Mechanical Engineering

Momentum

Winter 2018

Bat-Inspired Sonar

Helping drones move safely in cluttered airspace

COLLEGE OF ENGINEERING
MECHANICAL ENGINEERING
VIRGINIA TECH

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Vol 3.4 Winter 2018

Innovation Campus

A billion dollar, 1 million square foot innovation campus for Virginia Tech helped convince Amazon to make northern Virginia part of its second headquarters.

Nuclear engineering

The Nuclear Materials and Fuel Cycle Lab is up and running in the Corporate Research Center and has five projects worth more than $1.3M to get underway.

Professor Azim Eskandarian - ME Department Head, Nicholas and Rebecca Des Champs Professor
Rosaire Bushey - Communications & Outreach Manager
Contact us: 540-231-2965 email busheyr@vt.edu

On the cover: *A robotic bat-inspired sonar is used to record echoes in Stadium Woods as part of an NSF project to study sonar for use in aerial drones.*

Connect on social

https://youtu.be/INZFCf4jkds
shaker lab or innovation campus

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INSIDE THIS ISSUE

The Advanced Vibrations and Acoustics Lab took control of a one-ton shaker table in December. The table, loaned from the U.S. Naval Surface Warfare Center at Dahlgren, Virginia, can apply vibrational forces up to 2,000 kilograms and shake at frequencies up to 4,000 hertz, allowing researchers to recreate a wide variety of environmental conditions in the lab.

From the Dept Head

Azim Eskandarian

2019 shaping up for more ME success

Happy holidays wherever this issue of Momentum finds you. 2018 has been another great year for the department, the college and the university.

As I'm sure many of you are aware, Virginia Tech was instrumental in November's announcement that Amazon would make northern Virginia part of a split second headquarters for the company. As part of the plan, Virginia Tech will develop a 1M square foot Innovation Campus.

Mechanical engineering is well positioned to be a major player in this bold step forward, as we already have a presence in the greater Washington D.C. area. You can read more about the proposed campus on page 10.

While things are going to start gearing up in northern Virginia, here in Blacksburg, our ever-increasing roster of world-class faculty, which now numbers more than 60, is producing ground-breaking research across a wide variety of disciplines within the field.

In Dubai, mechanical engineers were part of a team that built the international award-winning FutureHaus as part of the 2018 Solar Decathlon. You can read about their accomplishments on page 9 and I urge you to click the link to read the entire story on VTNews.

On page 14 you can read about how our nuclear engineers are using a new lab in the Corporate Research Center to solidify their place as a national leader in the field. The new lab is one of only a handful in the country to incorporate a large number of tools to design our next generation of nuclear technology.

On page 16 our DREAMS Lab team is continuing to exploit their mastery of 3D printing Kapton, and on page 18, one of our vibrations lab has new tech on loan courtesy of the U.S. Navy, giving us more capacity for leading-edge research.

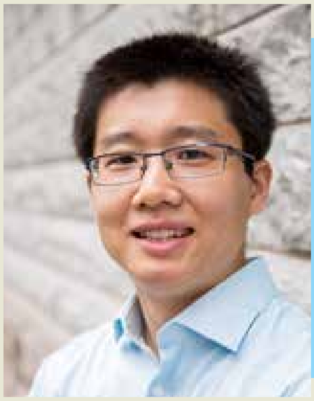
Our cover story starts on page 18 and involves a collaborative effort with Virginia Tech and several other universities using bats to understand, and improve upon sonar signal processing. The applications of this work include national security, drone research and much more.

As always, we present some of the great work of our department, so please take a few minutes, click some links, watch some videos, and enjoy your ME department.

briefly

Sandu receives McFarland Award at ASME IDETC

Professor Corina Sandu received the 2019 Forest R. McFarland Award from SAE International in November. The award recognizes sustained outstanding contributions with SAE Engineering events or facilitating or enhancing the interchanges of technical information. Also in attendance were Associate Professor Costin Untaroiu, BEAM (Secretary, Vehicle Design Technical Committee), L.S. Randolph Professor Robert Parker (Chair, Technical Committee of Vibration and Sound), Sandu (who also received a certificate of appreciation for serving as Chair of the Design Engineering Division), Associate Professor Pinhas Ben-Tzvi, Assistant Professor Oumar Barry (Best Paper Subcommittee), and John R. Jones III Faculty Fellow and Professor Lei Zuo (Vice Chair, VDTC).



Ling Li receives AFYI Award

Assistant Professor Ling Li has received the Air Force Young Investigator award for his study of lightweight cellular skeletons of deep sea sponges to help design stronger and more damage-tolerant engineering materials. The award is for three years.

Parker named Honorary IIAV Fellow

L.S. Randolph Professor Rob Parker has been named an Honorary Fellow of the International Institute of Acoustics and Vibration; the institute's highest honor. Parker is also a Fellow of the ASME, and the American Association for the Advancement of Science.

Lockheed Martin donates to Ware Lab

Lockheed Martin's Sr. VP of Corporate Engineering, Technology and Operations, Rod Makoske, presented a check for $18,000 to the Ware Lab in November. The funds will be split among the Formula SAE, Baja SAE, BOLT, Astrobotics, Human Powered Submarine, and Design, Build, Fly teams.

news notes

Nain seminars


Nain and Bucky

Associate Professor Amrinder Nain gave the following invited seminars:

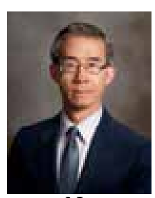
Mechanobiology of cell protrusions – to the University of North Carolina Department of Pharmacology

Fiber curvature drives cell protrusive behavior – to the University of Wisconsin Department of Biomedical Engineering

Quantitating fiber curvature driven protrusive behavior in-line and lateral to cell migration direction – to University of Pennsylvania, Physical Sciences and Oncology

Nain is also scheduled to be a speaker at Innovate Nanomedicine 2019 in Houston, Texas.

Wing Ng


Ng

Gave the keynote lecture in October at the International Conference on Fluid Dynamics and Aerodynamics in Berlin, Germany. Ng spoke on: Gas turbine flow characterization using non-intrusive acoustic measurements.

Roop Mahajan


Mahajan

Roop Mahajan, the Lewis E. Hester Chair Professor of Mechanical Engineering, was presented the Distinguished Alumnus Award for Excellence in Career, during Foundation Day celebrations Nov. 14 at Punjab Engineering College, Chandigarh India. Mahajan's brother-in-law accepted the award on his behalf.

Yang Liu


Liu

Yang Liu's research group recently won best paper awards for two conference papers.

Shanbin Shi, Yalan Qian, Dewei Wang, Yang Liu, Xiaodong Sun, Liquid phase turbulence measurements in air-water two-phase flows using particle image velocimetry, presented at the 12th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics, Operation and Safety in Qingdao, China.

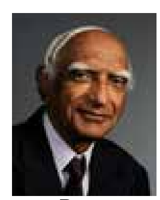
Yucheng Fu, Yang Liu, Bubbly flow synthesis and labeling using the bubble generative adversarial networks, presented at the 2018 International Topical Meeting on Advances in Thermal Hydraulics, Orlando, Florida

Lei Zuo


Zuo

Lei Zuo and doctoral student Yongjia Wu received the 2018 ASME Best Paper Award in Advanced Modeling and Simulation, for their paper, Energy harvesting for nuclear waste sensing and monitoring. The paper included Wu, Jackson Klein, Hanchen Zhou, and Zuo.

Romesh Batra


Batra

Romesh Batra, Clifton C. Garvin Professor in the Biomedical Engineering and Mechanics department, and an affiliate faculty member of mechanical engineering, recently had the following publications:

From left: Alex Walker, marketing and communications manager with Lockheed Martin, Jason Lazar, Maxwell Baum, and Wade Titterton, all seniors in mechanical engineering, and Brad Fravel, director of business development with LINK, the center for advancing industry partnerships at Virginia Tech.

ME students unlock challenge box

In September, three mechanical engineering seniors Jason Lazar, Maxwell Baum, and Wade Titterton, cracked the code to unlock Lockheed Martin's Challenge Box and were rewarded with $10,000.

"Jason and I had just watched three different people answer the fourth question wrong right in front of us, so we weren't too hopeful when it was our turn," said Baum.

Baum analyzed the problem and recruited Lazar and Titterton, and the three decided to tackle the challenge together.

Students were presented with four tough engineering problems on a touchscreen display, the fourth being the key to unlocking the grand prize of $10,000. While the other three problems changed each day, the $10,000 question remained the same and was in fact, an actual problem that Lockheed Martin engineers were confronted with in the field while designing one of their military satellites.

In all, 802 students attempted the problems and 98 walked away with a special prize for answering one of the first three questions correctly. The prize was a vinyl disc replica of The Golden Record, a 12-inch gold-plated copper disk containing sounds and images from Earth that NASA sent into space via their Voyager spacecraft.

https://youtu.be/z5dSfE4Ufj0
VIDEO

G.J.Nie, Z. Zhong, R.C. Batra, Material tailoring for reducing stress concentration factor at a circular hole in a functionally graded material panel, Composite Structures.

G. Gopinath, R.C. Batra, A common framework for three micromechanics approaches to analyze elasto-plastic deformations of fiber-reinforced composites, International Journal of Mechanical Sciences.

R.C. Batra, G.J. Nie, Torsional deformations and material tailoring of orthotropic bi-directional FGM hollow truncated conical cylinders with curved lateral surfaces, International Journal of Engineering Science.

Y.Q. Zhao, Y. Zhou, Z.M. Huang, R.C. Batra, Experimental and micromechanical investigation of T300/7901 Unidirectional Composite Strength, Polymer Composites.

Ben-Tzvi presentations


Ben-Tzvi

Associate Professor Pinhas Ben-Tzvi recently served as Symposium Co-Chair for the Mobile Robotics Symposium as part of the 42nd Mechanisms and Robotics Conference at the 2018 ASME International Design Engineering Technical Conferences in Quebec City. He was also a technical session chair and a technical session co-chair, and served as a judge for the Mechanisms and Robotics Student Design Competition.

Ben-Tzvi and his graduate students published and presented four peer-reviewed conference papers at IDETC/CIE:

- Refour, E., Sebastian, B., Ben-Tzvi, P., “Design and implementation of an exoskeleton glove for infant medical rehabilitation”
- Sohal, S.S., Saab, W., Ben-Tzvi, P., “Improved alignment estimation for autonomous docking of mobile robots”
- Liu, Y., Ben-Tzvi, P., “Dynamic modeling of a quadruped with a robotic tail using virtual work principle”
- Sebastian, B., Williams, A., Ben-Tzvi, P., “Gaussian kernel controller for path tracking in mobile robots”

DREAMS lab gets new 3D printer

The Design, Research, and Education for Additive Manufacturing Systems, or DREAMS, Lab took delivery of a Innovent+ 3D printer by Exone. The latest model printer is capable of processing very fine powders of around five microns, with small binder drops of 10 picoliters. The system can process metals, ceramics, and pharmaceuticals and print parts with complex geometries at high resolution. The research team will use the new equipment to explore new materials such as metal and ceramic powders and nanoparticle inks, and conduct research into how droplet and powder size effect the quality of product microstructure, and overall product quality.

Virginia Tech builds world's best solar house

After years of research and development contributed by over 100 Virginia Tech students and faculty, the FutureHAUS Dubai team has officially built the world's best solar home.

The lone American team earned a first-place victory over 14 other selected teams and more than 60 total entrants of the 2018 Solar Decathlon Middle East, a competition launched by the United States Department of Energy and the United Arab Emirates' Dubai Electricity & Water Authority. The global competition aimed to accelerate research on building sustainable, grid-connected, solar homes.

The win follows nearly two decades of research and two years of accelerated development, overcoming a fire that burned down a previous iteration of the house, and more than a month spent in a desert in the outskirts of Dubai, where two dozen students and faculty erected the entire house.

The concept of FutureHAUS Dubai was brought to life through a university-wide effort, combining talents and research from Virginia Tech's College of Architecture and Urban Studies, College of Engineering, Myers-Lawson School of Construction, Pamplin College of Business, College of Liberal Arts and Human Sciences, College of Science, and various centers and labs within.

Read Erica Corder's full article here.

https://www.facebook.com/FutureHAUSdubai/videos/539738579823921/?t=0

Virginia Tech ready to move forward with 1 million square foot, $1B Innovation Campus in National Capitol Region

Virginia emerged as a winner in the fierce, nationwide competition to house a headquarters for Amazon. The commonwealth stepped up with a standout higher education package, including a new Virginia Tech Innovation Campus in Alexandria, which will be located less than two miles from Amazon's new location in Arlington.

Virginia Tech's historic commitment to build a revolutionary, 1 million-square-foot graduate campus is the centerpiece of plans that will drive technology education and research, serve high-tech disciplines of the future, and transform the commonwealth's innovation economy.

When fully realized, the $1 billion Innovation Campus, which includes state support, will spark discoveries and help fill immense demand for high-tech talent in the greater Washington, D.C., area and beyond. The Commonwealth of Virginia and Virginia Tech have committed to provide $250 million each to seed the project.

The campus will bring together hundreds of new graduate students, dozens of new faculty members, and numerous industry partners. As part of its plan to increase undergraduate enrollment to 30,000 students, Virginia Tech also will increase undergraduate enrollment by 2,000 students in computer science, computer engineering, software engineering, and related disciplines at its Blacksburg campus over the next eight years.

Amazon credited the Innovation Campus in Alexandria as a key component in its decision to locate in Northern Virginia.

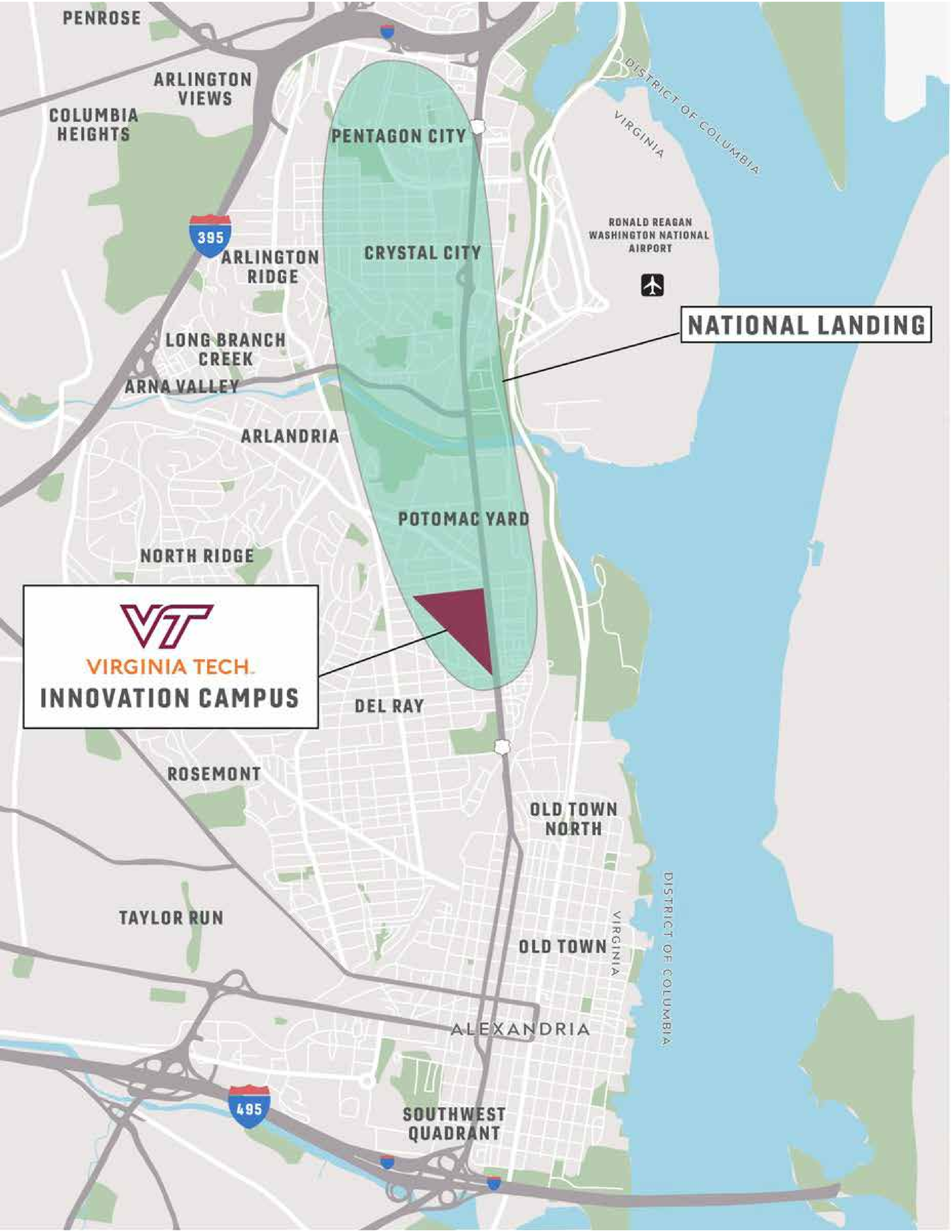
“Launching the Innovation Campus is a watershed moment for Virginia Tech and a great day for the commonwealth we are committed to serve,” university President Tim Sands said. “As the land-grant research institution, we stepped up to claim our role of driving economic development by leveraging our strengths in technology and engineering and building on our strong partnerships in Washington, D.C. The Innovation Campus will bring together the highest-caliber students, world-class faculty, smart ideas, and forward-thinking companies. It’s a once-in-a-generation opportunity for Virginia Tech to grow.”

A winning proposal

In the greater Washington, D.C., region, both the private and public sectors already are clamoring for high-tech expertise.

The Innovation Campus will be located on U.S. Route 1 at National Landing in Alexandria near Potomac Yard. Virginia Tech has entered into an memorandum of understanding with Stonebridge Associates Inc. and the City of Alexandria to expedite construction. The campus will be located in the Alexandria portion of National Landing, on land owned by investment

https://youtu.be/6cNNtx5YOqE
INNOVATION CAMPUS


PENROSE
ARLINGTON VIEWS
COLUMBIA HEIGHTS
PENTAGON CITY
DISTRICT OF COLUMBIA
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395
ARLINGTON RIDGE
CRYSTAL CITY
RONALD REAGAN WASHINGTON NATIONAL AIRPORT
NATIONAL LANDING
LONG BRANCH CREEK
ARNA VALLEY
ARLANDRIA
POTOMAC YARD
NORTH RIDGE
VIRGINIA TECH.
INNOVATION CAMPUS
DEL RAY
ROSEMONT
OLD TOWN NORTH
TAYLOR RUN
OLD TOWN
VIRGINIA
DISTRICT OF COLUMBIA
ALEXANDRIA
495
SOUTHWEST QUADRANT

firm Blackstone Group LP's real estate fund. The land, commonly referred to as Oakville Triangle, will be developed by Stonebridge.

"This is a great example of higher education, the public sector, and the private sector working together to create jobs and new investment in Virginia," said Del. Kirk Cox, speaker of Virginia's House of Delegates. "Amazon and the new Virginia Tech Innovation Campus will ... solidify Virginia's position as the talent capital of the world."

Del. Chris Jones, chairman of Virginia's House Appropriations Committee, said Virginia Tech's team played a leading role in creating the broad higher education package that helped Northern Virginia stand out among the localities trying to attract Amazon. "The Innovation Campus is critical to building a pipeline of talent for the state's growing technology economy," he added.

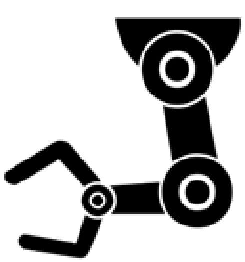
The Innovation Campus's funding model also calls for private philanthropy, industry partnerships, research expenditures, and other revenue streams generated through innovative, shared spaces on the campus.

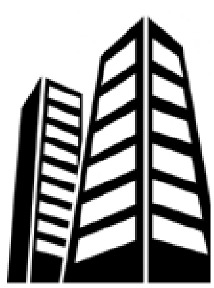
"Research universities like Virginia Tech have tremendous potential to bring together students, researchers, industry, and leading technology professionals in new and creative ways," said Charlie Phlegar, Virginia Tech's vice president for advancement. "We live in a fast-paced and demanding world. To keep pace, universities have to be willing to evolve. We look forward to engaging the many partners who will help us make the Virginia Tech Innovation Campus a transformative initiative."

"Today is a historic day for the commonwealth. The Innovation Campus will transform Virginia's high-tech economy...it will benefit educational institutions and regions across the commonwealth"

Mark Warner, US Senator

The Virginia Tech Innovation Campus will triple the university's footprint in Northern Virginia. It will include:


300,000sf of academic/research & development facilities

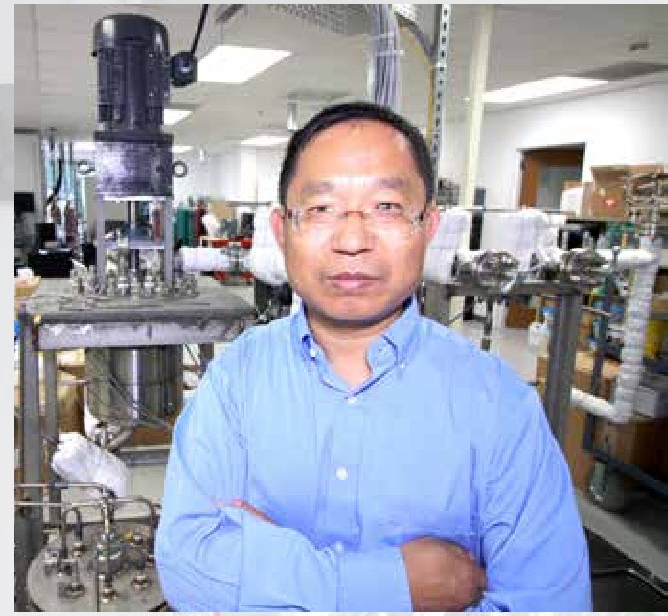

250,000sf of space dedicated to startups & corporate facilities


350,000sf available for housing students and faculty


100,000sf of retail and support spaces.

STORY, PHOTOS BY ROSAIRE BUSHEY
MECHANICAL ENGINEERING

Molten salt cooling heats up mechanical engineering laboratory



In 2018, five separate projects worth a total of more than $1.3 million to the Nuclear Materials and Fuel Cycle Lab (NMFC), have been approved to take advantage of Virginia Tech's capabilities to study molten chemistry, corrosion and corrosion control as well as simulation.

As co-PI on four of the projects funded by the Department of Energy, Jinsuo Zhang, a professor of mechanical engineering in the College of Engineering, will use his new lab space in the Virginia Tech Corporate Research Center to perform research for nuclear and solar-based projects with an eye toward lowering the cost of solar power, and making nuclear power more efficient.

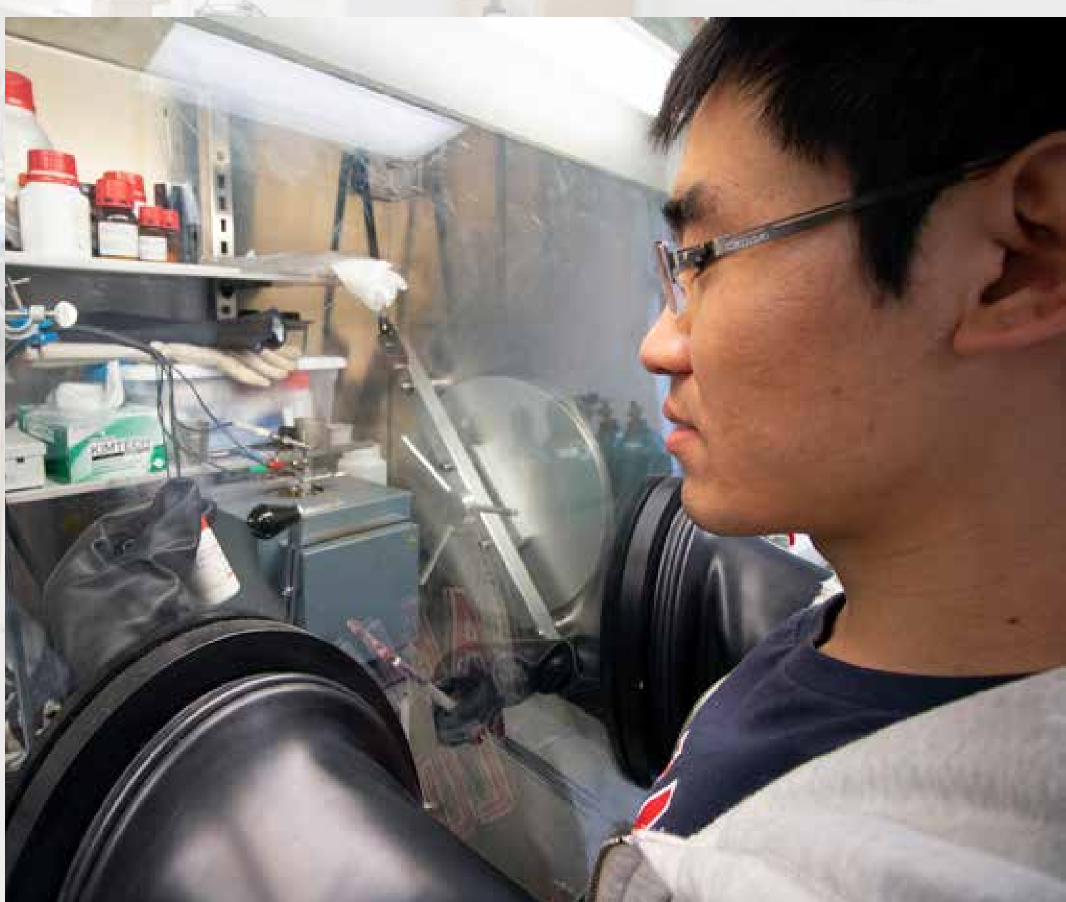
Two of the projects are part of a DOE Technologies Office program to study high-temperature molten salt properties and corrosion mechanisms as part of a $72 million program called Concentrating Solar Power research, with a goal to create less expensive solar power.

"Molten salt has excellent heat transfer characteristics, and can attain very high temperatures in excess of 700c," said Zhang. "The idea is that molten salt can be used to absorb heat from solar facilities, and for creating clean power in nuclear facilities. It's a very sought-after and useful material because of its low vapor pressure at high temperatures. The solar programs are looking at temperatures of around 700c and the nuclear reactors are looking at temperatures in the 700-800c range, so the chemistry and corrosion of the salts is very important."

In Zhang's lab, equipment such as a molten salt loop, gloveboxes, electro-chemical cells, and corrosion test autoclaves, are used to perform corrosion and chemistry studies, providing critical and fundamental data to energy engineers to use as part of simulations and in the design of more efficient solar and nuclear power plants.

The NMFC lab focuses on studies of advanced structural and coolant materials and their compatibility, and materials corrosion and coolant chemistry in high temperature applications such as nuclear reactors. Ongoing research activities in the center include: Nuclear Materials compatibility (materials corrosion, degradation and characterization, metallic nuclear fuel); Nuclear fuel cycle technology; Electrochemical separation and technology development; and Advanced coolant (liquid sodium and molten salt) chemistry, corrosion and corrosion control.

The lab has been operational Since January, 2017, and currently houses eight graduate and one postdoctoral student, and a research scientist. The lab includes space in both the CRC and Goodwin Hall, combining for about 4,000 square feet of space allowing for a variety of instrumentation including a high-temperature water, molten salt, and stress-corrosion-cracking, and very high temperature steam corrosion loops; and a variety of high-temperature/pressure autoclaves, electrochemical cells, machines for molten salt, liquid metal and more.



“The lab makes Virginia Tech one of only a very few places where such a wide array of specialized capabilities can be found for research to improve materials compatibility for energy systems,” Zhang said.

STORY BY ANDREW TIE
MACROMOLECULES INNOVATION INSTITUTE

Researchers expand breakthroughs in 3D printing Kapton, the 'ultimate' polymer

An interdisciplinary team of researchers at Virginia Tech's Macromolecules Innovation Institute (MII) have developed a new process to 3D print one of the most-desired materials in the electronics and aerospace industries.

The material, commonly known by its trade name Kapton, is a polyimide with exceptional thermal and electrical properties. Kapton has a degradation temperature around 550 degrees Celsius, doesn't dissolve in solvents, acts as an electrical insulator, and is resistant to ultraviolet irradiation. Because the molecule is all-aromatic, containing rings that restrict rotation, Kapton is also very stable.

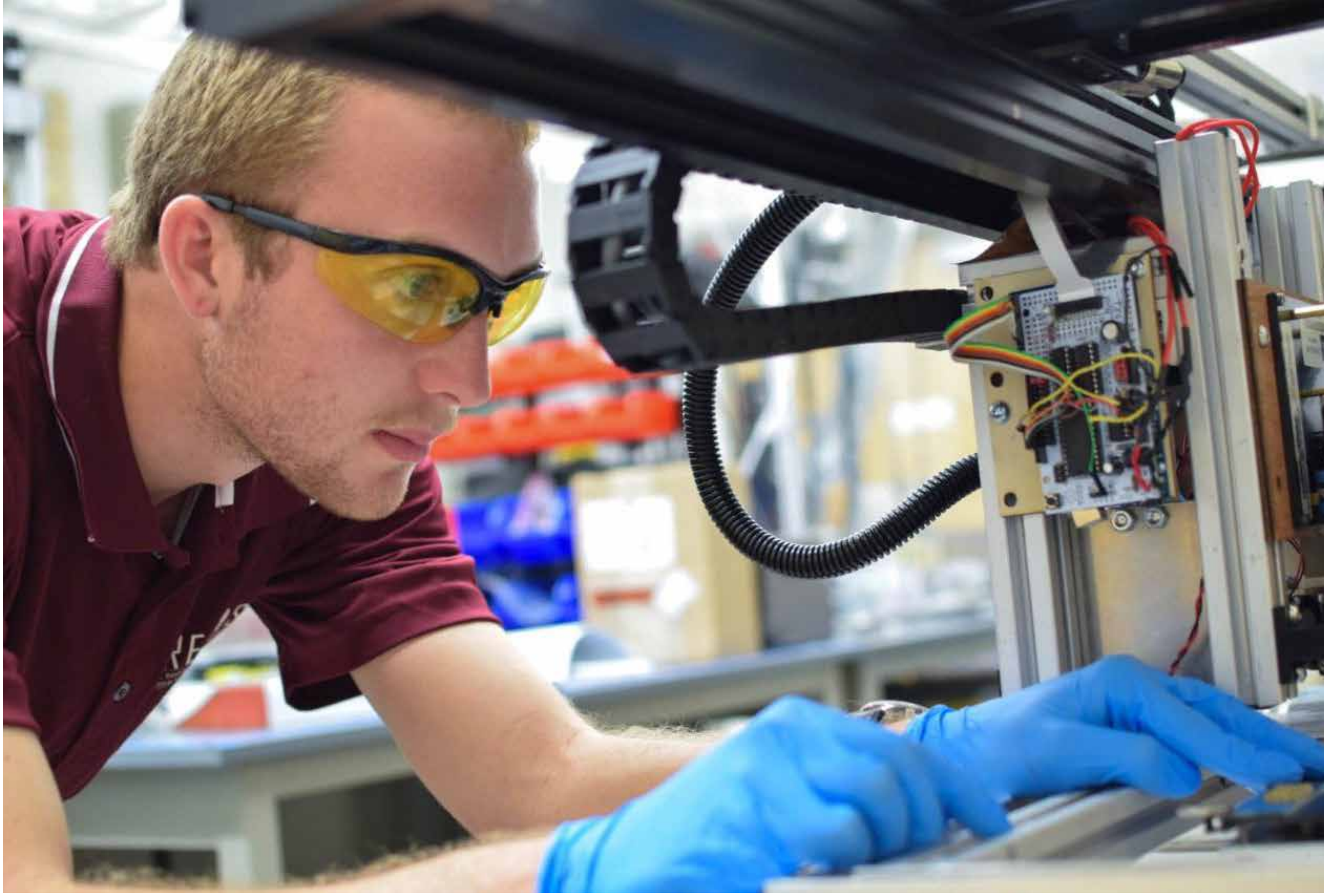
"(Kapton) can withstand all kinds of harsh environmental insults: radiation, high temperature, chemical reagents," said Timothy Long, a professor of chemistry, the director of MII, and one of the researchers in the study. "It's one of these molecules that is the ultimate in terms of performance."

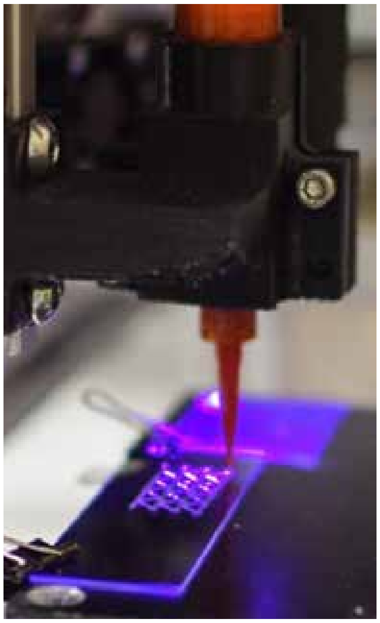
Kapton was previously available only in thin 2D sheets and is known as the basis for the "gold foil" that wraps around satellites to insulate them.

But last year, Long and other collaborators in the College of Science and the College of Engineering discovered a path to 3D printing Kapton for the first time using a process called stereolithography.

The researchers, from the Long Group in the Department of Chemistry and the Design, Research, and Education for Additive Manufacturing Systems (DREAMS) Lab in the Department of Mechanical Engineering, have now found a second way to 3D print Kapton. This process, called direct ink write (DIW), was detailed in a recent article in ACS Applied Materials & Interfaces. The researchers now have greater flexibility in incorporating Kapton into manufacturing processes.

"If you think of caulking a bathtub or decorating a cake with icing, (DIW is) a very similar





process," said Daniel Rau, one of the co-authors and a Ph.D. student in the DREAMS Lab. "Because it's so simple, (DIW) gives us incredible flexibility on the ink, synthesis, and the properties it has."

Daniel Rau, a doctoral student in mechanical engineering, works with a 3D printer in the DREAMS Lab.

Even after 3D-printing the material via the DIW process, the subsequent parts had similar properties to the commercially available Kapton film. The DIW material has similar mechanical properties up to 400 °C, and its degradation temperature is 534 °C, only slightly lower than the commercial Kapton that degrades at 550 °C.

Christopher Williams, director of the DREAMS Lab and associate director of MII, said that beyond multi-material printing, they can also now print Kapton directly onto an existing material, which stereolithography cannot do.

"As soon as we were able to print Kapton, people asked us about applications," Williams said. "The answer we often gave was printed electronics, but that's challenging to do in stereolithography. This new technique could really enable that as we look towards simultaneous printing of conductive materials and this excellent insulator."

[Read the whole story at VTNews]

STORY & PHOTO BY ERICA CORDER
COLLEGE OF ENGINEERING

Shaking up a lab

Alumni helping make lab a world-leading facility for vibrations research

When you buy a mobile phone, you might not think about how far it's traveled to get to your pocket. You might think even less about the vibrational forces that acted upon it during its journey to you.

But in the Advanced Vibrations and Acoustics Lab (AVAL), founded and directed by mechanical engineering John R. Jones III Faculty Fellow and associate professor Pablo Tarazaga, researchers are poised to make important inroads into determining standards of just how much vibration an object can take, including objects like your phone.

Sriram Malladi continues to work in the lab as a postdoctoral researcher since earning his master's degree and Ph.D. in mechanical engineering from Virginia Tech. He says he was drawn to researching vibrations because it's one of the most ubiquitous forces in our daily lives — which means most of us forget about it.

But not in the lab where certifying the structural integrity of objects from cell phones to car parts to military equipment takes prominence. And with the help of alumni who work at the U.S. Naval Surface Warfare Center at Dahlgren, Virginia, the lab was loaned new equipment that enables further research capabilities.

In December 2017, Tarazaga and Malladi watched as a crew unloaded a 2,000-pound, navy blue shaker table and its components into AVAL's first floor space in Durham Hall. The shaker table, which can apply a vibrational force of up to 2,000 kilograms, can shake objects at frequencies as high as 4,000 hertz — meaning the researchers can recreate a wide array of environmental conditions in the lab like those seen in the field.

The loan was orchestrated by alumni who work at NSWC Dahlgren, including shock and vibration technical expert Luke Martin (M.S. in mechanical engineering '04, Ph.D. in mechanical engineering '11), who was a classmate of Tarazaga's.

"We use shakers as a tool in our field to basically qualify equipment in weapon systems to go

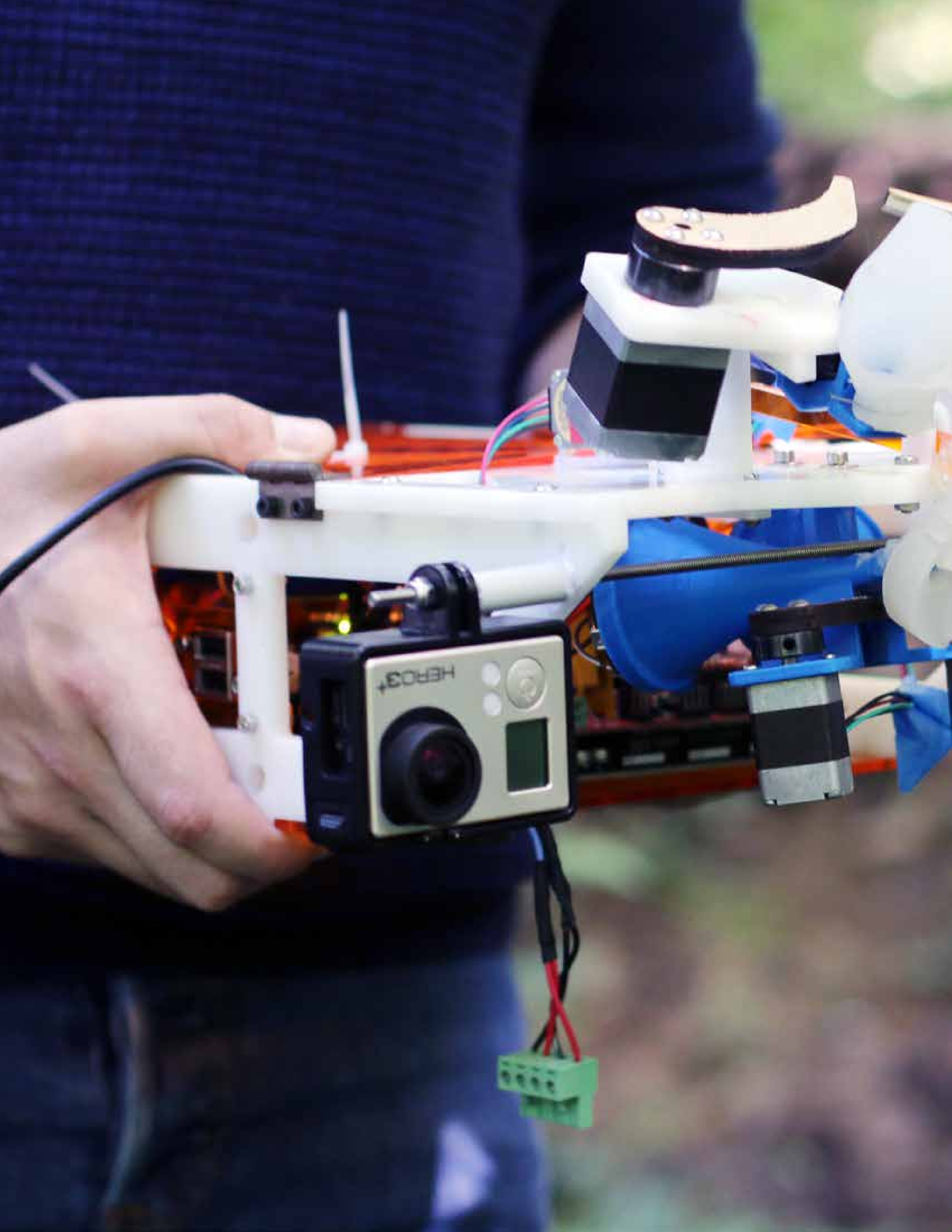
The day of the shaker table ribbon cutting ceremony, mechanical engineering professor Pablo Tarazaga and postgraduate researcher Sriram Malladi show visitors from the Naval Surface Warfare Center at Dahlgren the Advanced Vibrations and Acoustics Lab on the first floor of Durham Hall.

out in the fleet, and this was a shaker we had that we really weren't using," Martin said. "So we thought under our educational partnering agreement with Virginia Tech that we can essentially loan it down to Virginia Tech indefinitely, and they can get really good use out of it."

Luke Martin, shock and vibration technical expert at NSWC Dahlgren and alumnus (M.S. in mechanical engineering '04, Ph.D. in mechanical engineering '11), cuts the ribbon at the lab's ceremony debuting the new, fully operational shaker table.

Not only does the equipment expand the lab's research capabilities, the partnership signals progress in a plan to ultimately create a vibrations and adaptive structures consortium among Virginia Tech, other universities, government, and industry — a consortium Tarazaga and other College of Engineering faculty hope to base out of the Blacksburg campus.

If it pans out, Malladi explained, it will position Virginia Tech to play a central role in an ongoing movement to develop international standards of environmental testing. Currently, objects are certified by demonstrating how much vibrational force they can take until they break. But the hope is to develop a certification framework that can assist in the design stage when creating objects and to better understand the forces acting upon objects in transport and field operation.


HERO3+

Bio-inspired technology has team reinterpreting sonar signal processing

Story & Photos by
Rosaire Bushey
Mechanical Engineering

Bats may provide the answer to a glaring problem of drone operation - navigating in dense natural environments. As part of a five-year project for the Office of Naval Research, mechanical engineering professors Rolf Mueller and Michael Roan, are collaborating with three other universities to develop a better model for the sonar skills of bats.

In an effort to more effectively process sonar technology, the U.S. Navy has turned to an unlikely source for help – bats.

In 2017 the Office of Naval Research provided a grant of more than $7 million to a collaborative group of four universities. Led by Brown University, Virginia Tech joined Texas A&M, and Johns Hopkins to see if they could find a new approach to sonar signal processing. The Virginia Tech team, supported by more than $1.7 million of the grant, is led by Professors Rolf Mueller and Michael Roan of mechanical engineering in the College of Engineering.

“When we started the project the Navy briefed us and said up front that they wanted good, basic research into sonar signal processing,” Mueller said. “The Navy has always had a strong interest in sonar signal processing as they operate in a location where sonar is the only way to ‘see’.”

Mueller said, however, that operating in shallower water, or over land at low altitudes, presents a different set of problems for sonar, namely the jumble of echo information from all the stuff in the shallows or at low altitude – rocks, trees, people, buildings, signposts, etc.

Of the four university teams, Virginia Tech is unique for its ability to test with bat-based

models, the efficacy of sonar processing.

Changing Questions

"Mike and I are the oddballs in the project because everyone else is studying the bats' brains," Mueller said. "They say, 'I have an idea' but does it work? The bat won't tell you, but if an electrode in the bat's brain gives you a signal, you think you know what's going on, but can you be sure? The only way to be sure is to have an engineer build it and try it. If you have a gizmo and it works, you understand it. Everything else is just cheap talk."

Fortunately, such a gizmo exists. Mueller has been developing a bat robot for several years, using data from his two decades of study of horseshoe and Old World round leaf nosed bats in Asia and Europe. Mueller can implement the data provided by brain researchers to test theories.

"The idea is the input to the robot, which is a collection of echoes taken from the forests nearby, are run through a computer simulation of what we think the bat's brain is doing," Mueller said. "Then we try to make sense of the signals. It's like focusing a camera lens – you keep adjusting your input until you get the clearest image."

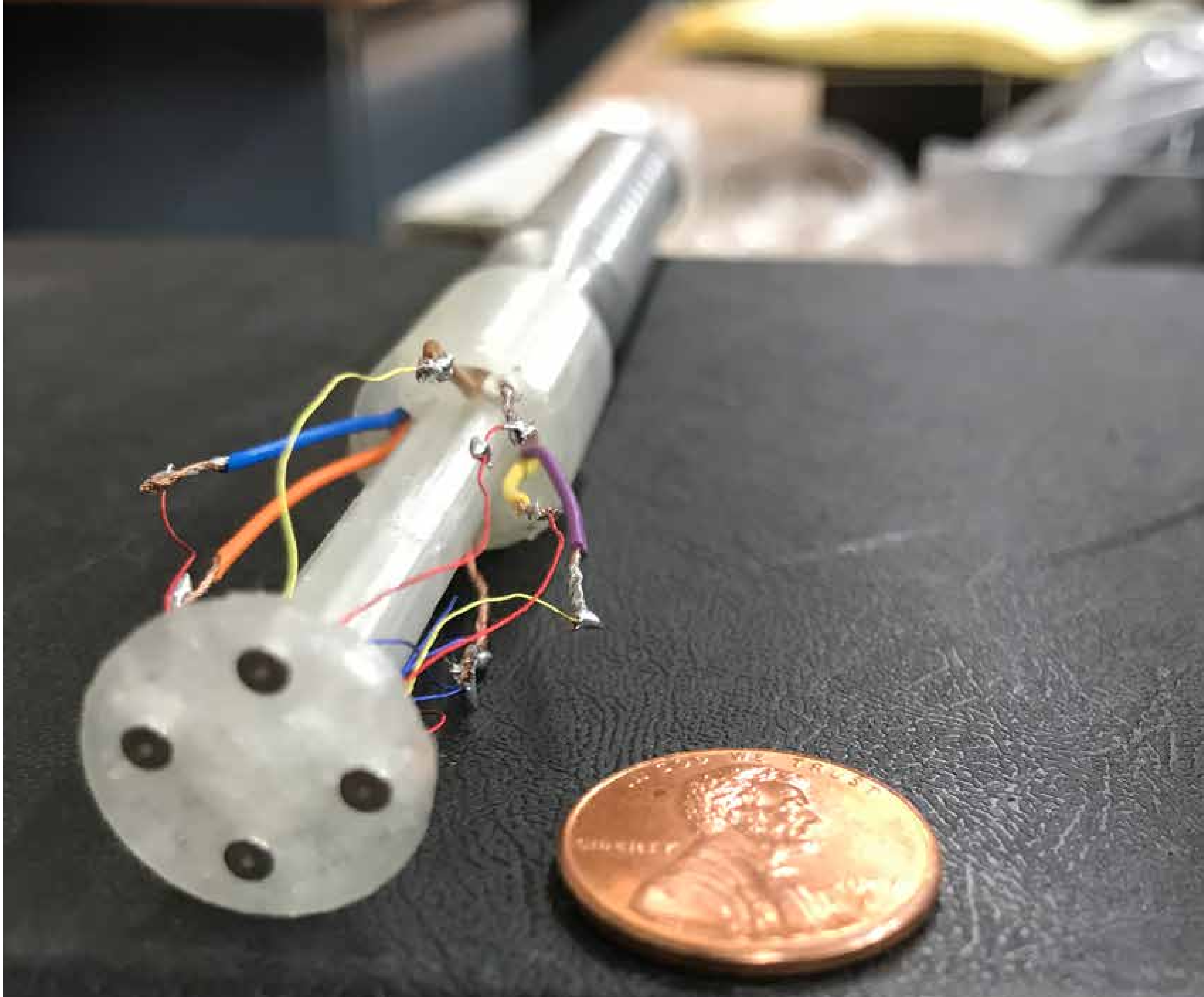
The first year of the project found the teams reviewing data from the literature to use as a starting point. Since then, as other universities provide brain data that's been incorporated into Mueller and Roan's model, connections are starting to be made that Mueller feels confident will improve sonar signal processing.

"The basic question is why is the bat so capable? Why can it just fly through the forest and we can't. I think the ear motion, the dynamics, the mobility is very important

but it's also important that the system is integrated," Mueller explained. In a biological system it's not so much, 'oh, it's this one secret…' it's all the pieces you have that work together very well and they come together to get to that performance. It's not one thing. It's not that, oh, the wiggle their ears, that's why they can do it; or it's their brain…. It's because their nose, ears, and how they wiggle them in a certain way, and how the brain processes the information…that's the hypothesis."

Despite decades of research, the project has caused Mueller to rethink how he's approached the issue of sonar signal processing, a deviation that came about because of the Navy's insistence to focus on foundational, basic research.

"I think there are alternatives of how to make sense out of sonar. The concepts of deep sea sonar from World War II still work well, but not for shallow water where there are reflections all over the place. It's essentially the same problem for a bat in the forest.," Mueller said. "For a long time we were using these concepts to find gaps in the foliage – concentrating sound energy and pointing a beam at a perceived gap. You shoot the beam and get a series of returns as the beam hits objects. You'll see some areas where there is very little return or no return and these indicate gaps."



Changing Frequencies

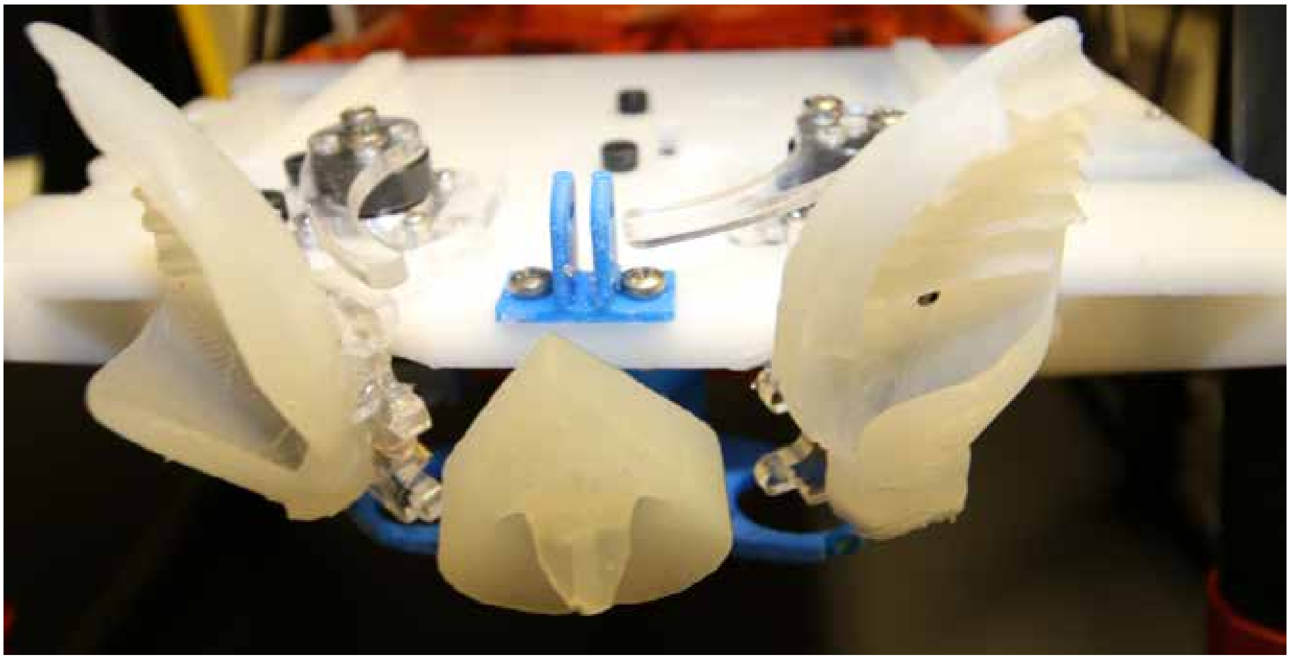
A big part in deciphering the signaling process may come from a very small component – a small cluster of one-half centimeter microphones being designed by Roan, that will create an additional correlation for brain researchers.

"The project is really about creating a biosonar," Roan said. "by mimicking the biological process, the researchers at Brown and Johns Hopkins are examining neuroscience and how bats process audio signals by recording a bat as it emits a signal at various objects and clutter, they can measure the brain signals to see what's happening."

Researchers understand what's happening with a bat's brain signals as it's detecting a target. The bats move their noses and ears in a multitude of ways and has certain behaviors that allow scientists to tell what it's doing. But no one, to Roan's knowledge, has ever been able to understand why it's doing what it is doing when it is doing it.

"We're going to take this tiny microphone array and putting it above the bat's head and video the bat as it's going through the exercise," Roan explained. "The video coupled with data from the microphones will give us an 'image' where we will be able to see sounds come from different directions."

The microphone array picks up sounds from various points, allowing Roan to distinguish where in a sphere the sound comes from, and connecting a signal coming from point A, to movement of the bat's ears and nose that's related to that direction. This cycle lets the acoustic signal track to the brain signal.



"This is new and difficult because of the frequencies involved," Roan said. "Humans hear at below 20khz, but bats emit between 10-100khz. All the audio stuff in the world is made for below 20khz, so we had to build special microphone capsules, special pre-amps, amps, spectrum shaping – everything that goes with collecting sound in those higher frequencies."

To make the sound field microphones work, four one-half centimeter mics sit on a tetrahedron – a four-sided pyramid. The mics can't touch and have to be glued together on a little ball.

"We can reach to 80kHz but beyond that we've got nothing," Roan said. "But that should give us a really good look at what the bats are doing and being able to characterize that much should provide a lot of good data."

Changing Perspective

The work done by Roan's team has encouraged Mueller to look at what he was doing and rethink the whole process in the same way Roan has tackled capturing and correlating sound. So, instead of using a concentrated sonar signal to look for a gap, he decided to distribute the sound energy widely. Based on acoustic returns, any resulting gaps would be very small, but Mueller wasn't if they were actual gaps.

"So, we said, ok, let's try to think what the sonar engineers would do, and we came up with the question, how likely is it that if there is a gap we're going to miss it? And how likely is it if there is no gap that we'll think there is?" Mueller explained.

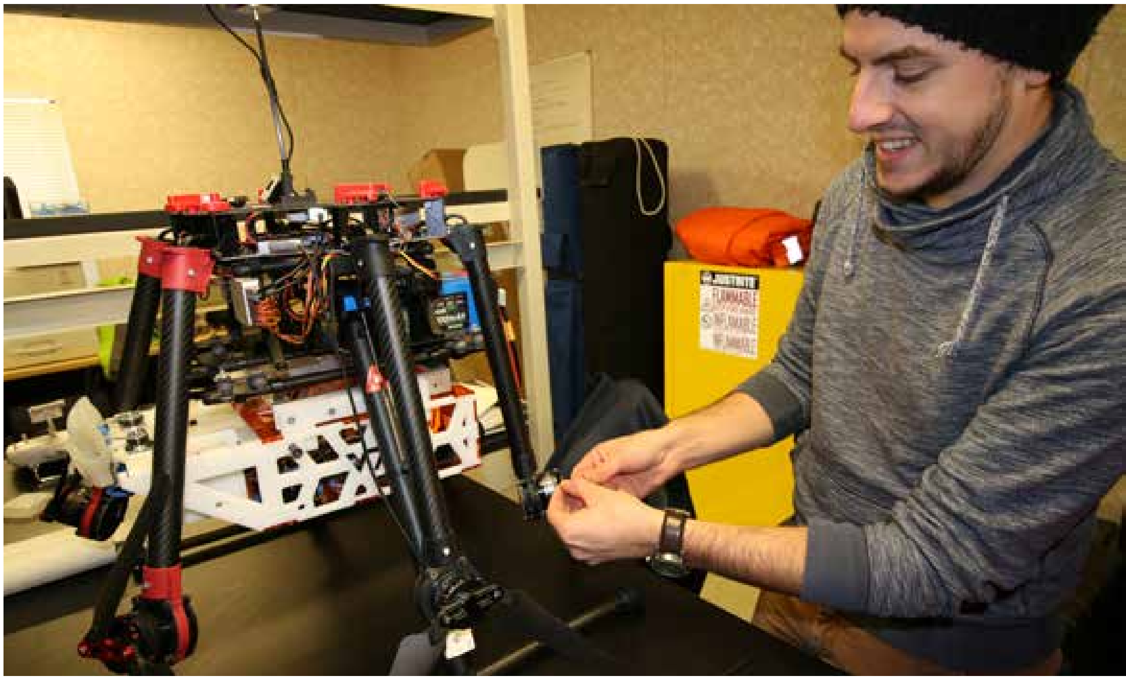
Using his method, the team found that in ten percent of the cases where they thought there was a gap, there was none; and in fifty percent of cases they missed gaps that actually existed. It was better than guessing, but not good enough to support the dexterous navigation of bats in a forest .

"What we did was to throw the energy out altogether," Mueller said. "The one thing sonar engineers worry about, we said, forget it – just throw it out and look at the rest of the signal and try to do something like what the brain might do."

By rethinking how they approached the problem, Mueller's team found new features in the signal that let them know whether or not gaps existed.

"We do this with a single echo. It's not focused, but rather dispersed and sonar people think it's crazy," Mueller said. "There's thick foliage, there's a small gap inside, we disperse the sound energy all across the foliage, look at the pattern we get back, process it a bit like a brain, and we can tell you whether there is a gap or not – more than ninety-nine percent of the time!"

Mueller's change in tactics wasn't a shot in the dark. Even though he's spent a career working with bats, he's a neuroscientist by education and training, and he looked back to his doctoral work to make the connection.



"We took a deep neural network model called Convolutional Neural Network, which is a type of deep learning architecture," Mueller said. "Typically, neural networks connect input to output and in the old days there was perhaps one level of input, a processing level, and an output level. That's too limited. Then came deep neural networks that have many layers providing lots of flexibility in the transformations you can make between the input and output. That was the idea we used."

For the current ONR project, Mueller hopes to incorporate the brain model into his robotic bat sonar head to create a closed loop, where the system would sense something through the nose, receive it through the ears, and make control changes to adapt based on what it senses.

"Closing a loop is easy but we want it to be useful. I hope in four years we have built a useful closed loop system," Mueller said.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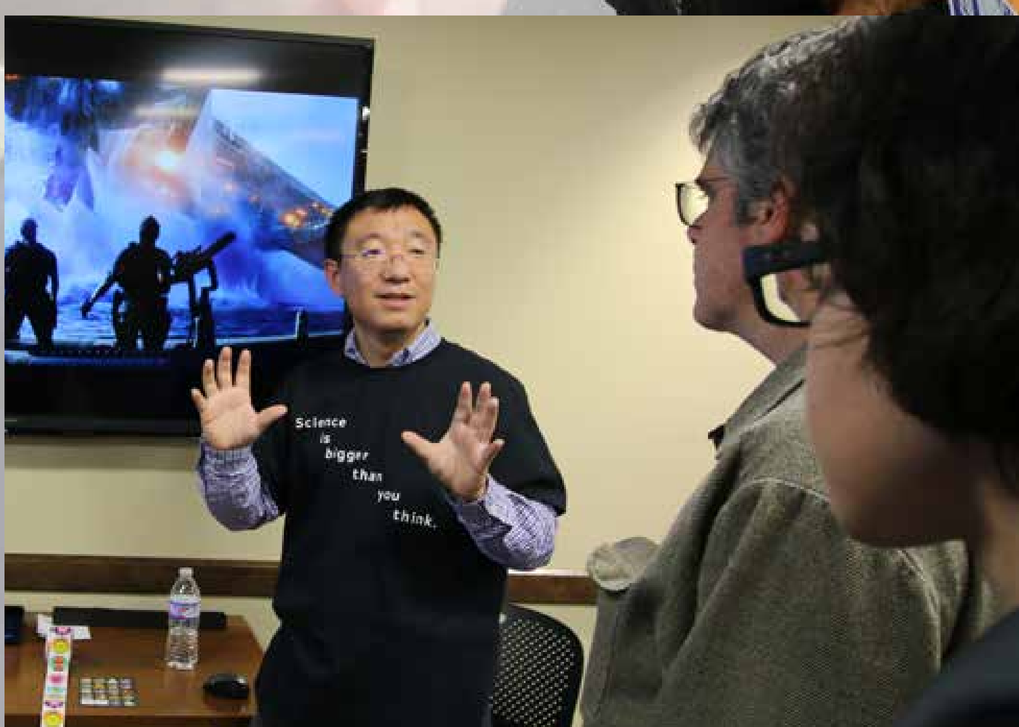
Science
is
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Mechanical engineers show off at Virginia Tech Science Festival

last look

A snowman on the Drillfield, Dec. 10, 2018.
Photo by Erin Williams