vertically aligned nanotubes should have a much higher stiffness than what scientists were actually measuring. The reduced effective modulus had been blamed on uneven growth density, and on buckling of the nanotubes under compression.

Individual "straight" carbon nanotubes have a modulus ranging from 100 gigapascals to 1.5 terapascals. Arrays of vertically aligned carbon nanotubes with a density of 5 to 10 percent would be expected to a have an effective modulus of at least 5 to 150 gigapascals, Sitaraman said, but scientists have typically measured values that are four orders of magnitude less – between 1 and 10 megapascals. Although low growth density and buckling under compression would contribute to reduction in the effective modulus, the new study found the arrays of carbon nanotubes would have a reduced modulus under tension as well as when the arrays were fully compressed beyond buckling.

Based on experiments, scanning electron microscope (SEM) imaging, and mathematical modeling, the new study found that kinked sections of nanotubes may be the primary mechanism reducing the modulus.

"We believe that the mechanism making these nanotubes more compliant is a tiny kinkiness in their structure," said Suresh Sitaraman, a professor in the George W. Woodruff School of Mechanical Engineering. "Although they appear to be perfectly straight, under high magnification, we found waviness in the carbon nanotubes that we believe accounts for the difference in what is measured versus what would be expected."

The research, which was supported by the Defense Advanced Research Projects Agency (DARPA), was published in the journal *Carbon*.

To understand what might be causing this variation, Sitaraman and Ph.D. students Nicholas Ginga and Wei Chen studied forests of carbon nanotubes grown atop a silicon substrate, then covered the tips of the structures with another layer of silicon. They then used sensitive test apparatus – a nanoindenter – to compress samples of the nanotubes and measure their stiffness. Alternately, they also placed samples of the silicon-nanotube sandwiches under tensile loading – pulling them apart instead of compressing them.

What they found was that the effective modulus remained low – as much as 10,000 times less than expected – regardless of whether the nanotube sandwiches were compressed or pulled apart. That suggests growth issues, or buckling, could not fully account for the differences observed.

To look for potential explanations, the researchers examined the carbon nanotubes using scanning electron microscopes. At magnification of 10,000 times, they saw the waviness in sections of the nanotubes.

"We found very tiny kinks in the carbon nanotubes," said Sitaraman. "Although they appeared to be perfectly straight, there was waviness in them. When we replicated the waviness in computer models, including the confining effect among neighboring carbon nanotubes, we found that the models also showed the dramatic reduction in effective modulus as observed in experiments."

This research was supported by the Defense Advanced Research Projects Agency (DARPA-MTO) under contract N66001-09-C-2012. The opinions and conclusions expressed are those of the authors, and do not necessarily represent the official views of DARPA.

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High Levels of Molecular Chlorine Found in Arctic Atmosphere

Scientists studying the atmosphere above Barrow, Alaska, have discovered unprecedented levels of molecular chlorine in the air, a new study reports.

Molecular chlorine, from sea salt released by melting sea ice, reacts with sunlight to produce chlorine atoms. These chlorine atoms are highly reactive and can oxidize many constituents of the atmosphere including methane and elemental mercury, as well activate bromine chemistry, which is an even stronger oxidant of elemental mercury. Oxidized mercury is more reactive and can be deposited to the Arctic ecosystem.

The study is the first time molecular chlorine has been measured in the Arctic, and the first time scientists have documented such high levels of molecular chlorine in the atmosphere.

"No one expected there to be this level of chlorine in Barrow or in polar regions," said Greg Huey, a professor in Georgia Tech's School of Earth and Atmospheric Sciences. The study was published January 12, 2014, in the journal *Nature Geoscience* and was supported by the National Science Foundation (NSF).

The researchers directly measured molecular chlorine levels in the Arctic in the spring of 2009 over a six-week period using chemical ionization mass spectrometry. At first, the scientists were skeptical of their data, so they spent several years running other experiments to ensure their findings were accurate.

The level of molecular chlorine above Barrow was measured as high as 400 parts per trillion, which is a high concentration considering that chlorine atoms are short-lived in the atmosphere because they are strong oxidants and are highly reactive with other atmospheric chemicals.

Molecular chlorine concentrations peaked in the early morning and late afternoon, and fell to near-zero levels at night. Average daytime molecular chlorine levels were correlated with ozone concentrations, suggesting that sunlight and ozone may be required for molecular chlorine formation.

Previous Arctic studies have documented high levels of oxidized mercury in Barrow and other polar regions. The major source of elemental mercury in the Arctic regions is coal-burning plants around the world. In the spring in Barrow, ozone and elemental mercury are often depleted from the atmosphere when halogens – chlorine and bromine – are released into the air from melting sea ice.

Chlorine atoms are the dominant oxidant in Barrow, the study found. The area is part of a region with otherwise low levels of oxidants in the atmosphere, due to the lack of water vapor and ozone, which are the major precursors to making oxidants in many urban areas.

This research is supported by the National Science Foundation under award numbers ATM-0807702, ARC-0806437, and ARC-0732556. Any conclusions or opinions are those of the authors and do not necessarily represent the official views of the NSF.

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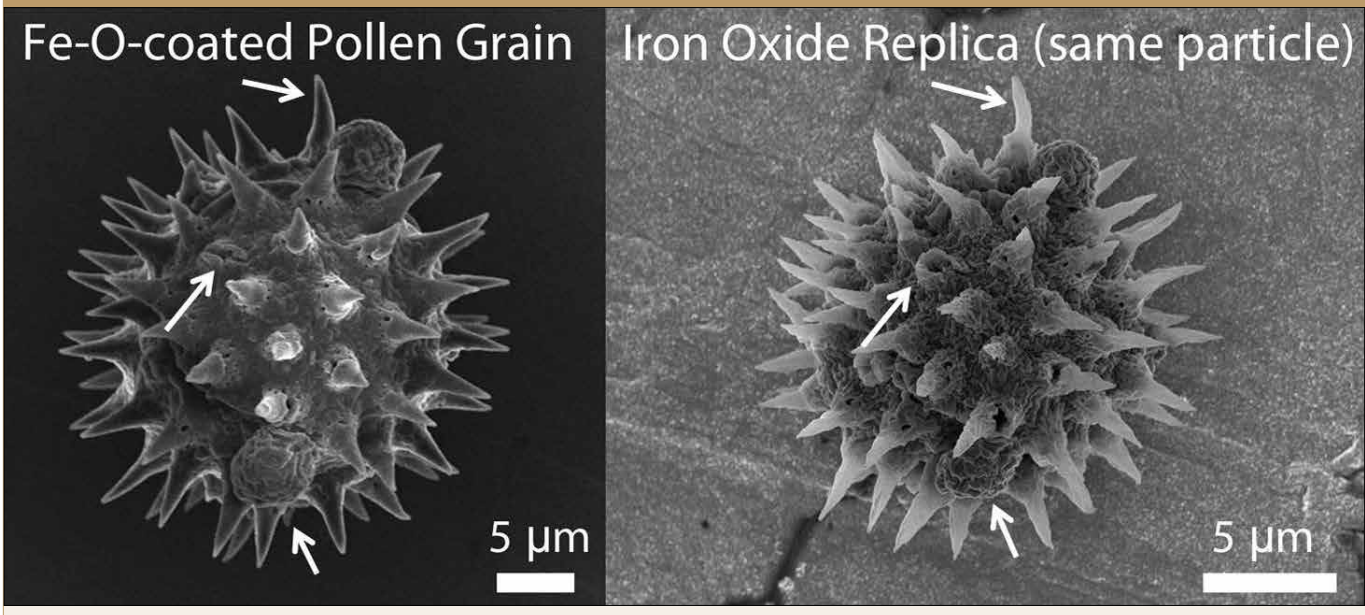
The Arctic may look like a pristine environment, but Georgia Tech scientists have found a very strong oxidant in the polar air. The researchers measured high levels of molecular chlorine in Arctic atmosphere, the first time that such a measurement has been made.

Photo: NASA Earth Observatory

Magnetic Pollen Replicas Offer Multimodal Adhesion

Image: Brandon Goodwin, Ken Sandhage



Scanning electron microscope images show a pollen particle (left) that has been coated with iron oxide and a replica of the same particle (right) after firing at 600 degrees Celsius to remove the organic material and crystallize the iron oxide.

Georgia Tech researchers have created magnetic replicas of sunflower pollen grains using a wet chemical, layer-by-layer process that applies highly conformal iron oxide coatings. The replicas possess natural adhesion properties inherited from the spiky pollen particles while gaining magnetic behavior, allowing for tailored adhesion to surfaces.

By taking advantage of the native pollen grain shape and a non-natural oxide chemistry, this work provides a unique demonstration of tunable, bio-enabled multimodal adhesion. The spikes inherited from the sunflower pollen provide short-range adhesion – over nanoscale distances – while the oxide chemistry provides an adhesion mode that operates over longer distances – up to one millimeter.

The work was supported by the Air Force Office of Scientific Research and has been published in the journal *Chemistry of Materials*.

"Pollen grains are inexpensive and sustainable templates that are readily available in large quantities," said Ken Sandhage, a professor in the School of Materials Science and Engineering. "Because pollen grains are already designed by nature for adhesion, we thought that it would be interesting to try to augment such natural behavior with an additional, non-natural mode of adhesion."

Sandhage and graduate student Brandon Goodwin began by examining the microscopic shapes of several types of pollen – including ragweed, pecan and dandelion – before choosing particles from the sunflower. The sunflower pollen grains are nearly spherical but covered with spikes that can entangle with the hairs on bees' legs, or adhere to surfaces via van der Waals forces at nanometer-scale distances, Sandhage explained.

The researchers washed the burr-like pollen particles with chloroform, methanol, hydrochloric acid, and water to clean the surfaces and expose hydroxyl groups for chemically attaching their coating. They then applied iron oxide using an automated, layer-by-layer surface sol-gel process they had developed earlier for coating diatom shells made of silica. Reaction of the iron oxide precursor with the hydroxyl groups on the surface of the pollen particles resulted in highly conformal coatings.

The sol-gel process used alternating cycles of exposure to an iron (III) isopropoxide precursor solution and water to apply 30 thin layers of iron oxide onto the pollen. Heating the particles to 600 degrees Celsius then burned out the organic material from the original pollen grains and crystallized the iron oxide, leaving hollow 3D hematite particles. The shells were then heated again in a controlled oxygen atmosphere to convert the hematite into magnetite, which is more strongly magnetic.

"We examined individual pollen grains before and after firing, and we could see that the shape and surface features were well preserved," said Sandhage. "The conformal nature of the coating process allowed us to generate ceramic replicas that retained even tiny surface features on the starting pollen grains."

Also contributing to the research were graduate student Ismael Gomez and Professor Carson Meredith, both from Georgia Tech's School of Chemical and Biomolecular Engineering.

This research was supported by the U.S. Air Force Office of Scientific Research through award number FA9550-10-1-0555. Any conclusions are those of the authors and do not necessarily represent the official views of the U.S. Air Force.

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New Solar Car Concept Shines at Electronics, Cars Shows

Image: Ford Motor Company

The C-MAX Solar Energi Concept is a first-of-its-kind sun-powered vehicle with the potential to deliver the best of what a plug-in hybrid offers – without depending on the electric grid for fuel.

Ford Motor Company, in collaboration with Georgia Tech, has debuted a new solar car concept.

The C-MAX Solar Energi Concept is a first-of-its-kind hybrid electric vehicle with the potential to free drivers of their dependence on the electric grid. Instead of recharging its battery from an electrical outlet, C-MAX Solar Energi Concept harnesses the power of the sun by parking under a special concentrator that acts like a magnifying glass, directing intensified rays from the sun onto solar panels on the parked vehicle's roof below.

The result is a car that takes a day's worth of sunlight to deliver the same performance as Ford's conventional C-MAX Energi plug-in hybrid.

"Ford didn't just want to build an electric car, but a plug-in hybrid electric car that actually uses green electricity," said Bert Bras, a professor in the George W. Woodruff School of Mechanical Engineering. "Just putting photovoltaic cells onto a car is not going to do it, so they reached out to us to help progress the concentrator idea."

Ford and California-based SunPower co-developed the solar panel-based roof specifically for C-MAX Solar Energi Concept. Because of the time that would be needed for conventional solar panels to absorb enough energy to fully charge the vehicle, Ford turned to the Sustainable Design and Manufacturing Lab at Georgia Tech for ways to amplify the sunlight to make a solar-powered hybrid feasible for daily use.

The lab helped develop a carport-type solar concentrator that uses lenses similar to what lighthouses use to amplify a small light. Special Fresnel lenses in the carport direct sunlight to the solar panels on the vehicle's roof, so the concentrator acts "like a magnifying glass," Bras said. Grooves in the thin glass reflect the sunlight down to the car, boosting the sunlight's impact by a factor of eight.

The patent-pending system tracks the sun as it moves from east to west, drawing enough power from the sun daily to equal an 8 kilowatt-hour battery charge. The car's self-parking features can automatically move the car to keep the sunlight focused on the rooftop panels.

"There is more work to do, but the basic question is: Can you charge a car with 8 kilowatt hours per day using pure sunlight? Yes, you can," Bras said. "The next step will be to test it in practical situations."

— Brett Israel

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Laser Radar Will Test Atmosphere for Navy's Laser Weapons

Photo: U.S. Navy

A new lidar designed to measure haze in sea air is now being built and is expected to be tested in the spring of 2015 on the Navy's Self Defense Test Ship (SDTS).

The U.S. Navy is sailing toward a future where ships fire laser weapons to defend themselves against attackers. But these futuristic weapons might not always be the best choice. Hazy days siphon a laser's power. Turbulence and water vapor cause problems, too. To help the Navy decide whether to fire a defensive laser or a missile, engineers at the Georgia Tech Research Institute (GTRI) have designed a laser radar system to scan the sea air for haze-creating aerosol particles.

When completed, the Department of Defense-sponsored project may represent the first time that an atmospheric laser radar, or lidar, has been deployed on a Navy ship. Lidar measures distance by sending a speed-of-light pulse at a target with a laser and analyzing the reflected light.

"In a Navy environment, where we're one step away from a military operation, this system is the first of its kind," said GTRI senior research scientist David Roberts.

The GTRI team has completed design and computer simulations for the atmospheric characterization lidar. The lidar is now being built and is expected to be tested in the spring of 2015 on the Navy's Self Defense Test Ship (SDTS).

"The Navy has had a desire to have lidar on a real ship for many years, but they've never found a way to do it until this program," said GTRI principal research scientist Gary Gimmestad.

To test its laser weapons, the Navy installs them on the SDTS, a 550-foot former naval destroyer. For testing lasers, one common experiment is to see at what range and power the laser can damage specific targets. Depending on atmospheric conditions, more or less power might be needed to disable or destroy a target at a given range.

"The problem is that the atmosphere does bad things to your laser beam," Gimmestad said. "Lasers are trying to transmit light through aerosol particles, but it doesn't all get to the other end."

Aerosol scatters light from the laser beam. When the beam loses photons, power is lost.

"Hazy days are bad for laser weapons," Roberts said. "There may be times when you don't want to use the laser weapon because the atmosphere is not cooperating, and you're better off throwing something hard and fast."

This project is funded by the Test Resource Management Center (TRMC) Test and Evaluation/Science & Technology (T&E/S&T) Program through the U.S. Army Program Executive Office for Simulation Training and Instrumentation (PEO STRI) under Contract No. W900KK-14-C-0010. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the TRMC, T&E/S&T Program and/or the U.S. Army PEO STRI.

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Artist concept of test lidar.

Imaging Technology Could Unlock Childhood Disease Mysteries

By the time they're 2 years old, most children have had respiratory syncytial virus (RSV) and suffered symptoms no worse than a bad cold. But for some children, especially premature babies and those with underlying health conditions, RSV can lead to pneumonia and bronchitis – which can require hospitalization and have long-term consequences.

A new technique for studying the structure of the RSV virion and the activity of RSV in living cells could help researchers unlock the secrets of the virus, including how it enters cells, how it replicates, how many genomes it inserts into its hosts – and, perhaps, why certain lung cells escape the infection relatively unscathed. That could provide scientists information they need to develop new antiviral drugs and, perhaps, even a vaccine to prevent severe RSV infections.

"We want to develop tools that would allow us to get at how the virus really works," said Philip Santangelo, an associate professor in the Wallace H. Coulter Department of Biomedical Engineering at Georgia Tech and Emory University. "We really need to be able to follow the infection in a single living cell without affecting how the virus infects its hosts, and this technology should allow us to do that."

The research was supported by the National Institutes of Health's National Institute of General Medical Sciences and published in the journal *ACS Nano*.

"We've shown that we can tag the genome using our probes," explained Santangelo. "What we've learned from this is that the genome does get incorporated into the virion, and that the virus particles created are infectious. We were able to characterize some aspects of the virus particle itself at super-resolution, down to 20 nanometers, using direct stochastic optical reconstruction microscopy (dSTORM) imaging."

The research team, which included scientists from Vanderbilt University and Emory University, used a probe technology that quickly attaches to RNA within cells. The probe uses multiple fluorophores to indicate the presence of the viral RNA, allowing the researchers to see where it goes in host cells – and to watch as infectious particles leave the cells to spread the infection.

"Being able to see the genome and the progeny RNA that comes from the genome with the probes we use really gives us much more insight into the replication cycle," Santangelo said.

Work done by graduate student Eric Alonas to concentrate the virus was essential to the project, Santangelo said. The concentration had to be done without adversely affecting the infectivity of the virus, which would have impacted its ability to enter host cells.

In addition to those already mentioned, the research team included James Crowe, professor of pediatrics at Vanderbilt University; Elizabeth Wright, assistant professor in the School of Medicine at Emory University; Daryll Vanover, Jeenah Jung, Chiara Zurla, Jonathan Kirschman, Vincent Fiore, and Alison Douglas from the Coulter Department; Aaron Lifland and Manasa Gudheti from Vutara Inc. in Salt Lake City; and Hong Yi from the Emory University School of Medicine.

The research described here was supported by the National Institute of General Medical Sciences of the National Institutes of Health (NIH) under contract R01 GM094198-01. Any conclusions or opinions expressed are those of the authors and do not necessarily represent the official views of the NIH.

– John Toon

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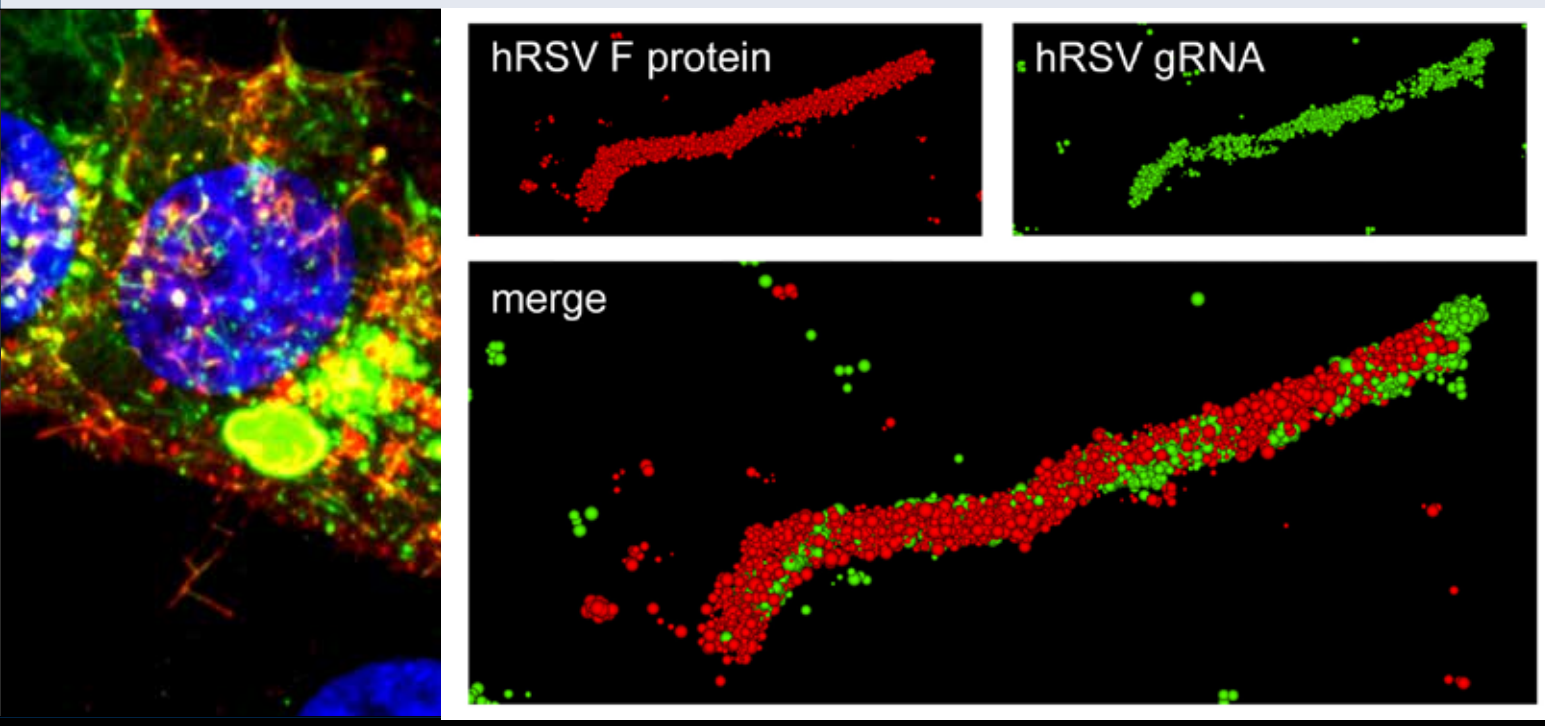
Inset shows a super-resolution optical image of a specific hRSV viral filament produced with dSTORM technology. The viral filament is approximately 4 microns in length, typical of hRSV. The inset is shown over a microscope image of a cell infected with RSV.



Images: Eric Alonas, Philip Santangelo

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