



FALL 2009

# ME TRICS

MECHANICAL ENGINEERING  
A. JAMES CLARK SCHOOL of ENGINEERING

A NEWSLETTER FOR ALUMNI AND FRIENDS OF THE DEPARTMENT OF MECHANICAL ENGINEERING AT THE A. JAMES CLARK SCHOOL OF ENGINEERING, UNIVERSITY OF MARYLAND.

## ME RESEARCH Impacting Industry

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AND MINDS

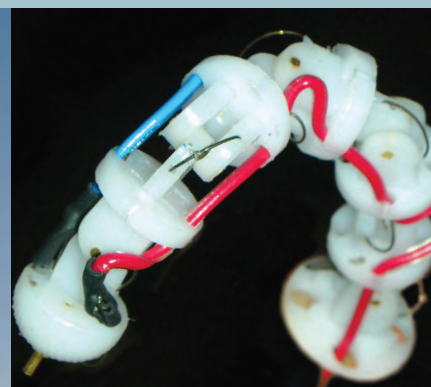
BIRDS & BUGS

CREATING A BETTER  
PETROLEUM PROCESS

ENERGY-EFFICIENT  
ENTERPRISE

GREAT MINDS

LIFE-SAVING RESULTS



## and Touching Lives

Dear Friends,

In this issue of METRICS, we focus on the research taking place within our department and how it impacts industry, and I am proud to say that there is much news to share.

Professors Jeffrey Herrmann and Jaydev Desai are making great contributions to the health care industry with their respective research. Professor Herrmann is responsible for developing an emergency preparedness planning model used by state and county health departments nationwide. And recently, Professor Desai received NIH funding for his research on a more effective use of robotics in the detection and treatment of breast cancer and brain tumors.

In our feature on bioinspired engineering, we look to nature and what it has to offer engineers. Professors Satyandra Gupta and Sarah Bergbreiter are both involved with projects that were inspired by nature. Professor Gupta has looked to the skies and the abilities of birds in his development of drive mechanisms for groundbreaking micro air vehicles while Professor Bergbreiter's project on autonomous jumping microrobots was inspired by an article in *Nature* magazine about the frog hopper insect.

In other articles, we show how our research can inform industry. More specifically, Dr. Diganta Das, a member of CALCE (Center for Advanced Life Cycle Engineering), speaks frequently at conferences and symposiums attended by members of private industry, the government and the military on how to detect and prevent the use of counterfeit electronics and he is eager to share his research with us.

We also focus on the EERC (Energy Education and Research Collaboration), CALCE and CEEE (Center for Environmental Energy Engineering). All of these organizations conduct research for industry and do so successfully and with high regard.

Finally, we focus on faculty involvement with academic journals and their importance to the engineering profession; the recent success of our Product Innovation and Realization Laboratory Suite; the latest inductee into the Clark School's Innovation Hall of Fame; and a few other important updates.

I hope you enjoy reading about our research efforts and how we're impacting industry - and impacting lives everywhere.



Dr. Avram Bar-Cohen  
Chair and Distinguished University Professor  
Mechanical Engineering



BAR-COHEN

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Production Coordinator:  
Felicia Stephenson  
Writer/Editor: Lisa Gregory  
Contributors: Rebecca Copeland (ISR); Caron Wildy (CALCE)  
Designer: Jennifer Paul  
Portraits: John Consoli

Please send comments to:  
[me\\_communications@umd.edu](mailto:me_communications@umd.edu)

# Keeping It Real

## RESEARCHER EDUCATES INDUSTRY ON PERILS OF COUNTERFEIT ELECTRONICS

During the last several years, the number of incidents of counterfeit electronic parts has grown steadily. Today, these items are being reported in the computer, telecommunications, automobile, avionics and military systems industries, with no areas immune from attack. “It’s an equal opportunity area,” says Dr. Diganta Das, a member of the Center for Advanced Life Cycle Engineering (CALCE) research team. It’s also an expensive problem. “Some market analysts estimate that the legitimate electronics companies miss out on about \$100 billion of global revenue every year because of counterfeiting,” says Das. As a researcher, Das not only wants to better understand the process of counterfeiting and its impact on industry, he is also using what he has learned to educate others.

Some examples of counterfeit electronic products include items that have been relabeled, illegally manufactured or obtained from scrap salvaging. Das tells the story of a military parts supplier that went out of business a decade ago. “Today you can buy parts that have the name of the company on them and a date code of 2008. How can that be if the company has been out of operation since the 1990s? It would be almost comical if it wasn’t so serious.”

According to Das, the military and avionics industries are especially vulnerable targets for counterfeit electronics due to the complex approval process required in creating new systems. Instead of redesigning the technology, these industries attempt to use the same systems as long as possible. “When these parts go obsolete after many years, companies go begging around the world and online.” Finding a broker for electronic parts is as easy as “three keystrokes on a computer,” adds Das.

“Does it mean counterfeit parts never work? No,” says Das. But when a part doesn’t work, the economic repercussions reach far beyond the cost of merely replacing the item. “An electronic component that may be worth only \$2 can cost as much as \$20 to replace if it’s detected to be counterfeit after it is mounted onto a circuit board,” he says. “Then there are the issues of when systems and parts fail, resulting in the loss of a mission, safety problems, and significant maintenance and logistics costs. The user of a counterfeit part may also have to bear the cost of liability completely.”

To prevent the purchase of counterfeit electronic parts, Das recommends avoiding unauthorized high-risk sources such as brokers. “These individuals have no direct relation or any commitment to the manufacturer or the buyer of the parts,” says Das. All

electronic part distributors from whom parts are purchased need to be evaluated with equal technical depth following industry standard methods of distributor assessment, such as the ones developed by CALCE, according to Das.

“Smaller sources such as brokers should not be given a lower level of scrutiny,” he says. In addition, a mechanism for inspection of parts and materials from high-risk sources needs to be developed and implemented to detect and isolate nonconforming parts.

“One also needs to delve into the pedigree of the part to find out the path the part took from the original manufacturer to the



DAS

**“THIS IS A SERIOUS PROBLEM AND IT IS IMPORTANT TO ENCOURAGE AN AWARENESS OF IT, AS WELL AS PROVIDE THE TOOLS TO ADDRESS AND AVOID IT.”** — DR. DIGANTA DAS

product,” says Das. “It is possible that some of those parts made a detour through dumpsters and recycling centers. It is so important to be aware of what you are actually purchasing and to do so from a reputable source.”

“This is a serious problem, and it is important to encourage an awareness of it as well as provide the tools to address and avoid it,” says Das, who speaks frequently at conferences and symposia attended by members of private industry, government and the military. He has also organized two highly successful symposia on the subject of counterfeit electronics on campus in the last two years. And, due to high demand, he offered one symposium in Denmark in June 2009. Das has also been asked to join the anti-counterfeiting task forces of several industry groups such as the Semiconductor Industry Association and Aerospace Industry Association, among others. For more information on Dr. Das’ research and his December 2-3, 2009 symposium in College Park, please visit: [www.calce.umd.edu](http://www.calce.umd.edu).

# Healing Hands...and Minds

ME RESEARCHERS WORK TO DEVELOP NEW TOOLS FOR HEALTH CARE INDUSTRY

For ME researchers, **Jeffrey Herrmann** and **Jaydev Desai**, their work is about more than just research. Both are involved with projects that directly impact the lives of countless individuals.

Herrmann is one of 24 recipients, statewide, of the *Maryland Daily Record's* Innovator of the Year award. Herrmann was selected for the award based on his development of a Clinic Planning Model Generator, or CPMG, an emergency preparedness planning model used by state and county public health departments nationwide. The Innovator of the Year award recognizes Maryland residents and companies who have introduced innovations that positively effect their business, industry or community.

"I began this project with the hope of helping the folks in public health prepare for an emergency that you hope never happens," says Herrmann, an associate professor who holds a joint appointment with the Institute for Systems Research (ISR) and conducts research in the areas of operations research and engineering decision-making. Herrmann adds, "However, if something bad does happen, perhaps this process can minimize the impact and keep people safe. That gives me a sense of satisfaction."

"The idea of having an impact on human life is very gratifying and the reason why I do this work," says Desai, an associate professor and director of the Robotics, Automation, Manipulation and Sensing (RAMS) Laboratory, whose research focuses on medical robotics, haptic interfaces for robot-assisted surgery, surgical simulation, model-based teleoperation and cell manipulation.

Desai recently received two grants from the National Institutes of Health (NIH) to conduct research on a more effective use of robotics in the detection and treatment of breast cancer and brain tumors.

## Professor Herrmann's Research

The CPMG developed by Herrmann is a spreadsheet application that generates customized analytical models of mass dispensing and vaccination clinics also known as Points of Dispensing, or PODs. The CPMG software creates accurate models for planning mass dispensing or vaccination campaigns using PODs.

Herrmann's work is part of an exciting and innovative process that uses operations research and applied mathematics to improve planning for bioterrorism attacks, pandemic flu or other events. "Poorly conceived plans can cause confusion, delay responses to events, and reduce the effectiveness of responses, all of which increase the number of victims," says Herrmann.



FLU CLINIC IN MONTGOMERY COUNTY, MARYLAND

Emergency preparedness planners can use the models to answer the following questions: (1) Given a resident flow rate (calculated from population size and duration of campaign), how many people are needed to staff each station? (2) How much does each workstation need to accommodate residents waiting in line? (3) How long will residents spend inside the POD? (4) How will the PODs operations be affected if stations are eliminated or combined?

"The software automatically generates a spreadsheet from a minimal set of user inputs," says Herrmann. "And, the software provides useful data that includes processing-time distributions for different types of workstations, but allows the user to make modifications as necessary."



HERRMANN

Planners can easily adjust staffing levels and various inputs until they are satisfied with the efficiency of the clinics. Users can also accept default values if they have little information about their clinics or input more detailed information, such as routing probabilities and process times.

"In addition to its use for emergency preparedness planning, the software can be used to plan annual flu shot clinics and other similar medical applications," says Herrmann. "The spreadsheet software approach has many benefits as planners do not have to create spreadsheets from scratch or understand the mathematics of queuing networks; yet, they generate a spreadsheet capacity planning and queuing network model that reflects the design they want to use."

The POD planning models are portable and self-contained, requiring only Microsoft Excel. “Because most public health emergency preparedness planners already use Excel, they do not have to buy new software,” says Herrmann. “Moreover, the spreadsheet concept is so familiar that users can learn the software quickly.”

Herrmann and his research team first became involved with this project several years ago when Herrmann was approached by public health officials in Montgomery County, Maryland, requesting mathematical models to help county health departments create plans for dispensing medications and vaccines during emergencies. “I immediately saw that this was an important problem, and I wanted to help solve it,” he says. “My team and I have worked very hard on this.”

Today, the federal government recommends the use of CPMG and public health departments across the country are doing just that. “For me, that’s why I’m here and doing this type of research,” says Herrmann.

The CPMG software is available free of charge on Herrmann’s website for public health emergency preparedness planners to download. Additionally, there is no charge to receive assistance on its use.

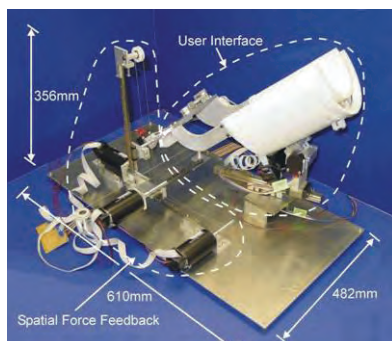
### Professor Desai’s Research

Professor Desai’s research in the use of medical robotics to diagnose and treat breast cancer and brain tumors addresses areas with urgent needs. According to Desai, this became evident after both of his grant applications received extremely positive reviews from the NIH. “For example, the American Cancer Society states that 182,000 women would be diagnosed with breast cancer in 2008,” he says. “And individuals diagnosed with a tumor deep within the brain have a median survival of four to eight months due to primary or intrinsic malignancy or a secondary or metastatic malignancy.”

The NIH funded Desai’s work on a teleoperated robotic haptic feedback system for biopsy (Bx) and radiofrequency ablation (RFA) of breast tumors under continuous MRI with a \$1.3 million grant. Desai is the principal investigator on this project, which is conducted in collaboration with Dr. Rao Gullapalli and other co-investigators at the University of Maryland School of Medicine.

“The goal of the proposed haptics or sense of touch enabled tele-

robotic system is to operate under continuous MRI, for both breast biopsy and radiofrequency ablation of a breast tumor, in a manner that minimizes sampling errors during biopsy and



JAYDEV DESAI'S DESIGN OF THE 7-DOF HAPTIC FEEDBACK DEVICE



delivers optimal therapy during radiofrequency ablation,” says Desai.

According to Desai, the system will enable a patient to have the biopsy and treatment in the same sitting. Currently, there is no such teleoperated robotic system with haptic feedback capability available for breast biopsy and radiofrequency ablation of breast tumor under continuous MRI. As a result, “the patient has to

be moved inside the MRI bore for imaging and brought outside so that the physician can insert the biopsy needle to the target location. The patient is then re-entered into the MRI bore to see if the needle has been accurately placed. This is a blind-targeting approach,” says Desai. The robotic system, however, will allow the physician to guide the needle to the target location while continuously imaging under MRI. “This will enable accurate guidance of the biopsy needle and/or radiofrequency ablation probe and hence improve the outcome of the procedure,” Desai adds.

Desai’s second grant from NIH, in the amount of \$397,541, will be applied to the development of a MRI-compatible, minimally invasive neurosurgical intracranial robot, or MINIR. Again, Desai is the principal investigator, working with fellow ME faculty member Satyandra Gupta and Drs. Rao Gullapalli and Marc Simard from the University of Maryland School of Medicine.

“As envisioned, MINIR will be under the direct control of a human operator, with targeting information obtained exclusively from frequently updated MRI,” explains Desai.

Unlike available technology, MINIR will require only a very narrow corridor to approach and resect the tumor and will be capable of operating outside the line-of-site entry trajectory. At its operating end, MINIR will be multidigitated and highly maneuverable, with all movements under the dynamic control of a human operator.

“Like any human neurosurgeon currently, MINIR will resect the tumor by positioning the end-probe comprised of, say, bipolar electrocautery to liquify tissue,” says Desai. “Dedicated irrigation and aspiration channels in the MINIR body will ensure washing out the debris and its removal.”

Desai is just beginning research on these two projects, but he is hopeful. “This is an amazing time in which we live,” he says. “Technology has taken such a leap in the last 50 to 70 years. We can do so much more now to help people.”

For more information on Dr. Herrmann or Dr. Desai’s research, please visit: [www.enme.umd.edu](http://www.enme.umd.edu).

# Birds and Bugs

## ME RESEARCHERS LOOK TO NATURE FOR INSPIRATION

ME researchers **Satyandra K. Gupta** and **Sarah Bergbreiter** view the natural world around them in different ways. As researchers who use bioinspired engineering in their research, they have a unique appreciation for how nature works and what it can offer.

“About 10 years ago, when I began this work, we were discovering that the traditional robots were having difficulty in doing certain simple tasks,” says Gupta, a professor who also holds a joint appointment with the Institute for Systems Research and whose research focuses on computer-aided design, manufacturing automation and robotics. “Then, you think about humans and other animals that can do these tasks fairly easily. I was intrigued by the whole idea of how things get done in nature and what can be learned from it and used for engineering.”

For his own recent research, Gupta has looked to the skies and the abilities of birds in his development of drive mechanisms for groundbreaking micro air vehicles.

Bergbreiter’s project on autonomous jumping microrobots, was inspired by an article in *Nature* magazine on “the frog hopper insect, which the article described as the new jumping champion of the insect world,” recalls Bergbreiter, an assistant professor who holds a joint appointment with ISR and whose research focuses on microrobots, networked multirobot systems and sensor networks.

“This insect could jump the highest for its size, and I began to think maybe this isn’t too far off from what I could actually engineer,” she says. “That article and that insect pushed me in the right direction.”

### Professor Gupta’s Research

Gupta, working with a team of students, has developed several versions of an ornithopter, a birdlike micro air vehicle, or MAV, that both flaps and folds its wings. “Ornithopters offer greater possibilities both for miniaturization and maneuverability in the field than their fixed-wing or rotary-wing MAV cousins,” says Gupta.

The research is funded in part by an Army Research Office Multidisciplinary University Research Initiative grant and the National Science Foundation. The MAVs are expected to play a big



GUPTA

THE OMITHOPTER IS A BIRDLIKE MICRO AIR VEHICLE DEVELOPED BY PROFESSOR SATYANDRA GUPTA



role in future surveillance and reconnaissance missions. “These remote-controlled MAVs are expected to be stealthy and highly maneuverable for operations in constrained spaces,” says Gupta. The U.S. military hopes that someday these MAVs will be able to carry surveillance cameras and other payloads that will aid operations, according to Gupta.

Until Gupta’s research made it possible, ornithopters were generating lift primarily by flapping their wings. Gupta’s work on lightweight drive mechanisms has enabled his team to start testing designs with folding wings.

“When flying, larger birds like hawks or seagulls fold their wing on the upstroke,” he explains. “This slows their forward velocity and enables them to carry large payloads. Since it would be highly desirable for surveillance MAV to fly slowly and carry a significant sensor payload, developing a folding-wing technology that actually flies is a large step forward in making these aircraft possible.”

The drive mechanism is a critical part of the MAV design because it transfers power from the motor to the flapping wings. Gupta’s team has developed multipiece molding technology that enables development of geometrically complex structures. Using this technology they have developed a new lightweight drive mechanism. This drive mechanism minimizes moving parts by exploiting biologically-inspired compliant structures. The elimination of moving parts eliminates power loss during the transmission.

“Folding wings are heavier than nonfolding wings. So advances in lightweight, highly efficient drive mechanisms have been crucial in achieving folding wing flight,” says Gupta.

Gupta’s team first developed four flapping-wing MAVs that did not have folding wings and demonstrated their capacity to fly. Each of these ornithopters was successively larger, so that increasingly heavy payloads could be carried. “The length of flight is determined by the capacity of the batteries onboard the aircraft,” says Gupta. “The largest of these ornithopters, which weighs 1.5 ounces, can carry a video camera with a transmitter as well as its batteries, and stay aloft for 14 minutes in calm air. The video cam-

## “I WAS INTRIGUED BY THE WHOLE IDEA OF HOW THINGS GET DONE IN NATURE AND WHAT CAN BE LEARNED FROM IT AND USED FOR ENGINEERING.”

— PROFESSOR SATYANDRA GUPTA

era’s images can be stabilized via software.”

The folding-wing version of these MAVs began flying in September 2008 and the aircraft could slow its flight velocity by 10 percent without any appreciable decrease in its payload capacity. The folding-wing MAV weighs 1.3 ounces with its batteries, and has a wing span of 22.5 inches. It is capable of carrying a payload (usually a surveillance camera) that weighs .35 ounces.



Importantly, Gupta’s MAVs do not use a propeller system to “help” the wings. Such motors are too loud for reconnaissance purposes, forfeiting the element of stealth. “These MAVs are truly bird-inspired,” Gupta says.

### Professor Bergbreiter’s Research

Bergbreiter, who received a 2008 Young Faculty Award from the Defense Advanced Research Projects Agency (DARPA) for her work on the autonomous jumping microrobot, says that jumping offers numerous benefits to millimeter-sized robots. “As the robot size shrinks, obstacles around the robot grow comparatively larger and jumping provides a relatively simple mechanical means of dealing with those obstacles,” she says.

“Ultralow power parasitic locomotion, in which the microrobot uses other objects moving nearby to provide the locomotion power, becomes feasible when the microrobot can jump on and jump off.”



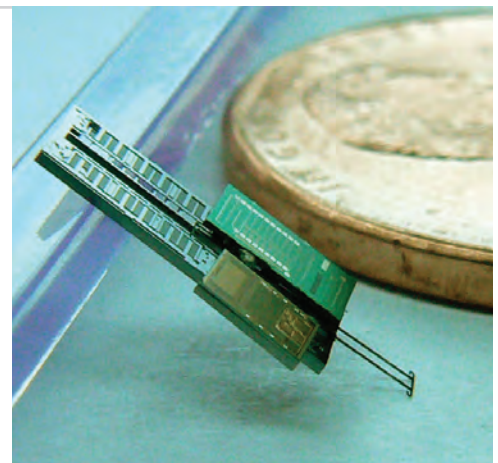
According to Bergbreiter, for basic functionality, a jumping microrobot benefits from its relative simplicity. “It requires only a motor, an energy storage element to store and quickly release mechanical energy for a jump, a controller and a power supply,” she says.

However, while the robot itself is fairly simple, the components have performance requirements above those offered by current technologies. To achieve the performance and robustness necessary to make this vision feasible, microrobot mechanisms such as motors and springs will be fabricated in a silicon/elastomer process.

The very tiny robots could be used in many ways, says Bergbreiter, from surveillance to search and rescue. Even environmental studies, where robots would have a minimal impact on the environment. For example, she tells of a study involving the monitoring of rare birds. “The birds saw the sensors that were being used to monitor them and would bury them,” she says. “That made the sensor useless. They were glaringly obvious in their environment. Our robots on a millimeter scale could avoid that.”

And, perhaps bring the cycle of bioinspired engineering full circle - back to nature.

For more information on Dr. Gupta or Dr. Bergbreiter’s research, please visit: [www.enme.umd.edu](http://www.enme.umd.edu).



SMALLER THAN A PENNY - BERGBREITER’S AUTONOMOUS JUMPING MICROBOT



# Creating a Better Petroleum Process

COLLABORATION WITH ABU DHABI INSTITUTE ADDRESSES ISSUES CONFRONTING OIL INDUSTRY

Since the University of Maryland (UMD) and the A. James Clark School of Engineering entered into a partnership with the Petroleum Institute (PI) of Abu Dhabi, United Arab Emirates (UAE) in 2006, ME researchers and their colleagues at the institute have been addressing issues confronting the oil industry. The Petroleum Institute is sponsored by a consortium of Abu Dhabi National Oil Company and its international partners (Shell, BP, Total, and Japan Oil Development Company).

“The goal of the university’s work with the Petroleum Institute is to move toward enhanced oil recovery and exploration,” says ME department chair, Avram Bar-Cohen. “We’re doing this specifically by applying advanced ME knowledge to fossil fuels.”

“By supporting this research now, the industry is investing in the future,” says Azar Nazeri, research manager of the Energy Education and Research Collaboration (EERC), which was created on the UMD campus as result of the collaboration.

The collaboration isn’t just engaged in research, but looks to develop future researchers as well. “Education is a key component of this partnership,” says Bar-Cohen. This has resulted in students from PI attending school at UMD as students and interns, and students from UMD participating in internships at PI. “Some of these PI students who are obtaining their PhDs in ME will return as faculty members at PI,” says Nazeri.

Current collaboration projects include:

**Robust Optimization of Petrochemical Systems** will develop a framework for robust optimization of distillation column design while considering the net profit effect at the plant level.

**Dynamics and Control of Drill Strings on Fixed and Floating Platforms** will develop and, analytically and numerically, study control-oriented models for drill strings; investigate control of an under-actuated nonlinear system (drill string) that has complex interactions with the environment; and build a drill string testbed for the institute and university to test the theoretical findings.

**Thermally Enhanced Polymer Heat Exchanger for Seawater Applications** will address the fundamental thermal performance issues associated with the use of thermal high-conductivity polymer materials in heat exchangers.



**EHD-Enhanced Gas/Liquid Separator** will study hybrid inertia-EHD, gas/liquid separation phenomena for electrically conductive and nonconductive liquid particles suspended in a moving gaseous medium.

**Force-Fed Cooling of Photovoltaic Arrays for High-efficiency Solar Energy Conversion Systems** will create a database of the available cooling techniques for the high heat flux solar concentrator arrays necessary for efficient conversion of solar energy to electric power and design and fabricate an experimental prototype and associated setup to verify the feasibility of this concept and the capacity for force-fed cooling.

**Condensing Flows in a Microscale Channel with a Microelement Array and Visual Techniques** will investigate the fundamentals of the two-phase condensing flow phenomenon in submillimeter micro-channels.

**Sulfur Recovery from Gas Stream, Using Flameless and Flame Combustion Reactor** will obtain fundamental information on the thermal process of sulfur recovery from sour gas by conventional flame combustion and flameless combustion using numerical and experimental studies. The ultimate goal is to determine the optimal operating conditions for sulfur conversion.

**Waste Heat Utilization in the Petroleum Industry** will utilize waste heat in petroleum processing plants to minimize overall energy consumption.

For more information on the EERC and PI collaboration, please visit: [www.enme.umd.edu/projects/collaborations/eerc.htm](http://www.enme.umd.edu/projects/collaborations/eerc.htm).





# Passing It On

## FACULTY SHARE RESEARCH THROUGH LECTURES AND SEMINARS

ME faculty not only conduct research, but are enthusiastic to share what they have learned with the academic community. Each year, they present countless seminars and lectures on their specific areas of expertise. Presentations this past year include:

### Balakumar Balachandran

Nonlinear Dynamics and Control, *Pusan National University, Korea, and Amrita University, India*

Nonlinear Phenomena in Microscale Oscillators: Understanding and Utilizing Them, *Duke University*

### Avram Bar-Cohen

On-chip Hot Spot Remediation with mTEC Coolers, *University of Texas at Austin*

Polymer Heat Exchangers for Seawater Applications, *Texas A&M University*

### Sarah Bergbreiter

Challenges for Autonomous Mobile Microrobots, *Ecole Polytechnique Federale de Lausanne, Switzerland*

### Nikhil Chopra

Delay-Independent Stability and Synchronization of Interconnected Nonlinear Systems, *Rutgers University and Technische Universitaet Muenchen, Germany*

### Abhijit Dasgupta

Mechanics of Damage in Electronic Assemblies under Flexural, Vibration and Drop Loading, *Stokes Institute, University of Limerick, Ireland*

### Jaydev Desai

Medical Robotics in Microscale and Macroscale Interventions, *University of Maryland School of Medicine*

Image-guided Surgical Robotics: From Macroscale to Mesoscale, *University of Pennsylvania*

### James Duncan

Nonlinear Gravity-Capillary Wave Patterns Generated by a Slow-moving Pressure Source, *University of Chicago*

Incipient Breaking Conditions, *Howard University and MIT*

### Satyandra K. Gupta

Towards a New Manufacturing Approach to Realizing Bioinspired Robots, *Johns Hopkins University and University of Connecticut*

### Gregory Jackson

Fuel Oxidation in Solid Oxide Fuel Cells: From Electrocatalyst to Integrated Systems, *West Virginia University and Cornell University*

Decoupling Fuel Cells and Hydrogen: The Promise and Challenge of Carbonaceous Fuel in Solid Oxide Fuel Cells, *University of Delaware*

### Jungho Kim

Boiling Heat Transfer Mechanisms in Earth and Low-gravity Environments, *MIT*

### Teng Li

Nanostructures in Flexible Electronics: Mechanics Challenges and Solutions, *SUNY-Binghamton University*

### Michael Pecht

Advanced Prognostic Techniques for Aerospace Applications, *Beihang University of Aeronautics & Astronautics, Beijing and China Aerospace Institute, Shen Yang*

Prognostics-based Product Qualification for Advanced Microelectronic Systems, *Hong Kong University of Science & Technology*

A New Perspective on Electronic Product Reliability, *City University of Hong Kong*

Monitoring the Health of Products, *University of Greenwich (Old Royal Naval College), UK*

### Elisabeth Smela

Polymer Microactuators, *MIT*

Electroactive Polymer Microactuators and their Applications, *University of Texas at Dallas*

Cell-based Sensors and Cell "Clinics," *University of Illinois, Urbana-Champaign*

Mapping Nucleic Acids in Tissue Sections, *University of Maryland Greenebaum Cancer Center*

### Santiago Solares

Towards 3D Force-Distance Measurements with Dual-frequency-Modulation AFM, *Yale University*

Continuum-Atomistic Simulation of AFM Imaging Artifacts and 3-Dimensional Dual-frequency Force Spectroscopy, *Karlsruhe Institute of Technology, Germany*

### Michael Zachariah

Understanding and Tuning the Reactivity of Energetic Nanoparticles, *University of Southern California*

Ion Mobility to Manipulate and Characterize Nanoparticles in the Gas-Phase, *Johns Hopkins University and Swiss Federal Institute of Technology, Zurich*

Ion Mobility: An Aerosol Dynamics Approach to Manipulate and Characterize Nanoparticles, *NJ Institute of Technology*

### Guangming Zhang

Computer-aided Design and its Applications, *Frostburg State University, Maryland*

The department is also pleased to host seminars and lecturers throughout the year. For a listing of guest speakers to our department, please visit: [www.enme.umd.edu/seminars/index.html](http://www.enme.umd.edu/seminars/index.html).



# From Money in Hand to Eye in the Sky

## CENTER TAKES LEADERSHIP ROLE IN MANAGING THE LIFE CYCLE OF ELECTRONIC SYSTEMS

The reliance of modern technologies on complex electronics poses significant and growing challenges to managing life cycle risks. “From the annoyed customer at the ATM or the business traveler on a delayed flight, to the dangerous malfunction of automobiles or the loss of \$100 million satellites and aircraft, failure to adequately manage the life cycle of electronic systems touches everyone,” says George Dieter Chair, Professor Michael Pecht, founder and director of the Center for Advanced Life Cycle Engineering (CALCE).

Since its inception in 1985 as a National Science Foundation (NSF) Center of Excellence, CALCE has been a leader in enabling technologies and providing solutions that mitigate life cycle risks for electronic products and systems. CALCE now conducts over \$6 million in research per year for over 200 organizations worldwide and hosts a consortium of over 50 major companies. Today, many leading domestic and international best practices standards are based on CALCE research and publications. Additionally, CALCE prognostics and health management efforts for electronics are being implemented by leading international companies.

Recently, CALCE received the NSF Schwarzkopf Award for its technological innovation, the highest award bestowed to an NSF center. “If you go to any company that deals with electronics and ask about reliability, the first name that is mentioned is CALCE at the University of Maryland. All the faculty and researchers on our team are quite famous and highly respected by companies,” says Pecht. In fact, Pecht was awarded the highest reliability honor, the IEEE Reliability Society’s Lifetime Achievement Award in 2008.

Significant contributions made by CALCE include:

### **Processes and models developed by CALCE are the de facto standards for physics-of-failure (PoF)-based analyses of electronic systems.**

- CALCE developed the concept of organizational reliability capability as the measure of the effectiveness of an organization’s reliability program, practices and activities in meeting customer requirements for product reliability. Companies in areas as diverse as telecommunications, industrial control systems and power electronics have used CALCE organizational reliability capability reviews as the basis for organizational improvements.
- Aerospace, automotive, household, industrial, medical and telecommunication organizations worldwide actively use CALCE PoF-based reliability assessment software and accelerated testing approaches in their product development and assessment processes.
- The U.S. Army created and maintains a PoF analysis group that

uses calcePWA software and techniques to assess electronic designs for U.S. Department of Defense programs.

- GM experienced a 10% reduction in development time and an 80% reduction in design verification failures using CALCE PoF calcePWA software and accelerated-qualification approaches. As a result, CALCE software was made a requirement in GM Design Standard GM3172.
- NASA’s use of CALCE PoF models is enabling plans for extended manned missions to the moon and Mars.
- Aerospace, telecommunication and medical equipment manufacturers use the solder fatigue model derived and validated by CALCE.
- The top avionics equipment suppliers in the world use CALCE-developed models to assess the failure risk presented by tin whiskers.

### **CALCE is recognized as the pre-eminent technical organization for up-rating, counterfeit electronic part management and electronic part obsolescence forecasting and management.**

- The core of the Electronic Components Management Plan (ECMP) for the commercial avionics industry is based on the parts management methodology developed by CALCE.
- CALCE developed the concept of up-rating, a process for mitigating the risk of using semiconductor devices outside manufacturers’ specifications. Up-rated components are now used in nearly all avionics, military and other extreme environment applications.
- CALCE developed the first quantitative analysis of lifetime buy sizes for electronic parts, permitting major electronics integrators to reduce their safety stock inventory sizes, resulting in significant cost savings.

### **CALCE is a leader in supplying tools and methodologies for the strategic management of long-field-life systems.**

- CALCE developed the most widely used strategic methodology for managing electronic part obsolescence. In one example, Motorola realized a \$33 million cost avoidance by adopting the CALCE software generated refresh plan for a base station communications system.

### **CALCE has formed the first collaborative research effort to address the application of prognostics and health management concepts to electronic systems.**

- CALCE developed a new paradigm for reliability prediction of electronics based on prognostics, whereby sensor data can be integrated with models that enable in-situ assessment of the deviation or degradation of a product from an expected normal operating condition, and the prediction of the future state of reliability.

For more information about CALCE, please visit: [www.calce.umd.edu](http://www.calce.umd.edu).



# Energy-Efficient Enterprise

## CEEE'S RESEARCH FOCUSES ON DEVELOPMENT OF ENERGY CONVERSION SYSTEMS

The Center for Environmental Energy Engineering (CEEE) is a leader in the research of environmentally responsible and economically feasible distributed energy conversion thermal management systems for buildings, transportation and electronic cooling.

“Our goal is to bring to fruition research that can be used on a day-to-day basis and because of that collaborating with industry is very important. After all, no one is more invested in that goal than industry, the ones who will implement these systems,” says ME Professor Reinhard Radermacher, director and co-founder of CEEE.

The center, which was established in 1991 by integrating the heat pump and refrigeration laboratories originally founded in 1983, is divided into four consortia based on the research pursued by each group. The consortia are: Alternative Cooling Technologies and Application (ACTA), Integrated Systems Optimization (ISOC), Small Autonomous Energy Systems (SAES) and Advanced Heat Exchanger/Electronic Cooling (AHX/EC).

Corporate sponsors involved with CEEE are: Baltimore Aircoil (BAC), Ballard, Carrier, Daikin, Danfoss, Delphi U.S., DOE, DuPont, Godrej, Gree, Güntner, Emerson, Honeywell, Ingersoll Rand, Johnson Controls, LG, Luvata, Marlow, Panasonic, Mitsubishi, Mitsubishi Plastics, Modine, Office of Naval Research (ONR), Petroleum Institute, Sanden, Sanyo, Shanghai-Hitachi, Subros, Sub-Zero, Suez/Trigen, Thermogly, Trane, Whirlpool and Wolverine.

Specific areas of research and accomplishments include:

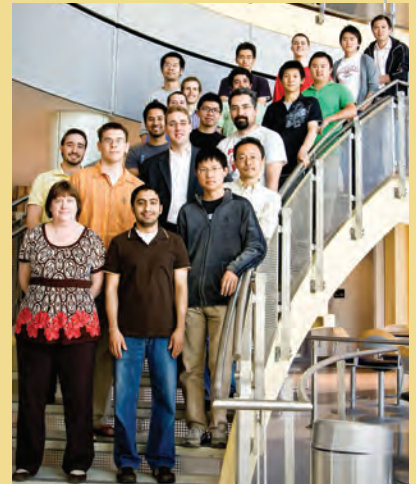
- CEEE's research has led to energy savings in refrigerators in excess of 50 percent. “These were achieved by taking advantage of synergistic improvements resulting from cabinet, refrigeration system and working-fluid selection benefits,” says Radermacher, who introduced ternary working-fluid mixtures for absorption heat pump technology. His contributions to the use of working-fluid mixture in vapor compression systems resulted in advanced cycles with a new degree of freedom for special applications. A CEEE-designed suction line heat exchanger is now in production in the automotive industry.
- CEEE faculty and students built the first carbon dioxide hot water heat pump in the United States. “Since no suitable compressors were available we developed our own,” says Radermacher.
- The center developed a novel test method for measuring oil retention within air-conditioning systems, applying it to a wide range of refrigerants and miscible and nonmiscible lubricants. The resulting correlations are predicting oil retention in a wide range of systems. Then, CEEE, together with one of its sponsors, developed

an oil concentration sensor.

“Furthermore, we've created a test facility and method for the measurement of vapor compression system performance under dynamic conditions,” says Radermacher. “An automotive air conditioner can be tested over an entire drive cycle without ever leaving the lab.”

- CEEE is evaluating and designing cooling, heating and power systems for natural gas and petroleum processing plants, leading to significant energy savings. Additional research extends to solar-cooling systems. “We have developed the design for the most efficient solar-cooling concept to date,” says Radermacher.
- Fuel cell research by SAES has led to the creation of a new fuel cell test facility in cooperation with the U.S. Army and Ballard.
- CEEE installed some of the first building-sized cooling, heating and power systems in the U.S. Subsequent research led to the development of an air-cooled absorption chiller concept that accomplishes air cooling by skillfully integrating the chiller with the application. A side benefit is increased operating hours which greatly increases economic feasibility. “Our research results and guidelines from this project contributed to the successful development of fully integrated packaged CHP (cooling, heating and power) systems,” says Radermacher.
- Research by AHX led to the development of an electro-hydrodynamically-enhanced (EHD-enhanced) oil separator device, air-side heat transfer enhancement techniques, mechanical and thermal design of microchannel heat exchangers, EHD-enhanced tube bundle condenser and development of microevaporators and microcondensers for use in ultracompact cooling systems.
- ISOC develops the tools for systematic optimization of thermal systems. This effort is based on the development of component-based, highly flexible and user friendly simulation packages for components, subsystems and systems. “The unique strength of this effort is the inclusion of optimization routines that allow a systematic search for better systems using gradient-based and/or heuristic approaches that are commercially available,” says Radermacher.

For additional information, please visit: [www.enme.umd.edu/ceee](http://www.enme.umd.edu/ceee).



MEMBERS OF THE CEEE RESEARCH TEAM



# The Thought Leaders

## ME FACULTY PARTICIPATE IN SETTING THE DIRECTION OF FUTURE RESEARCH

ME researchers are rather prolific when it comes to the written word, becoming involved with numerous academic journals. “Our faculty’s involvement with academic journals, especially in the role of editor, is a recognizable mark of leadership and distinction for our department,” says Avram Bar-Cohen, ME department chair.

For example, Bar-Cohen is currently the editor-in-chief of *IEEE’s CPMT (Components, Packaging, and Manufacturing Technology) Society Transactions*. Other faculty journal editors include Reinhard Radermacher, editor of the *ASHRAE HVAC&R Research Journal*, and Michael Pecht, chief editor of *Microelectronics Reliability International*. And, the editorial expertise does not stop there. Many faculty members are also involved in producing books, such as Ashwani Gupta, editor of the *Energy and Engineering Science Series* (CRC Press).

“Many of our faculty members are drawn to the idea of service and see themselves playing an important role in leading the academic community,” says Bar-Cohen of these editorial efforts.

This is particularly true in the case of those individuals who serve as editors, giving the final say on what papers will or will not appear in the journal and passing along this information to both industry and government.

“As an editor, for example,” says Bar-Cohen, “you are setting the direction of future research and defining the gaps between the technological needs of particular areas of research and the existing knowledge base. By identifying those gaps

you can better address research funding for such agencies as DARPA, NSF and DOE who can devote resources to closing that gap.”

Adding, “You’re vetting the results. In a way you are really shaping the whole field of research. You’re becoming the thought leader. Our faculty here at ME does this very well.”

ME faculty members and their journal affiliations include:

### Shapour Azarm

Review Editor, *Structural and Multidisciplinary Optimization*  
Associate Editor, *ASME Transactions, Journal of Mechanical Design*  
Associate Editor, *Mechanics Base Design of Structures and Machines*  
Editorial Board Member, *International Journal of Reliability and Safety*

### Bala Balachandran

Associate Editor, *ASME Journal of Computational and Nonlinear Dynamics*  
Deputy Editor, *AIAA Journal*  
Editorial Board, *Journal of Vibration and Control*

### Avram Bar-Cohen

Editor-in-chief for *IEEE’s CPMT (Components, Packaging, and Manufacturing Technology) Society Transactions*  
Editor, *Advances in Heat Transfer*

### Hugh Bruck

Associate Editor, *Experimental Mechanics*

### Jaydev Desai

Associate Editor, *ASME Journal of Medical Devices*  
Associate Editor, *IEEE Transactions on Information Technology in Biomedicine*  
Guest Co-editor, *Letters Special Issue: Emerging Technologies in Biomedical Robotics and Biomechanics*  
Co-editor, special issue on medical robotics in *International Journal of Robotics Research*

### Don DeVoe

Associate Editor, *ASME/IEEE Journal of MicroElectroMechanical Systems*  
Editorial Advisory Board, *Journal of Clinical Bioinformatic Science*

### William Fourney

Co-editor, *FRAGBLAST—International Journal for Blasting and Fragmentation*

### Ashwani Gupta

Associate Editor, *Journal of Propulsion and Power*  
Associate Editor, *Journal of Applied Energy*  
Editor, *International Journal of Reacting Systems*  
Editor, *International Journal of Spray and Combustion Dynamics*

### Satyandra K. Gupta

Associate Editor, *SME Journal of Manufacturing Processes*  
Associate Editor, *ASME Journal of Computing and Information Science in Engineering*  
Associate Editor, *IEEE Transaction on Automation Science and Engineering*  
Editorial Advisory Board, *Computer-Aided Design and Applications*  
Editorial Advisory Board, *Assembly Automation*

### Bongtae Han

Associate Technical Editor, *Journal of Electronic Packaging, Transactions of the ASME*



### Jeffrey Herrmann

Associate Editor, *ASME Journal of Mechanical Design*  
Associate Editor, *IIE Transactions on Scheduling and Logistics*

### Jungho Kim

Associate Editor, *International Journal of Multiphase Flow*  
Associate Editor, *Journal of Heat and Technology*

### F. Patrick McCluskey

Associate Editor, *IEEE Components and Packaging Technologies*

### Mohammad Modarres

Associate Editor, *International Journal on Performativity Engineering*  
Editorial Board, *International Journal of Reliability and Safety*  
Editorial Board, *Journal of Risk and Reliability*  
Editorial Board, *Nuclear Technology Journal*

### Ali Mosleh

Engineering Editor, *Risk Analysis*  
Editorial Board, *Journal of Risk and Reliability*  
Editorial Board, *Journal of Reliability Engineering and System Safety*

### Michael Ohadi

Technical Associate Editor, *Journal of Enhanced Heat Transfer*  
Advisory Editorial Board Member, *Scientia, International Journal of Science and Technology*

### Michael Pecht

Chief Editor, *Microelectronics Reliability International*  
Associate Editor, *IEEE Transactions on Components, Packaging and Manufacturing Technology*  
Associate Editor, *International Microelectronics Journal*

### Reinhard Radermacher

Editor, *ASHRAE HVAC&R Research Journal*

### Jan Sengers

Associate Editor Emeritus, *International Journal of Thermophysics*

### Michael Zachariah

Associate Editor, *Journal of Nanoparticle Research*

For more information, please visit: [www.enme.umd.edu](http://www.enme.umd.edu).

**“MANY OF OUR FACULTY MEMBERS ARE DRAWN TO THE IDEA OF SERVICE AND SEE THEMSELVES PLAYING AN IMPORTANT ROLE IN LEADING THE ACADEMIC COMMUNITY.”** — AVRAM BAR-COHEN

## New Frontiers

### PROFESSOR FOCUSES RESEARCH ON MANAGING PRODUCT OBSOLESCENCE

ME Professor **Peter Sandborn** is currently investigating novel research approaches to understanding and managing technology obsolescence challenges. “The results of this research will overcome limitations in existing design methods that do not adequately consider obsolescence issues,” says Sandborn, who has received a two-year National Science Foundation collaborative research grant for “Knowledge Representation and Design for Managing Product Obsolescence.” Technology obsolescence adversely impacts products that use short procurement-life components such as electronic parts that may only be available from their original manufacturer for a few years but have to be maintained in long-life systems (e.g., aircraft and infrastructure) for decades.

Sandborn explains that in today’s world, complex systems are often maintained within “sustainment stovepipes,” where the same obsolescence issue may be resolved separately by the same organization for each of the different systems it supports. “The research conducted in this program will help break down the stovepipes so that information can be readily shared, ultimately leading to more proactive obsolescence management throughout the product life cycle,” he says.

As part of his research, he is also developing fundamental principles, teachable methods, and guidelines for designing product architectures that can facilitate information exchange and collaboration for technology obsolescence management and mitigation efforts between existing tools and databases, and across multiple organizations.

“My goal is to provide a platform for the exploration and understanding of interactions among the elements of product design and sensitivities to obsolescence,” says Sandborn, who is also affiliated with CALCE and the Institute for Systems Research. “The research will provide the knowledge base that enables designers to effectively develop and use the software tools they need to manage the issue of obsolescence.”



SANDBORN

# Great Minds

## INVENTOR OF HYBRID POWER SYSTEM INDUCTED INTO INNOVATION HALL OF FAME



SEVERINSKY

Alex Severinsky, the inventor of the hybrid power system used in the Toyota Prius and in other hybrid vehicles, was inducted into the the A. James Clark School Innovation Hall of Fame. Severinsky, a visiting professor of mechanical engineering, was honored at a special induction ceremony in October. The Clark School's Innovation

Hall of Fame was developed and funded by Stanford W. Berman, B.S. '50, to recognize great engineering and to inspire young engineers.

Severinsky developed the Hyperdrive power-amplified internal combustion engine powertrain, a unique successor technology to the conventional internal combustion engine powertrain, and founded PAICE Corporation to license Hyperdrive to hybrid vehicle manufacturers.

The Hyperdrive system utilizes a unique combination of existing technologies, along with inventive functionality, significantly improving performance and decreasing the cost of the powertrain.

Hyperdrive's key innovation is in the use of an alternating current electrical subsystem, which offers significant performance advantages over conventional powertrains and other hybrid technologies, with average fuel economy improvements of greater than 50 percent at equivalent cost, broad applicability across chassis sizes and vehicle types, lower environmental impact and ample power for all vehicle accessories.

The Hyperdrive system is utilized in the Toyota Prius, Camry and several SUVs, and has made hybrid technology commercially viable and played a key role in moderating the increase in gasoline consumption.

Severinsky contacted



DARRYLL PINES, DEAN, CLARK SCHOOL; MARILYN BERMAN POLLANS (LATE HUSBAND STANFORD W. BERMAN DEVELOPED AND FUNDED THE IHOF); ALEX SEVERINSKY, INDUCTEE; NATHAN BLUZER, SELECTION COMMITTEE CHAIR AND PREVIOUS INDUCTEE; HERBERT RABIN, PROFESSOR AND DIRECTOR OF MTECH; NARIMAN FARVARDIN, PROVOST; TOYOTA PRIUS COURTESY OF ZIPCAR.

the Maryland Technology Enterprise Institute (Mtech) at the Clark School in 1986 and enrolled Viteq, a company that developed uninterrupted power supplies for computer systems, in Mtech's Technology Assistance Program. In 1992, he enrolled PAICE Corporation, which licenses the Hyperdrive technology, in the same Mtech program.

He consulted with Clark School faculty members to develop and refine his ideas for Hyperdrive. Severinsky served as CEO and chairman of PAICE until 2006. He then founded Fuelcor LLC, an intellectual property development company focused on synthetic fuels, where he continues to serve as CEO. He holds 21 patents in the United States, with additional patent filings worldwide.



## From Ideas to Industry

### RESEARCHERS YU AND BALACHANDRAN AWARDED PATENT

ME researchers **Miao Yu** and **Balakumar Balachandran** have been awarded a U.S. patent for their development of a micro-optical sensor system for pressure, acceleration and pressure gradient measurements (U.S. Patent 7,428,054). Yu is an assistant professor of mechanical engineering who holds an affiliate appointment with the Institute for Systems Research. Balachandran is a professor of mechanical engineering and associate chair of ME.

The invention is a micro-optical fiber tip-based sensor system for pressure, acceleration and pressure gradient measurements over a wide bandwidth. The design, which allows for multiplexity on the system input side, is based on micro-electromechanical fabrication techniques. The optical portion of the system is based on low-coherence fiber-optic interferometry techniques, and also has a sensor Fabry-Perot interferometer and a read-out interferometer combination that allows a high dynamic range and low sensitivity to the wavelength fluctuation of the light source. A phase modulation and demodulation scheme takes advantage of the integrated optical circuit phase modulator and multistep phase-stepping algorithm for providing high-frequency and real-time phase signal demodulation. The system includes fiber tip-based Fabry-Perot sensors, each of which has a diaphragm that is used as a transducer.

This is the third patent for Yu and Balachandran in this particular area of research. Previous patents include one for the invention of a fiber tip-based sensor system for measurement of pressure gradient air-particle velocity and acoustic intensity (U.S. Patent 7,224,465) and another for the invention of fiber tip-based fiber-optic sensor systems (U.S. Patent 6,901,176). Both previous patents have been licensed by two companies, Odexia and Pervasive Technology Engineering.



YU



BALACHANDRAN

## Working Together

### PRODUCT INNOVATION AND REALIZATION LABORATORY SUITE ASSISTS AWARD-WINNING COMPANY

When TRX Systems, a leading innovator in the development of personnel tracking solutions, placed first in the third annual Global Security Challenge (GSC) for “Most Promising Security Start-up,” the company gave a nod to ME’s **Product Innovation and Realization Laboratory Suite (PIRLS)**.

“One of the reasons we won this award was because we showed our manufacturing viability and focus as a product development team,” says David Lemus, the lead mechanical engineer at TRX, located in Greenbelt, Md., and founded by Gil Blankenship, a professor and associate chair of the Department of Electrical and Computer Engineering. “Surely we could not have reached this point without the help of the PIRLS lab.”

TRX Systems placed first for creating an advanced personnel tracking system that provides first responders with accurate and real-time locations of individuals deployed inside a building. TRX’s technology is self-contained, requires no preinstalled infrastructure and can create virtual floor plans in real time.

For winning, TRX Systems, a recent graduate from the university’s Technology Advancement Program, the incubator facility for startups which is part of the Clark School’s Maryland Technology Enterprise Institute, received a \$500,000 federal contract.

In an email to the PIRLS lab, Lemus, wrote, “Initial prototyping with ABS (acrylonitrile-butadiene-styrene) was important in developing an alpha system for the TRX tracking system. Greg Teitelbaum, research graduate assistant and PIRLS lab manager, and I had countless interactions and went through several iterations to ensure that the enclosures I was designing met specified tolerances and design for manufacturing/design for assembly guidelines. I have worked with a few different prototyping companies, and the PIRLS lab has delivered quality parts and has effectively communicated with TRX Systems.”

It is a working relationship with a future. “Over the coming months,” continues Lemus, “I will be designing the next generation enclosures for our system, and I hope to come to the PIRLS lab for my initial prototyping needs.”

“We are honored to have been involved in and to have offered assistance with this outstanding project,” says Linda Schmidt, ME associate professor and lab director.



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SCHOOL OF ENGINEERING

Department of Mechanical Engineering

2181 Glenn L. Martin Hall

University of Maryland

College Park, MD 20742

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## Life-saving Results

### OFF-ROAD VEHICLES RECALLED FOLLOWING TESTING BY FACULTY MEMBER, STUDENTS

Testing completed by ME adjunct associate professor **Greg Schultz** and ME graduate students Mike Cook and Greg Ramsey has contributed to a recall of the Yamaha Rhino 450, 660 and 700 off-highway recreational vehicles by the Consumer Product Safety Commission (CPSC).

“The work we did for the CPSC was a key element on the 146,000 Yamaha Rhino units that were recalled for repairs,” says Schultz. The repairs are designed to reduce roll-over risk as well as improve handling. According to the CPSC, 46 deaths and hundreds of injury claims had been reported with these vehicles before the recall.

Schultz and his team, working at an Army testing facility in Maryland that uses a roadway simulator, “have been running kid-size ATV and off-road utility tests for the last year and half (under contract) for CPSC,” says Schultz, who is also a senior test engineer at the facility. Cook and Ramsey are also employed full-time at the facility. “We ran the tests, educated

CPSC on how to interpret and use the data, and demonstrated potential improvements to the vehicle. This was strong data, indisputable data. In doing this type of work, you’re just doing the best you can and hopefully you can help people out in the process,” says Ramsey.

Both Cook and Ramsey, who received their undergraduate degrees in ME, have been involved with the university’s Terps Racing program, including the Formula SAE (Society of Automotive Engineers) program and Baja SAE program. Schultz, the faculty advisor for Terps Racing says, “I feel that they are taking what they learned from their experiences as undergraduates and members of the racing team and further developing those skills with projects such as this.” He adds, “It’s rewarding to watch.”

