

MECHANICAL ENGINEERING AT VANDERBILT UNIVERSITY

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Vanderbilt University School of Engineering

The School of Engineering is internationally recognized as a leader in engineering research and education. Its faculty expertise and graduate programs are aimed at solving complex societal problems through collaborations among the disciplines, across campus, and beyond the university. That culture of collaboration provides endless opportunities for students and faculty from all disciplines to work in any of our nine core competencies we call intellectual neighborhoods – big data science and engineering; biomedical imaging and biophotonics; cyber-physical systems; energy and natural resources; nanoscience and nanoengineering; regenerative medicine; rehabilitation engineering; risk, reliability and resilience; and surgery and engineering,

The School comprises five main buildings and several satellite facilities. William W. Featheringill Hall houses a three-storey atrium designed for student interaction and social events, more than 50 teaching and research labs, and project rooms. The new Engineering and Science Building is an eight-storey state-of-the-art facility that houses the Wond'ry at the Innovation Pavilion, numerous research labs, interactive classrooms, clean rooms and space for students to work, study and socialize. School administrative offices and several classrooms are located on the ground floor of the Science and Engineering building in Stevenson Center, which also houses the Biomedical Engineering Department on the eighth and ninth floors. Jacobs Hall, adjacent to Featheringill Hall, contains labs, offices and classrooms serving the Civil and Environmental Engineering Department and the Electrical houses Mechanical Engineering, Chemical and Biomolecular

Satellite facilities include the labs and offices of the Biomedical Photonics Center located in the W. M. Keck Free Electron Laser Center; the Laboratory for Systems Integrity and Reliability (LASIR), an off-campus hangar-style facility dedicated to scaling up experiments to realistic and full size, including a wind tunnel and military aircraft; and on Nashville's famed Music Row, the Multiscale Modeling and Simulation facility (MuMS); the Vanderbilt Institute of Software Integrated Systems; and the Institute for Space and Defense Electronics, providing office space, dry lab and conference space.

Vanderbilt

Cornelius Vanderbilt had a vision of a place that would "contribute to strengthening the ties that should exist between all sections of our common country" when he gave a million dollars to create a university in 1873. Today, that vision has been realized in Vanderbilt, an internationally recognized research university in Nashville, Tennessee, with strong partnerships among its 10 co-located schools, neighboring institutions and the community.

Vanderbilt offers undergraduate programs in

engineering, the liberal arts and sciences, music, education and human development, as well as a full range of graduate and professional degrees. The combination of cutting-edge research, liberal arts education, nationally recognized schools of law, management and divinity, the nation's top ranked graduate school of education and a distinguished medical center create an invigorating atmosphere where students tailor their education to meet their goals and researchers collaborate to address the complex questions affecting our health, culture and society.

An independent, privately supported university, Vanderbilt is the largest private employer in Middle Tennessee and the second largest private employer based in the state.

Nashville

Vanderbilt's hometown of Nashville is a vibrant, engaging city known proudly as "Music City, U.S.A." and one of the fastest growing areas in the Mid-South. The university's students, faculty, staff and visitors frequently cite Nashville as one of the perks of Vanderbilt, with its 330-acre campus located a little more than a mile from downtown.

Nashville's downtown features diverse entertainment, dining, cultural and architectural attractions. The Broadway and emerging SoBro areas feature entertainment venues and an assortment of restaurants. North of Broadway lie Nashville's central business district, Legislative Plaza, Capitol Hill and the Tennessee Bicentennial Mall. Cultural and architectural attractions are found throughout the city.

Named America's friendliest city three years in a row, Nashville is a metropolitan place that exudes all the charm and hospitality one expects from a rapidly growing capital in the new south. Fortune magazine named Nashville one of the 15 best U.S. cities for work and family. It has ranked as the No. 1 most popular U.S. city for corporate relocations by *Expansion* magazine. GQ posted an article dubbing the city "Nowville." *The New* York Times has declared Nashville a new "it" city. CBRE ranked Nashville as the most rapidly growing small market for tech talent in the U.S. and Canada in their 2018 Scoring Tech Talent report.

COVER, Students walk to classes and labs on the Clark Grand Stair in Vanderbilt's newest building – the Engineering and Science Building, which is home to a number of state-of-the-art mechanical engineering laboratories. The striking spiral staircase is dedicated in honor of engineering alumni and longtime university supporters Sue, BA'77, and G. Edmond Clark, BE'76. The Clark Grand Stair circles through four levels of a building designed for interdisciplinary collaboration and innovation.

ME

MECHANICAL ENGINEERING AT VANDERBILT UNIVERSITY 2018-2019



hen I came to the School of Engineering in 2000 as a new assistant professor, I found a strong, classical mechanical engineering department primarily focused on traditional mechanical engineering topics. Over time, there has been a concerted effort by our talented faculty and leadership in the school and the university to modernize the department to support more

interdisciplinary research, and to position the department to tackle some of the 21st Century Grand Challenges for Engineering, identified in 2008 by the National Academy of Engineering.

As a result, the department is now in the forefront of a number of diverse, cutting-edge research fields such as energy, nanotechnology, and robotics, to name a few. The curricula, both undergraduate and graduate, are continuously modernized, and faculty take pride in their teaching commitment. Our external and internal research funding has grown significantly, contributing to a rise in recognition and reputation nationally and internationally.

When I became chair of the department in January 2018, I considered myself extremely fortunate to serve and lead a faculty who are enthusiastic,

dynamic, and eager to help our students and our community. We have a thriving and diverse undergraduate and graduate student body who receive an excellent engineering education, and excellent staff who go the extra mile to ensure the smooth functioning of the department.

While the curriculum has always emphasized a solid foundation in mathematics and physics, I want to promote a more immersive curriculum where the students have the opportunity to design, build and test the concepts they learn in the classroom. I also want to expand opportunities for undergraduate research and internships. We will continue to provide and build a robust research environment so our students can establish themselves in academia as well as industry.

Interdisciplinary research will play a key role in addressing the Grand Engineering Challenges and I believe the mechanical engineering faculty "Our external and internal research funding has grown significantly, contributing to a rise in recognition and reputation nationally and internationally."

Nilanjan Sarkar Professor and Chair Department of Mechanical Engineering

are outstanding in this regard. My own research in robot-mediated intervention of autism and dementia, virtual reality-based intervention of schizophrenia, and design of assistive robotic systems involves strong collaboration with faculty from the medical school, nursing school, and psychology department.

As an ardent supporter of diversity and inclusion, I know a diverse faculty and student community tremendously enrich both research and education. In this regard, we have made large strides. If I can continue to foster an environment where everyone feels welcome and receives all the possible opportunities to become successful, I will feel that I have done my job.

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MECHANICAL ENGINEERING AT VANDERBILT



hen you study mechanical engineering at Vanderbilt, you will start with a strong foundation in basic math and physics and will move on to upper-division courses in all major areas of mechanical engineering. You won't be stuck in a textbook, either. You will develop hands-on skills in labs and as part of teams in laboratory studies and design projects, and use the most modern computational tools. In fact, our unique curriculum will have you working on design projects from your freshman year until you graduate.

Plus, you will work side by side with some of the top minds in the business. Your professors are not only experts in the mechanical engineering field, but also terrific mentors who will help you find the best application of your talents and interests.

Like all other undergraduate engineering students, you will get an excellent liberal arts education that will enrich your technical and scientific training and help you become a better problem solver, team member and manager. You also will be prepared to advance into graduate studies in engineering, management, law, medicine, or finance.

Graduate students have the opportunity to design an interdisciplinary curriculum with a mechanical engineering focus area that will provide a competitive advantage in obtaining an academic faculty position, or a leadership position in research and development at a startup company, government laboratory, or in a leading company in the area of interest to the student.

Our engineering graduates are widely known and valued for their expertise, interdisciplinary experience, intellectual independence, communication skills, and leadership, and are thoroughly prepared for the 21st century global work environment.

The department has earned a national reputation in several areas, including surgical robots, rehabilitation engineering and socially assistive robotics, mechatronics, control and design, energy, fluids, nanotechnology, and manufacturing.



ME

PROGRAMS OF STUDY UNDERGRADUATE

To earn a bachelor of engineering degree, a student must complete a broadbased engineering curriculum that requires a theoretical understanding of physical systems as well as practical experience in designing, implementing and testing engineering solutions. In addition, our curriculum provides opportunities for students to perform research, study specific engineering challenges and build specialization in focused areas of interest.

This multi-faceted approach to education prepares our students to enter the workforce to make a significant and immediate impact. The B.E. in mechanical engineering requires a minimum of 126 credit hours. The curriculum can be designed to achieve both the bachelor's and the master of engineering within five years.

Our program leading to the bachelor of engineering degree in mechanical engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

Minors

A minor consists of a minimum of five courses of at least three credit hours each within a recognized area of knowledge. Currently, minors are offered in engineering management, materials science and engineering, computer science, environmental engineering, energy and environmental systems, nanoscience and nanotechnology, scientific computing, and most disciplines of the College of Arts and Science, Blair School of Music, and Peabody College. Students should declare their intention to pursue minors by completing forms available in the Student Services Office of the School of Engineering.

Admission to the undergraduate program is managed by the Vanderbilt Office of Undergraduate Admissions.

Office of Undergraduate Admissions

Vanderbilt University 2305 West End Avenue Nashville, TN 37203-1727 Phone: (615) 322-2561 or (800) 288-0432 Website: admissions.vanderbilt.edu

Mechanical Engineering

Prof. Kenneth Frampton Director of Undergraduate Studies Department of Mechanical Engineering Office: 330 Olin Hall Email: ken.frampton@vanderbilt.edu Phone: (615) 343-0610

Yes, Vanderbilt engineering students do study abroad

You can choose from more than 25 direct-credit programs in engineering in locations ranging from Dublin to Sydney, Cape Town to Hong Kong. Engineering study abroad opportunities include exchange programs with Budapest University of Technology, City University of Hong Kong, Hong Kong University of Science and Technology, National University of Singapore, Politecnico di Torino and more!

Financial aid applies to study abroad during the academic year and scholarships are available to support summer study abroad. Students should discuss with their academic advisers how best to incorporate study abroad into their four-year plans of study. Check out Vanderbilt's Global Education Office (vanderbilt.edu/geo) for more information.



Irfaan Khalid Engineering, 2019 Studying abroad at Hong Kong University of Science and Technology

PROGRAMS OF STUDY GRADUATE

Vanderbilt University's Graduate School, in collaboration with the School of Engineering, offers master of engineering, master of science, and doctoral degrees in mechanical engineering.

The master of engineering is a professional degree program designed especially for engineering practitioners who may pursue the degree one course at a time or as fulltime students. The M.Eng. degree is administered by the School of Engineering.

The master of science degree requires the completion of 30 didactic semester hours or 24 hours plus 6 hours of research. Courses are selected on an individual basis with the guidance of the student's major professor and the approval of the department.

A student's doctoral program is tailored to his or her interest in consultation with a major professor and in a format specified by the department. The student chooses a major professor and area of specialization. Each program requires 48 research hours beyond the 24 didactic hours for a master's degree. Half of these hours are course work. The remaining hours represent research work for the dissertation. Students must successfully complete qualifying exams prior to candidacy for the degree. After a dissertation is submitted and approved, a public oral presentation and examination are held.

Both the M.S. and Ph.D. programs are administered by the Vanderbilt University Graduate School.

To apply for admission to the graduate program in mechanical engineering, you must first meet the general requirements for admission by the Vanderbilt University Graduate School. Application for admission may be made electronically through the Graduate School website at **vanderbilt.edu/** gradschool. The Graduate School Catalog is here: **vanderbilt.edu/** catalogs.

Vanderbilt University Graduate School

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Mechanical Engineering

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SAFE SOLID-STATE LITHIUM BATTERIES HERALD 'PARADIGM SHIFT' IN ENERGY STORAGE



The race to produce safe, powerful and affordable solid-state lithium batteries is accelerating and recent announcements about gamechanging research using a solid nonflammable ceramic electrolyte known as garnet has some in the race calling it revolutionary.

"This is a paradigm shift in energy storage," said Kelsey Hatzell, assistant professor of mechanical engineering. A paper describing her novel research on the failure points of a garnet electrolyte was published in the American Chemical Society's Energy Letters.

Lithium-ion batteries typically contain a liquid organic electrolyte that can catch fire. The fire risk is eliminated by the use of a nonflammable garnet-based electrolyte. Replacing liquid electrolytes with a solid organic like garnet also potentially lowers the cost by increasing battery life.

"Solid-state batteries are desirable for all-electric vehicles and other applications where energy storage and safety are paramount," Hatzell said. "While there is still a lot of research to be done to bring solid-state devices to the market, their promise for applications in highenergy density batteries and electric vehicle applications is stirring a lot of interest across the globe."

Hatzell's team tested Li7La3Zr2O12 – Lithium lanthanum Zirconium Oxide or LLZO – a garnettype material that shows great promise for all-solid-state battery applications due to its high Li-ion conductivity and its compatibility with Li metal.

"Understanding the failure mechanisms within these electrolyte systems is critical for designing resilient solid electrolyte systems," said Hatzell. "The primary limitation of LLZO is the propensity for shortcircuiting events at low current densities."

Hatzell's study tracks structural changes in LLZO after realistic charging and discharging events using synchrotron X-ray tomography. This technique allows the researchers to look inside the battery and view 3D structural features with submicron resolutions.



Far left, Assistant Professor Kelsey Hatzell works with a graduate student Nicolas Hortance in her Inks and Interfaces lab in Vanderbilt's new Engineering and Science Building.

"Most techniques that image lithium in a solid electrolyte are done destructively or ex situ using scanning electron or optical microscopy techniques. Testing the material under more realistic conditions using synchrotron tools allows us to probe buried interfaces," said Hatzell, whose co-authors are Fengyu Shen, a postdoctoral scholar, and graduate students Xianghui Xiao and Marm Dixit.

Only a handful of synchrotrons and neutron sources exist in the world. Dixit was one of 60 graduate students selected for the 2017 National School on Neutron and X-ray Scattering. As a part of this program he spent one week at Oak Ridge National Lab and one week at Argonne National Lab. Hatzell's team conducted all of its testing at Argonne.

The results concluded that the presence of voids or connected pores led to a higher failure rate. "These results can potentially inform materials design for the next generation of all solid-state battery systems," Hatzell said.

PROFESSOR BUILDS HIS OWN SUPER SUIT TO REDUCE BACK STRESS

TV infomercials offer a world of potential solutions for back pain, but most of them have at least one of three problems — they're unproven, unworkable or just plain unattractive.

A team of mechanical engineers is changing that with a design that combines the science of biomechanics and advances in wearable tech to create a smart, mechanized undergarment.

Well over half of all adults will experience low back pain in their lifetimes, and the condition is estimated to cost \$30 billion in medical expenses and more than \$100 billion in lost productivity in the U.S. annually. Karl Zelik, assistant professor of mechanical engineering and the principal investigator on the project, experienced back pain himself repeatedly lifting his toddler son, which he said got him thinking about wearable tech solutions.

"I'm sick of Tony Stark and Bruce Wayne being the only ones with performance-boosting super suits. We, the masses, want our own," Zelik said. "The difference is that I'm not fighting crime. I'm fighting the odds that I'll strain my back this week trying to lift my 2-year-old."

The device consists of two fabric sections made of nylon canvas, Lycra, polyester and other materials, for the chest and legs. The sections are connected by sturdy straps across the middle back, with natural rubber pieces at the lower back and glutes.



The device is designed so that users engage it only when they need it. A simple double tap to the shirt engages the straps. When the task is done, another double tap releases the straps so the user can sit down, and the device feels and behaves like normal clothes. The device also can be controlled by an app that the team created—users tap their phones to engage the smart clothing wirelessly via Bluetooth.

Eight subjects tested the device leaning forward and lifting 25-pound and 55-pound weights while holding their position at 30, 60 and 90 degrees. Using motion capture, force plates and electromyography, Zelik's team demonstrated that the device reduced activity in the lower back extensor muscles by an average of 15 to 45 percent for each task

"The next idea is: Can we use sensors embedded in the clothing to monitor stress on the low back, and if it gets too high, can we automatically engage this smart clothing?" Zelik said.

The project is funded by a Vanderbilt University Discovery Grant, a National Science Foundation Graduate Research Fellowship and a National Institutes of Health Career Development Award. A patent has been filed.

VANDERBILT-DESIGNED EXOSKELETON WINS GOLD

Michael Gore, a T10 complete paraplegic, is wearing the Indego Exoskeleton, which allows him to walk. The Vanderbiltdesigned Indego® exoskeleton is a gold award winner in medical design excellence.

Indego is a powered lower limb exoskeleton enabling people with spinal cord injuries to walk and participate in overground gait training. It was developed by Professor Michael Goldfarb with a team of engineers and students in the Center for Rehabilitation Engineering and Assistive Technology.

The device is the result of an intensive, 10-year

effort. It acts like an external skeleton. It straps in tightly around the torso. Rigid supports are strapped to the legs and extend from the hip to the knee and from the knee to the foot. The hip and knee joints are driven by computercontrolled electric motors powered by advanced batteries. Patients use the exoskeleton with walkers or forearm crutches to maintain their balance.

"You can think of our exoskeleton as a Segway with legs," Goldfarb said. "If the person wearing it leans forward, he moves forward. If he leans back and holds that position for a few seconds, he sits down. When he is sitting down, if he leans forward and holds that position for a few seconds, then he stands up."

Indego is licensed by Parker Hannifin Corporation for commercialization and the company markets and sells the exoskeleton for both clinical and personal use in the United States.

STEERABLE ROBOTIC NEEDLES FOR LUNG BIOPSIES



collaboration between Professor of Mechanical Engineering Robert Webster, Vanderbilt pulmonologist Fabien Maldonado, and a University of North Carolina colleague has resulted in a \$2 million National Institutes of Health grant to help develop a steerable robotic

needle to safely biopsy hard-to-reach lung nodules.

Webster began to design a beveled, steerable tip surgical needle in 2004 while in graduate school. Once at Vanderbilt, he continued his work on steerable robotic surgery needles. "When Fabien came to Vanderbilt I had someone who could give me the clinical insight I needed to make this system work the way it needs to work," Webster said.

The team has designed a system that will reach suspicious nodules by deploying a steerable needle from a bronchoscope's tip.

The new system will harness the capabilities of a new class of steerable needles to extend the range of



Robert Webster and Fabien Maldonado

bronchoscopes and reliably and safely access nodules throughout the lung, including in the peripheral zone.

"It will be technically innovative because it combines three types of continuum devices that have not previously been unified, it integrates biopsy collection with a bevel tip steerable needle for the first time ever, and it provides a novel physician interface for visualizing and controlling steerable needles in the lung," Webster said.

EXPLORING A WAY TO RESTORE SILENCED VOICES

A swarm of cicadas left thousands of insect carcasses across the Vanderbilt University campus in 2011. Haoxiang Luo brought some of those cicadas to his Computational Flow Physics and Engineering Laboratory and created a model of their wing movements.

Luo, associate professor of mechanical engineering and otolaryngology, specializes in computational modeling of fluid-structure interaction (FSI) for biological systems. He has made similar models of the aerodynamics of hummingbird wings and the hemodynamics of blood as it interacts with heart valves, among other fluid flow systems.

His work is leading to trans-institutional research at the Vanderbilt Institute for Surgery and Engineering and Vanderbilt University Medical Center to develop a surgical planning tool to help restore speech for people with vocal fold paralysis.

Vocal folds are located on both sides of

the larynx and must come together and vibrate to produce sound. The study is focusing on unilateral vocal fold paralysis, which is when one of the vocal folds fails to close completely against the other.

People with the

condition have a hoarse voice, and require more effort to produce sound. They often



They often Luo experience

vocal fatigue and become winded during everyday activities. Such issues can seriously impact quality of life, leading to loss of productivity at work and long-term disability.

Luo's collaborator, Bernard Rousseau, chair of the Department of Communication Science & Disorders, University of Pittsburgh, found similarities in the way the cicada wings moved and the movement of human vocal folds, leading them to wonder how the model might be used to improve surgical techniques for paralyzed vocal folds.

Rousseau is the principal investigator of the multidisciplinary team, which includes Luo, associate chair of mechanical engineering, and Gaelyn Garrett, MD, professor and vice chair of otolaryngology.

This has culminated in the National Institutes of Health awarding a five-year, \$2.4 million research grant to design a software tool to help surgeons develop more precise surgery plans for the most common surgical intervention for unilateral vocal fold paralysis, type 1 laryngoplasty.

GETTING ROBOTIC SURGICAL TOOLS FROM THE LAB TO THE OPERATING ROOM

The path from a university lab to commercialization is especially complex in the biotech industry. Challenges range from long lead times, sometimes measured in decades, to the costs of transforming ideas into innovations, as well as issues of intellectual property, patenting and licensing.

Yet Nabil Simaan, a mechanical engineering professor who specializes in designing robots to help surgeons perform operations in areas of the body that are hard to reach, does not deter easily. He has years of experience working collaboratively with commercial entities while collecting numerous patents—three in 2017 alone.

Simaan's Advanced Robotics and Mechanism Applications Laboratory at Vanderbilt leads the way in advancing several robotics technologies for medical use, including miniature robots for single small-incision, cochlear implant and minimally invasive throat surgeries.

"A key focus of the research is the design of intelligent robotic devices that can sense and regulate their interaction with the anatomy," Simaan said. "These robots can be used collaboratively with a surgeon to safely excise or ablate tissue."

Simaan is co-inventor of the Insertable Robotic Effector Platform. IREP—a portfolio of multiple patents—is believed to be the world's smallest robotic system and was hailed as a medical science breakthrough in 2013. It is licensed to Titan Medical and led to the development of the Titan SPORT system for single-port access surgery.

The minuscule robotic surgical tool enters the body through a remarkably small incision—six-tenths



Above, Professor Nabil Simaan in his Advanced Robotics and Mechanism Applications Laboratory in Olin Hall.

of an inch, or 15 millimeters. Once inside the body, it unfolds to reveal a camera system for 3D visualization and imaging feedback, and two snakelike arms that perform the surgery.

"Typically, as a research lab, we try to be at least 10 years ahead of industry to help usher in new approaches to surgery via new technologies," he said. "But university researchers and industry are catching up."

The latest ARMA tech—a prototype robot system to remove bladder tumors—shows great promise, having proved successful in animal studies. The research, recently published by the *Journal of Endourology*, earned a best paper award received at the 2018 Engineering and Urology Society conference.

Among all cancer diagnoses, the incidence of bladder cancer

ranks fourth in the United States and seventh worldwide in males. "Bladder cancer also is very expensive to treat. It requires repeat resections because surgeons remove a bladder tumor 'piecewise' and that often results in recurrence and more surgeries," Simaan said.

Simaan and his team developed a transurethral robot platform called TURBot. It is the first endoscopic robotic system to provide full surgical coverage with visibility of the bladder, including the neck and dome, and the first to have been evaluated during in vivo animal experiments.

Simaan and two former students have co-founded a startup to develop such technologies for robot-assisted transurethral resection of bladder tumors.

Below, Professor Nilanjan Sarkar **(left)** and research scientist Joshua Wade adapt an offset cane with inertial and force sensors.

'SMART CANE' COULD HELP FLAG FALLING RISKS MORE QUICKLY

Imagine an instrumented cane that can analyze gait to determine the risk of falling in real time while still providing support.

Nilanjan Sarkar, professor and chair of mechanical engineering, says the "IntelliCane" can quantitatively calculate falling risk as accurately as a physical therapist can with their own eyes.

Dizziness and balance problems are significant and costly public health issues. In the United States, every year one out of three adults over 65 years of age falls and the statistic climbs to one out of two after age 80. The problem is not restricted to the elderly. Illnesses that cause balance disorders range from ear infections, head injuries and poor blood circulation to Parkinson's, spinal stenosis and stroke. The cost of treating injuries from falls is estimated at \$34 billion annually.

"When I realized how big this problem was, we started searching for available solutions," Sarkar said. "Initially, my thought was to design something to prevent falls, but after more thought and a little experimenting we quickly realized this was not practical. The next best thing was to determine how to reliably estimate the fall risk so that intervention can be applied when a person's risk gets so high that they could fall at any time."

Sarkar and research scientist Joshua Wade wanted to develop a tool that could help therapists collect much richer data about their patients' gaits, enabling therapists to intervene more quickly if needed.

The engineers rigged an offthe-shelf offset cane – which has a J-shaped handle – with inertial and force sensors connected to a wireless microcontroller that provides realtime data on use as the person walks.



An algorithm analyzes the sensor data and pulls out information about the steadiness of the user's gait.

With a workable prototype, the engineers tested the system with nine patients who participated in a risk assessment procedure called the Dynamic Gait Index. After analyzing the cane data, the researchers determined that they could predict each patient's DGI score with a high degree of confidence.

Sarkar and Wade are convinced this approach could have multiple benefits. For people with balance problems who use the cane regularly, it may be able to detect when users' sense of balance begins to deteriorate and report this to physicians. The basic idea also could be applied to other devices such as wheeled walkers and crutches.

With more advanced analysis, the IntelliCane might be able to provide enough detail to enable doctors to diagnose specific diseases that affect a person's sense of balance. For example, Parkinson's might alter a person's gait in ways that are detectably different from multiple sclerosis, they suggested.

The Vanderbilt Center for Technology Transfer and Commercialization has applied for a patent on the technology. Sarkar and Wade have co-founded Adaptive Technology Consulting.



new hyperlens crystal is capable of resolving details as small as a virus on the surface of living cells in its natural environment.

Construction of instruments with this capability is now possible because of a fundamental advance in the quality of an optical material used in hyperlensing, a method of creating lenses that can resolve objects much smaller than the wavelength of light.

The achievement was reported by a team of researchers led by Joshua Caldwell, associate professor of mechanical engineering, in a paper published in the journal *Nature Materials*.

The optical material involved is hexagonal boron nitride (hBN), a natural crystal with hyperlensing properties. The best previously reported resolution using hBN was an object about 36 times smaller than the infrared wavelength used: about the size of the smallest bacteria. The new paper describes improvements in the quality of the crystal that enhance its potential imaging capability by about a factor of ten.

The research demonstrates that the inherent efficiency limitations of hyperlenses can be overcome through isotopic engineering. Controlling and manipulating light at nanoscale dimensions is notoriously difficult and inefficient. This work provides a new path forward for the next generation of materials and devices.

Researchers from the University of California, San Diego, Kansas State University, Oak Ridge National Laboratory and Columbia University also contributed to the study.

HYPERLENS CRYSTAL CAPABLE OF VIEWING LIVING CELLS IN UNPRECEDENTED DETAIL

Over the years, scientists have developed many instruments capable of producing images with nanoscale resolution. However, they are incompatible with living organisms: either they operate under a high vacuum, expose samples to harmful levels of radiation, require lethal sample preparation techniques like freeze drying or remove samples from their natural, solutionbased environment.

The primary reason for developing hyperlenses is the prospect that they can provide such highly detailed images of living cells in their natural environments using low-energy light that does not harm them.

In addition, using infrared light to perform the imaging can also provide spectroscopic information about the objects it images, providing a means to 'fingerprint' the material. These capabilities could have a significant impact on biological and medical science. The technology also has potential applications in communications and nanoscale optical components.

In 1674 Anton van Leeuwenhoek used one of the first handcrafted microscopes to discover the previously unknown world of microscopic life. This latest advance in hyperlens development is a significant step toward taking van Leeuwenhoek's discovery to a whole new level, one which will allow biologists to directly observe cellular processes in action, like viruses invading cells or immune cells attacking foreign invaders.

Various components and participants of this work were funded either in whole or part by the Office of Naval Research, the Army Research Office, the Air Force Office of Scientific Research, the National Science Foundation and the U.S. Department of Energy.

NSF EQUIPMENT GRANT EXPANDS NANOSCALE RESEARCH CAPABILITIES

An advanced tool that can create electrical gates for optoelectronic devices, coatings for steerable surgical needles, and exotic materials for use in batteries and fuel cells is now at home in the Vanderbilt Institute for Nanoscale Science and Engineering.

The ALD- atomic layer deposition – reactor system can create films as thin as a single layer of atoms and has become a ubiquitous process in nanoscale materials and device fabrication.

Jason Valentine, associate professor of mechanical engineering and principal investigator on the NSF Major Instrumentation Program grant, said the technology not only advances Vanderbilt's nanoscale capabilities but also provides a much needed resource for researchers across Middle Tennessee.

The ability to produce uniform and ultrathin surfaces is critical for microelectronics and biomedical applications, including the creation of flexible sensors and coatings that are biocompatible, Valentine said. The ALD tool will also support research and advancement of optoelectronic devices and meta-metamaterials.

The ALD Reactor joins other advanced tools acquired with the support of the NSF Major Instrumentation Program: FEI Helios Dual Beam Finely Focused Ion Beam Scanning Electron Microscope with nanomanipulators; ARRA: Advanced Deposition System; Raith Electron Beam Lithography System; X-ray Photoelectron Spectrometer; and a Finely Focused Ion Beam-Pulsed Laser Deposition System.

All the tools, including the ADL Reactor, are available to researchers outside Vanderbilt.



SIGNIFICANT CONTRIBUTIONS ADVANCE RESEARCH IN NANOSCALE ENERGY, NANOSTRUCTURES



Professor Deyu Li has made significant contributions in nanoscale energy transport as well as microfluidics and nanofluidics. He is recognized internationally for his pioneering work in thermal transport through individual nanostructures and their contacts, which has important implications in microelectronics cooling and nanocomposites.

Li's work on the thermal conductivity of individual silicon nanowires, published in *Applied Physics Letters* in 2003, has been widely recognized as a classical paper in nanoscale thermal transport.

Another of Li's papers, published in *Nature Nanotechnology*, describes remarkable findings that upend the classical view of energy transport through solid interfaces, which is one of the important but extremely challenging topics in energy transport.

Li's work could have significant impact in keeping computer chips operating in a safe temperature range, and have extensive applications in aerospace, flexible electronics, and energy conversion. He has authored or co-authored more than 120 technical papers that have been cited more than 9000 times, according to Google Scholar.

He currently serves on the editorial board of Scientific Reports. He performs proposal reviews for a number of agencies, including the NSF, NIH, NASA, U.S. DOE and others.

TINY CIRCUIT BOARDS STAY OPERATIONAL ONLY IN WARM WATER



Building transient electronics is usually about doing something to make them stop working: blast them with light, soak them with acid, dunk them in water.

Professor Leon Bellan's idea is to dissolve them with neglect: Stop applying heat and they come apart.

Using silver nanowires embedded in a polymer that dissolves in water below 32 degrees Celsius — between body and room temperature — Bellan and mechanical engineering graduate student Xin Zhang made a simple circuit board that, so far, just turns on an LED light. Its potential applications are far more promising.

"Let's say you use this technology to make an RFID wireless tag," said Bellan, assistant professor of mechanical engineering. "You could implant important information in a person and body temperature would keep it intact. If the tag were removed or the bearer died, it would dissolve. You could use it for implanted medical devices as well - to cause them to disintegrate, it would only require applying ice to the skin."

In the lab, his tiny circuit boards stay operational in water warmed by a hot plate. Turn off the hot plate, and they start dissolving in minutes.

The duo's paper in the journal ACS Applied Materials and Interfaces represents an application of technology Bellan developed last year. Using a special polymer and a cotton candy machine purchased from a department store, he spun networks of threads comparable in size, density and complexity to capillaries – the tiny conduits that deliver oxygen and nutrients to cells.

Bellan's cotton candy-like fiber networks can be embedded in materials that mimic the extracellular matrix and then be triggered to dissolve away, potentially producing capillary systems for artificial organs. He's using the same triggering system to produce transient electronics.



Left, These tiny circuit boards stay operational only in warm water. **Above,** Assistant Professor Leon Bellan and graduate student Xin Zhang work in the Laboratory for Advanced Materials in Olin Hall.

In this system, the silver nanowires are held together in the polymer so that they touch, and as long as the polymer doesn't dissolve, the nanowires will form a path to conduct electricity similar to the traces on a circuit board. Trigger the polymer to dissolve by lowering the temperature, and the nanowire network disintegrates, destroying the conductive path.

"Transient electronics are cool, and once you start coupling that to a stimulus-responsive material, you start coming up with really sci-fi ideas," Bellan said. "You could have any cascade of events that results in a very unique stimulus that causes it to degrade or prevent it from falling apart. Temperature is just the beginning."

The next steps are integrating semiconductors to make transistors and ensuring users can interact wirelessly with the device.

ULTRATHIN DEVICE HARVESTS ELECTRICITY FROM HUMAN MOTION

SIT, WALK, RUN - POWER YOUR CELLPHONE

How about slipping into a jacket, shirt or skirt that powers your cell phone, fitness tracker and other personal electronic devices as you walk, wave and even when you are sitting down.

A new, ultrathin energy harvesting system has the potential to do just that. Based on battery technology and made from layers of black phosphorus that are only a few atoms thick, the new device generates small amounts of electricity when it is bent or pressed even at the extremely low frequencies characteristic of human motion.

"In the future, I expect that we will all become charging depots for our personal devices by pulling energy directly from our motions and the environment," said Assistant Professor of Mechanical Engineering Cary Pint, who directed the research.

"Compared to the other approaches designed to harvest energy from human motion, our method has two fundamental advantages. The materials are atomically thin and small enough to be impregnated into textiles without affecting the fabric's look or feel, and it can extract energy from movements that are slower than 10 Hertz—10 cycles per second—over the whole low-frequency window of movements corresponding to human motion."

The harvester is calculated to operate at over 25 percent efficiency in an ideal device configuration and harvest energy through the whole duration of even slow human motions, such as sitting or standing.

The Vanderbilt lab's ultrathin energy harvester is based on the group's research on advanced battery systems. Over the past three years, the team has explored the fundamental response of battery materials to bending and stretching. They were the first to demonstrate experimentally that the operating voltage changes when battery materials are placed under stress. Under tension, the voltage rises and under compression, it drops.

This led Pint's team to reconstruct the battery with both positive and negative electrodes made from the same material. Although this prevents the device from storing energy, it allows it to fully exploit the voltage changes caused by bending and twisting and so produce significant amounts of electrical current in response to human motions. process to step up the voltage. They are also exploring the design of electrical components, like LCD displays, that operate at lower than normal voltages.

One of the more futuristic applications of this technology might be electrified clothing. It could power clothes impregnated with liquid crystal displays that allow wearers to change colors and patterns with a swipe on their smartphone. "We are already measuring performance within the ballpark for the power



Above, Assistant Professor Cary Pint watches graduate students Mengya Li and Nitin Muralidharan adjust the energy harvesting device on the arm of undergraduate Thomas Metke.

Safety isn't a problem. Batteries usually catch on fire when the positive and negative electrodes are shorted. The harvester has two identical electrodes, so shorting it will do nothing more than inhibit the device from harvesting energy.

Because the basic building blocks of the harvester are about 1/5000th the thickness of a human hair, the engineers can make their devices as thin or as thick as needed for specific applications.

One of the challenges they face is the relatively low voltage that their device produces. It's in the millivolt range. However, they are applying their fundamental insights of the requirement for a medium-sized lowpower LCD display when scaling the performance to thickness and areas of the clothes we wear," Pint said.

Pint also believes there are potential applications for their device beyond power systems. "When incorporated into clothing, our device can translate human motion into an electrical signal with high sensitivity that could provide a historical record of our movements. Or, clothes that track our motions in three dimensions could be integrated with virtual reality technology. There are many directions that this could go."

ME CLUBS + MAKERSPACES

American Society of Mechanical Engineering Student Chapter

ASME is an international, professional organization connecting mechanical engineers globally, both in the field and in academia. The Vanderbilt chapter offers students the opportunity to network with ASME members, industry and recruiting representatives, other ASME students and faculty. Students may participate in social activities, outreach events, ASME conferences, and more.

American Institute of Aeronautics and Astronautics Student Chapter

(Below) The Vanderbilt Aerospace Design Laboratory (VADL) competes in the NASA Student Launch Competition, presents the project results at AIAA student conferences, and publishes in select AIAA journals. VADL represents the AIAA Student Chapter at Vanderbilt University. VADL teams have won the national NASA launch competition five times.



Vanderbilt Robotics

Vanderbilt Robotics has three main focuses –competition, outreach events and campus workshops – and is open to all Vanderbilt students.

Vanderbilt Engineering Council

The Engineering Council is a student organization whose main goal is facilitating communication among administrators, faculty and students. Officers are elected by the engineering student body. Representatives from the school's student chapters of professional societies complete the membership.



Makerspaces

Two makerspaces are in the Wond'ry. Room 201 features rapid prototyping, woodworking, fiber arts, mold making and casting materials and more. Room 212 features circuitry, electronic and robotic materials. Research Assistant Professor Kevin Galloway directs the makerspaces.



Galloway

Mechanical Engineering Graduate Student Association

MEGA seeks to foster professional and social interactions among graduate students in the Department of Mechanical Engineering to create a sense of community. The organization holds bi-weekly meetings to encourage dialogue and idea exchanges through student seminars and discussions to share their current research. In addition, MEGA organizes frequent social gatherings to promote a student work-life balance and has recently started offering volunteer opportunities to its members.



the Wond'ry at the Innovation Pavilion

(Left and Below) The epicenter for innovation and entrepreneurship at Vanderbilt University is located adjacent to the new state-of-the-art Engineering and Science Building. It facilitates transinstitutional collaboration between students and faculty from all schools, levels and disciplines. From engineers to scientists to entrepreneurs to artists, the Wond'ry is the primary point of connection for students interested in innovation and entrepreneurship.



Other organizations of interest

Society of Women Engineers National Society of Black Engineering Society of Hispanic Professional Engineers Design for America Engineers Without Borders

Society of Automotive Engineers Student Chapter

This SAE chapter has strong links to Vanderbilt Motor Sports, a student-run organization located in Featheringill Hall that brings together engineering students to build cars that compete in the FSAE and the Baja SAE competitions.

Graduate Student Council

The GSC exists to enhance the overall educational experience at Vanderbilt University by promoting the general welfare and concerns of the Graduate School student body. The GSC also organizes a number of events and hosts/sponsors various projects during the year, including co-sponsoring seminars and panels with individual departments, organizing the Vanderbilt 3 Minute Thesis competition (spring semester), facilitating the Graduate Student Honor Council, planning community outreach activities, and offering many social opportunities. The GSC also awards travel grants to graduate students who wish to present their research at conferences throughout the year.

Vanderbilt Design Studio

The Vanderbilt Design Studio is a student-run workshop in the School of Engineering. It provides students and faculty with tools, materials, space and advice to help with projects both inside and outside the classroom. Under the supervision of mechanical engineering professors Thomas Withrow and Kenneth Frampton, volunteer student mentors monitor the space and assist users with their creations. The studio is located in Featheringill Hall, and some of the things users can do in the studio are print 3D plastic models, solder and test electronics; cut, drill and finish wood, plastic and aluminum; borrow an Arduino or Raspberry Pi and sensors; and find nuts, bolts, wire and other parts.

ME LABORATORIES

Advanced Robotics and Mechanism Applications Prof. Nabil Simaan

ARMA is focused on advanced robotics research including mechanism design, control and telemanipulation for medical applications. The lab has produced several robotics technologies for medical applications including high dexterity snake-like robots for surgery, steerable electrode arrays for cochlear implant surgery, robotics for single port access surgery and natural orifice surgery. We actively collaborate with industry. Examples include technologies for snake robots licensed to industry, technologies for microsurgery of the retina, and the IREP single port surgery robot.

Zelik Lab Prof. Karl Zelik

Zelik Lab is a core member of Vanderbilt's Center for Rehabilitation Engineering and Assistive Technology (CREATE). We investigate fundamental mechanisms underlying legged locomotion to improve assistive technologies such as prosthetic limbs, exoskeletons and smart clothing. We aim to develop devices that better interface with the human body and better augment performance, and new tools and methods to enhance our understanding of human movement biomechanics.

Goldfarb Lab Prof. Michael Goldfarb

Goldfarb Lab is a core member of Vanderbilt's Center for Rehabilitation Engineering and Assistive Technology (CREATE). The lab focuses on the design and control of electromechanical devices, with a particular emphasis on the emerging field of rehabilitation robotics. Current projects include a powered, multi-degree-offreedom prosthetic arm, a powered exoskeleton for gait restoration in spinal-cord injured victims and stroke rehabilitation, an upper-limb orthosis for paralysis following stroke, and powered lower-limb prostheses that enhance mobility and reduce falls for lower-limb amputees.

Computational Flow Physics and Engineering Laboratory Prof. Haoxiang Luo

This lab is part of the Multiscale Modeling and Simulation group, an interdisciplinary research facility with faculty and researchers from the departments of Mechanical Engineering, Chemical and Biomolecular Engineering and Civil Engineering. Current mechanical engineering research includes glottal laryngeal aerodynamics and vocal fold modeling, heart valve modeling, and developing computational fluid dynamics/fluid-structure interaction models of animals' flying and swimming in order to design biomimetic, miniaturized vehicles.

Inks and Interfaces Prof. Kelsey Hatzell

The lab studies solution-processed techniques for advanced materials and material systems manufacturing, which includes the synthesis, transformation, and processing of materials for energy, water and biomedical applications. We are also interested in understanding electrified interfaces and how they can be engineered for electrochemical separations processes. The lab's approach is multidisciplinary, using fundamental aspects of mechanical, chemical and environmental engineering, materials science, chemistry and condensed matter physics.

Laboratory for Advanced Materials Prof. Leon Bellan

The lab focuses on developing scalable fabrication techniques for making microfluidic materials with unique properties. We use these microfluidic materials for biomedical, structural, and energy related applications, keeping in mind that the processes involved should be easily translated to large-scale manufacturing lines. A major focus of the lab is to develop non-traditional fabrication techniques that are well suited for patterning microfluidic biomaterials for tissue engineering applications. Additionally, we are developing technologies that leverage thermoresponsive

polymers for transient circuitry. Such devices function in warm aqueous environments but irreversibly disintegrate when cooled.

Laboratory for the Design and Control of Energetic Systems Prof. Eric Barth

MRI-compatible surgical robots, soft robots, artificial hearts, exoskeletons, free-piston engines, and rocket fuel powered robots are just some on-going and past projects. The lab applies a system dynamics and controls perspective to problems involving the control and transduction of energy. This model-based or model-guided design approach provides insight and enables novel and innovative devices. Devices are designed, constructed, and experimentally validated for health care and other industries.

Laser Diagnostics of Combustion Laboratory Prof. Robert Pitz

The lab develops and applies new nonintrusive laser diagnostic techniques for combusting flows. The two main techniques we currently use measure different types of quantities: velocity/vorticity measurements, and multi-species/temperature measurements. We apply UV Raman scattering to measure mixing and chemistry in supersonic combustion for hypersonic propulsion. The Raman data is used to validate and improve hypersonic propulsion computational models.

Medical Engineering and Discovery Laboratory Prof. Robert Webster III

Engineers work side by side with doctors in the MED lab to design devices that make interventional medicine more accurate, less invasive, and more effective. We primarily design and build new kinds of surgical robots. Current projects include an endoscopic robot with tentacle-like arms the size of needles that removes tumors, robots to help deaf people hear again via cochlear implants, image guidance systems that give surgeons "X-Ray vision" in robotic surgery, steerable needles that accurately target tumors deep in the lung, and neurosurgical robots designed to cure epilepsy by accurately delivering thermal energy. Webster also teaches engineering entrepreneurship and he and his students have founded companies together to commercialize their research.

Micro/Nanoscale Thermal-Fluids Lab Prof. Deyu Li

Research in MNTFL includes experimental and numerical studies of thermal conductivities and thermoelectric properties of nanostructures, development of novel devices for energy conversion and biomedical applications. We pursue fundamental understanding of thermal and fluid transport through mciro/ nano structures by experimental techniques, molecular dynamics and Monte Carlo simulation. The acquired knowledge is used to develop high efficiency thermoelectric energy converters and micro/nanofluidic labon-a-chip devices.

Nanomaterials and Energy Devices Laboratory Prof. Cary Pint

NEDL's research efforts include a multidisciplinary team whose work spans energy systems, carbon nanotechnology and manufacturing. Their research focus includes energy storage materials and systems, sustainable conversion of CO2 into carbon nanomaterials, mechanochemistry of energy materials, multifunctional energy systems, and nanomanufacturing.

Nanophotonic Materials and Devices Laboratory Prof. Joshua Caldwell

The lab is centered around a customized Fourier transform infrared (FTIR) spectrometer and attached microscope that incorporates a variety of detectors, including a superconducting bolometer and a series of MCT detectors, providing spectral coverage from 1,000 to 1.25 μm. The system can perform static or time-domain experiments and work in emission mode, quantifying (blackbody) thermal emission, luminescence or fluorescence in the infrared from micron scale to macroscopic regions of interest. Modulated spectroscopies for research

on semiconductor superlattices or atomic-scale two-dimensional materials, and a custom-designed tool capable of ATR, Kretschmann and Otto configuration experiments over the mid- to far-infrared are available. A full electromagnetic modeling suite is also available.

Nanoscale Optics and Materials Laboratory Prof. Jason Valentine

The lab investigates how nanoscale structuring can be used to engineer the optical properties of metamaterials for applications including communications, on-chip photonics, imaging and solar energy conversion. Research involves both theoretical modeling as well as experimental demonstration and characterization. Researchers seek to develop new types of metamaterials with reduced optical loss in the infrared and visible frequency range as well as incorporating active constituents into metamaterials such as semiconductors to enable switching, light detection, or direct energy conversion.

Robotics and Autonomous Systems Lab Prof. Nilanjan Sarkar

RASL develops new generations of robots and computer-based intelligent systems that interact with people in a natural way by applying principles of design, dynamics, controls, machine learning and AI. Examples include adaptive robotic systems that can help individuals regain their balance and strength, socially assistive robots to teach social and adaptive skills and virtual reality systems that can sense human emotions from various implicit signals and cues. This is an interdisciplinary laboratory involving students and faculty from mechanical engineering, electrical engineering, computer science, psychology and medicine. Applications of our research range from helping individuals with neurodevelopmental disabilities such as autism, schizophrenia and dementia to learn new skills, to aiding stroke patients regain some movement abilities through robot-assisted rehabilitation, and to providing more autonomy in robots for a variety of tasks.

Thermal Engineering Laboratory Prof. Greg Walker

Researchers explore the physical effects of energy transport particularly in nanoscale structures to obtain a better understanding of the physical world that can lead to engineering discoveries in energy applications. One focus is in microscale energy transport in semiconductor devices designed for energy conversion. This includes thermoelectric devices, solar cells and fuel cells. A second focus area is in heat flux measurement using thermographic phosphors and ultrasonic approaches. Our techniques have been applied to gun barrels, aerospace testing in wind tunnels and combustion chambers.

Vanderbilt Aerospace Design Laboratory Prof. Amrutur Anilkumar

The main agenda of the lab is to design novel, rocket-flyable payload systems that highlight major challenges in space exploration and energy conversion as applicable to the aerospace sector. The current function of the VADL is to compete in the NASA Student Launch Competition, and to present the project results at AIAA Student Conferences, and publish in select AIAA journals. VADL also represents the AIAA Student Chapter at Vanderbilt University. VADL also is involved in designing and setting up of pilot field projects in renewable energy production through solar and wind facilities.

Welding Automation Laboratory Prof. Alvin Strauss

The lab develops control systems for advanced robotic welding and joining processes. We focus on process optimization and control for friction stir welding (FSW), a solid-state welding technique that is prevalent in aerospace, rail, automotive, and naval applications. FSW allows us to develop robust control systems capable of detecting undesirable flaws within the weld, monitor tool wear and react to dynamic changes in the process, among other things. Other notable research includes characterizing tool wear, dissimilar metal welding, computational fluid dynamic modeling of FSW and the development of technology for actively monitoring the FSW process for control and quality applications.

CENTERS + INSTITUTES

The richness of our engineering research community is enhanced by the presence of Vanderbilt University's interdisciplinary centers, institutes, laboratories and programs where members within the university and our peers collaborate on research, teaching and outreach. These collaborative partnerships allow faculty members and their students to share facilities, equipment, ideas and inspiration.

The **Department of Mechanical Engineering** is home to the Center for Rehabilitation Engineering and Assistive Technology and the Tennessee Space Grant Consortium.

Center for Rehabilitation Engineering and Assistive Technology

Michael Goldfarb, Karl Zelik engineering.vanderbilt.edu/create

CREATE consists of two mechanical engineering research laboratories that focus on restoring health, mobility and independence to individuals with disabilities, with a particular emphasis on the emerging field of rehabilitation robotics. Current projects include a powered, multi-degree-offreedom prosthetic arm, a powered exoskeleton for gait restoration in spinal-cord injured victims and stroke rehabilitation, an upper-limb orthosis for paralysis following stroke, and powered lower-limb prostheses.

Tennessee Space Grant Consortium

Alvin M. Strauss research.vuse.vanderbilt.edu/tsqc/

The Consortium's mission is to promote space and science research and education from K-12 to the graduate level. Since 1990, the Consortium has supported Space Grant Fellows within the department, in other areas of the Vanderbilt University, and at its member and affiliate institutions throughout the state. The Tennessee Space Grant Consortium is funded by a NASA grant. Mechanical engineering faculty and students work with collaborators in these Vanderbilt and School of Engineering research communities:

Interdisciplinary Program in Materials Science

Leon Bellan, Joshua Caldwell, Kelsey Hatzell, Deyu Li, Cary Pint, Jason Valentine, Greg Walker engineering.vanderbilt.edu/materialsscience

The IMS program includes faculty from engineering, chemistry, physics and medicine, and offers an individually customized curriculum to students who seek an advanced materials science degree. Research focuses include electronic materials, magnetic materials, superconducting materials, nanostructured materials, molecular engineering and science, thin films, surface modification, radiation effects in solid state devices, organic-based devices, materials synthesis, solidification, materials characterization, materials physics, and a long history of collaboration between the IMS program and the Oak Ridge National Laboratory.

Vanderbilt Institute for Surgery and Engineering

Eric Barth, Haoxiang Luo, Jason Mitchell, Nabil Simaan, Robert J. Webster III, Thomas J. Withrow vanderbilt.edu/vise

VISE is an interdisciplinary, transinstitutional center whose mission is the creation, development, implementation, clinical evaluation and commercialization of methods, devices, algorithms, and systems designed to facilitate interventional processes and their outcome. Research projects led by mechanical engineering faculty include novel endoscopic robot systems, single port robots, steerable needles, robots that facilitate cochlear implantation, and more.

Vanderbilt Institute for Integrative Biosystems Research and Education Deyu Li

vanderbilt.edu/viibre

VIIBRE's mission is to invent the tools and develop the skills that are required to conduct research in systems biology. VIIBRE's on- and off-campus collaborations are in research areas such as cellular biosensors, bioprocess controllers, mathematical models for wound healing and cancer, infectious disease detection, biomedical imaging, and cellular/tissue engineering.

Vanderbilt Institute of Nanoscale Science and Engineering

Leon Bellan, Joshua Caldwell, Kelsey Hatzell, Deyu Li, Cary Pint, Jason Valentine, Greg Walker vanderbilt.edu/vinse/

ViNSE offers a suite of laboratories for nanofabrication and nanocharacterization and serves faculty members from the School of Engineering, the School of Medicine, and the College of Arts and Science. Primary research areas include nanobio/ nanomedicine, nano-energy, nanoscale optics, computational nanoscience, and new nanoscale materials.

Vanderbilt Kennedy Center

Nilanjan Sarkar vkc.mc.vanderbilt.edu/vkc

An interdisciplinary research, training, diagnosis, and treatment institute, faculty from the Vanderbilt University Medical Center, College of Arts and Science, Peabody College of Education and Human Development, School of Engineering, Divinity School, and Blair School of Music work together in unique ways to solve the mysteries of development and learning.

FACULTY

Amrutur V. Anilkumar

Professor of the Practice of Mechanical Engineering Vanderbilt Aerospace Design Laboratory

Joel Barnett

Associate Professor of the Practice of Mechanical Engineering Welding Automation Laboratory

Eric J. Barth

Associate Professor of Mechanical Engineering Laboratory for the Design and

Control of Energetic Systems

Leon Bellan

Assistant Professor of Mechanical Engineering Laboratory for Advanced Materials

Joshua Caldwell

Associate Professor of Mechanical Engineering Nanophotonic Materials and **Devices Laboratory**

Kenneth Frampton

Associate Professor of the Practice of Mechanical Engineering Director of Undergraduate Studies Vanderbilt Design Studio

Michael Goldfarb

H. Fort Flowers Professor of Mechanical Engineering Goldfarb Lab/Center for **Rehabilitation Engineering and Assistive Technology**

Kelsey Hatzell

Assistant Professor of Mechanical Fnaineerina Inks and Interfaces

Deyu Li

Professor of Mechanical Engineering Director of Graduate Studies Micro/Nanoscale Thermal-Fluids Lab

Haoxiang Luo

Associate Chair and Associate Professor of Mechanical Engineering **Computational Flow Physics and Engineering Laboratory**

Cary Pint

Assistant Professor of Mechanical Engineering Nanomaterials and Energy

Devices Laboratory

Robert W. Pitz

Professor of Mechanical Engineering Laser Diagnostic of Combustion Laboratory

Nilanjan Sarkar

Professor and Chair of Mechanical Engineering **Robotics and Autonomous** Systems Lab

Nabil Simaan

Professor of Mechanical Engineering Advanced Robotics and **Mechanism Applications**

Alvin M. Strauss

Professor of Mechanical Engineering Tennessee Space Grant Consortium Welding Automation Laboratory

Jason Valentine Associate Professor of Mechanical

Engineering Nanoscale Optics and Materials Laboratory

D. Greg Walker

Associate Professor of Mechanical Engineering Director of the Interdisciplinary Graduate Program in Materials Science **Thermal Engineering Laboratory**

Robert J. Webster III

Professor of Mechanical Engineering Medical Engineering and **Discovery Laboratory**

Thomas J. Withrow

Assistant Dean for Design Associate Professor of the Practice of Mechanical Engineering Vanderbilt Design Studio

Karl Zelik

Assistant Professor of Mechanical Engineering Zelik Lab/Center for **Rehabilitation Engineering and Assistive Technology**

AFFILIATED FACULTY

Douglas E. Adams Daniel F. Flowers Professor Distinguished Professor and Chair of Civil and Environmental Engineering Professor of Mechanical Engineering

S. Duke Herrell III

Professor of Urologic Surgery Professor of Mechanical Engineering

Fabien Maldonado

Associate Professor of Medicine Associate Professor of Mechanical Engineering

Justus Ndukaife

Assistant Professor of Electrical Engineering Assistant Professor of Mechanical Engineering



Anilkumar

Caldwell



Barnett





Bellan



Mitchell





Frampton



Galloway















Walker





Webster III

RESEARCH FACULTY

Neal Dillon, Research Assistant Professor Shannon Faley, Research Assistant Professor Kevin Galloway, Research Assistant Professor Richard Hendrick, Research Assistant Professor Zheng Li, Research Assistant Professor Jason Mitchell, Research Assistant Professor Scott Webster, Research Assistant Professor

ADJUNCT/ADJOINT FACULTY

William Emfinger, Adjunct Assistant Professor Carl Hall, Adjoint Assistant Professor Pietro Valdastri, Adjoint Professor Peiyong Wang, Adjoint Professor Joseph Wehrmeyer, Adjoint Associate Professor

VANDERBILT | SCHOOL OF ENGINEERING 19





Strauss

Withrow

Engineering

Nutrition

Engineering

Engineering

Çağlar Oskay

Professor of Civil and

Environmental Engineering

Professor of Mechanical

Keith Obstein

Sankaran Mahadevan

Professor of Mechanical

John R. Murray Professor of Civil

Associate Professor of Medicine,

Gastroenterology, Hepatology, and

Associate Professor of Mechanical

and Environmental Engineering









Valentine

Zelik

NOTABLE

CREATE labs recognized for impact of National Biomechanics Day event

For the second year, the School of Engineering's biomechanics and assistive rehabilitation labs have received top honors for an event that introduces young students to a dynamic field that includes exoskeletons, sports and prosthetics.

Vanderbilt is core university partner in DOD Manufacturing Institute

Vanderbilt is one of 40 academic partners in a new robotics manufacturing institute funded with \$80 million from the Department of Defense and \$173 million in matching funds from more than 200 participating partners, including companies, local governments, academic and nonprofit organizations. Vanderbilt is a core university partner led by Eric Barth, associate professor of mechanical engineering.

Discovery Grants invest in cutting-edge research

Recent Discovery Grants awarded to mechanical engineering faculty include Assistant Professor Leon Bellan's transient electronics that dissolve when cooled and Professor Robert Webster's needle robots for lung cancer interventions. The Vanderbilt Discovery Grant program serves as a catalyst for significant external funding sources.

Zelik recognized with two young career awards

Karl Zelik, assistant professor of mechanical engineering, has received an International Society of Biomechanics Promising Scientist Award and American Society of Biomechanics Young Scientist Award.

ME Fellows list grows

Greg Walker, Deyu Li and Çağlar Oskay are American Society of Mechanical Engineers Fellows. Robert W. Pitz and Sankaran Mahadevan are American Institute of Aeronautics and Astronautics Fellows. Jason Valentine is a Chancellor Faculty Fellow and recipient of a Chancellor's Research Award.



A.V. Anilkumar wins Chancellor's Cup

Amrutur V. Anilkumar received the 2018 Chancellor's Cup. The cup is presented annually to the professor who makes the greatest intellectual and academic contributions to undergraduate students outside of classroom teaching. Anilkumar is director of the Vanderbilt Aerospace Design Laboratory. VADL teams have won five NASA rocketry national championships.

Two ME undergrads from same lab named Goldwater Scholars

Lauren Branscombe and Joshua Fleck have much in common. Both are juniors in mechanical engineering, focused on medical robotics. Both work in the Zelik Lab and both plan to pursue a Ph.D. in mechanical engineering, continue research and improve the lives of people with limited mobility. The Goldwater Scholarship is the premier undergraduate award of its type for students in science, math, and engineering fields. The selection process is rigorous internally as well as nationally.

Remember the solar eclipse?

Mechanical engineering graduate student Adam Jarrell served as team leader of the university's 2017 NASA Space Grant Ballooning Project. The weather balloon launch from the top of a Vanderbilt parking garage was a success—live streaming striking video from around 70,000 feet to a NASA website.

ADMISSIONS

UNDERGRADUATE

The Vanderbilt Office of Undergraduate Admissions manages admission to this program. Admissions staff can answer questions, arrange campus tours, provide additional information about degree programs and more.

Office of Undergraduate Admissions

Vanderbilt University 2305 West End Avenue Nashville, TN 37203-1727 Phone: (615) 322-2561 or (800) 288-0432 Website: admissions.vanderbilt.edu

Prof. Kenneth Frampton

Director of Undergraduate Studies Department of Mechanical Engineering Office: 330 Olin Hall Email: ken.frampton@Vanderbilt.Edu Phone: (615) 343-0610

GRADUATE

To apply for admission to the graduate program in mechanical engineering, you must first meet the general requirements of admission by the Vanderbilt University Graduate School. Application for admission may be made electronically here: www. vanderbilt.edu/gradschool/. The Graduate School Catalog may be viewed at www. vanderbilt.edu/catalogs/

Vanderbilt University Graduate School 117 Alumni Hall 2205 West End Avenue Nashville, TN 37240 USA ATTENTION: Mechanical Engineering Phone: (615) 343-2727

Prof. Deyu Li

Director of Graduate Studies Department of Mechanical Engineering Office: 333 Olin Hall Email: deyu.li@vanderbilt.edu Phone: (615) 343-4102

IMPORTANT DATES

January 1: Fall application deadline March 31: Fall admission offers April 15: Deadline to accept admission Oct. 15: Spring application deadline Dec. 1: Spring admission offers

FINANCIAL AID

UNDERGRADUATE

Vanderbilt is committed to enrolling talented, motivated students from diverse backgrounds. About 65 percent of Vanderbilt students receive some type of aid. Our admissions process is need-blind for U.S. citizens and eligible non-citizens, which means the ability to pay for a Vanderbilt education is not a factor in the admissions process. All need-based aid packages now include scholarships, grants (gift assistance), and employment opportunities in place of need-based loans. This initiative does not involve income bands of income cutoffs that limit eligibility. More information can be found at *vanderbilt.edu/financialaid*.

GRADUATE

Students wishing to be considered for financial awards administered by the Graduate School should check the appropriate box under "Financial Information" on the online application and make certain that a complete application is received by January 1. Prospective applicants are urged to apply for fellowships or grants from national, international, industrial, or foundation sources. More information can be found at *vanderbilt.edu/gradschool*.

Graduate students in the Department of Mechanical Engineering seeking the Ph.D. degree receive a competitive stipend, tuition waiver, health insurance and reimbursement for some incidental fees. This financial aid can be in the form of a Teaching Assistantship or a Research Assistantship. Assistantships may be supplemented by a departmental, service-free scholarship or fellowship.

- **Graduate Teaching Assistantships:** Financial aid for the academic year to students who assist in supervised teaching of undergraduates
- **Graduate Research Assistantships:** Financial aid for the calendar year to students carrying out thesis or dissertation research with support from a research grant

Teaching or Research Assistantships may be supplemented by a scholarship or fellowship through a competitive process supported by exceptional applicant qualifications. In order to be considered for these service-free awards, an applicant's file must be complete by January 1. The honor fellowships listed below are in addition to a Teaching or Research Assistantship.

- Harold Stirling Vanderbilt Graduate scholarships: \$6,000/year for up to five years
- University Graduate Fellowships: \$10,000/year for up to five years
- **Provost's Graduate Fellowships:** \$10,000/year for up to five years
- School of Engineering Fellowships: \$4,000/year for up to four years plus an award of \$1,000 for professional development



Vanderbilt University Department of Mechanical Engineering 2301 Vanderbilt Place PMB 401592 Nashville, TN 37240-1592

Campus Location Department of Mechanical Engineering 101 Olin Hall 2400 Highland Avenue Nashville, TN 37212 Phone: (615) 322-2413 Fax: (615) 343-6687 engineering.vanderbilt.edu/me/

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