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Northwestern Engineering

Mechanical Engineering

Robert R. McCormick School of Engineering and Applied Science
Northwestern University

SUMMER 2012

Patents, Awards Come out of Senior Engineering Design Class

Product engineers know that navigating the patent process can be long, arduous, and prohibitively expensive; patenting a product can cost upwards of $10,000 or even $20,000 — far more than most student inventors can afford.

But one senior design class at McCormick has given students the chance to apply for a patent free of charge by pairing them with client companies who do the financial heavy lifting for them.

The class, ME 398 Engineering Design, matches students with companies who are looking to launch new products or redesign current offerings. Over the 10-week course, the undergraduates meet with the clients, interview product users, and create prototypes of a new or improved product to fill that niche.

"The class takes students through the complete process of design, from the client's need to the prototype," said Wei Chen, Wilson-Cook Professor in Engineering Design and professor of mechanical engineering. "And some students get to experience the patent process, which is really valuable."

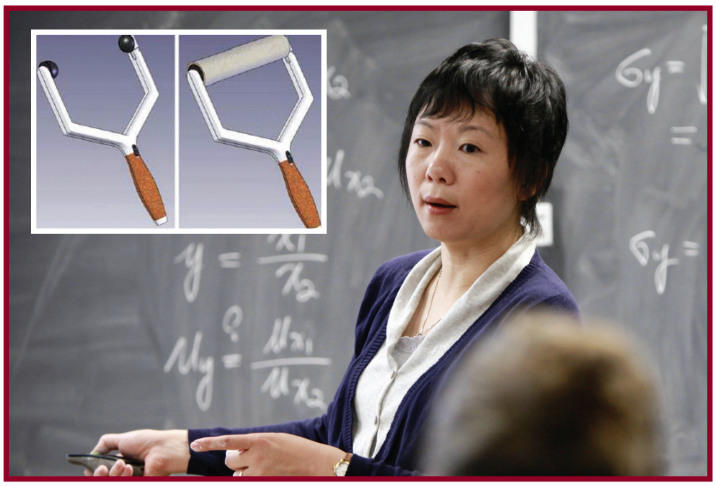
Products designed in recent years include a no-mess paint roller for home paint jobs and a conduit bender that allowed electricians and contractors to bend metal tubing to 90-degree angles. Another product currently has a patent pending: a hybrid pump used in prosthetic legs, a project of interest to the United States Department of Defense; another, an automatic meat casing remover for the meat processing industry, won McCormick's respected Margaret and Muir Frey Memorial Prize for Innovation and Creativity in 2010.

ME 398 begins with students selecting a client project from a list of proposals organized by Chen and McCormick's Office of Corporate Relations. After meeting with the clients to understand their needs, students get to work researching and brainstorming for their designs. After weeks of analyzing, measuring, and rigorous engineering analysis, they have a prototype they can bring to their client.

Students quickly learn that being a successful product designer requires more than engineering skills: it takes people skills.

"It's very demanding. Sometimes students come up with a very good idea that they're excited about, but it's ruled out right away by the client," Chen said. "But that is what happens as an employee, so it's a good experience."

One repeat client is Scott Pyle, general manager of the North Carolina-based Zibra LLC, a manufacturer of painting tools. For three years, from 2007 to 2009, Pyle worked with Chen's students on redesigning the company's quick-release paint roller frame and other products.



Students in Wei Chen's Engineering Design class created a quick-release paint roller (inset) for North Carolina-based Zibra LLC.

"We were manufacturing quick-release paint rollers already, but with this class, we saw an opportunity to look at new design possibilities," Pyle said. "We were looking for ways to make it more ergonomic, more user-friendly, and lower cost."

Nick Graham (mechanical engineering '07, certificate in engineering design) chose the paint roller design project sponsored by Zibra. He and three teammates started by collecting

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From the Chair

Much has happened in the past year, so this is a packed newsletter! Our research productivity continues to rise with increasing funding of externally sponsored research, despite increasing competition for such funds. Several articles in this newsletter highlight a few of our innovative, interdisciplinary research areas. Our faculty continue to develop and innovate in the classroom to deliver the best curriculum to our students at all levels, and you can see many high-level teaching awards honoring our faculty in recognition of these successful programs.

The department has developed a new strategic plan that overlaps optimally with that of the engineering school and the University, positioning us well for the coming years. You may know that the engineering school recently underwent ABET review, and I am delighted to report that the ME department passed with flying colors and was awarded a full six-year accreditation. Our faculty and students continue to be recognized with the highest honors. I mention only two here, and details on many others can be found on the back

Continued on page 3

Next-Generation Nanoelectronics: A Decade of Progress, Coming Advances

Professor Horacio Espinosa (left) with students in his lab

Traditional silicon-based integrated circuits are found in many applications, from large data servers to cars to cell phones. Their widespread integration is due in part to the semiconductor industry's ability to continue to deliver reliable and scalable performance for decades.

However, while silicon-based circuits continue to shrink in size in the relentless pursuit of Moore's Law — the prediction that the number of transistors that can fit on an integrated circuit doubles every two years — power consumption is rising rapidly. In addition, conventional silicon electronics do not function well in environments such as high temperatures or radiation.

In an effort to sustain the advance of these devices while curbing power consumption, diverse research communities are looking for hybrid or alternative technologies. Nanoelectromechanical (NEM) switch technology is one option that shows great promise.

"NEM switches consist of a nanostructure (such as a carbon nanotube or nanowire) that deflects mechanically under electrostatic forces to make or break contact with an electrode," said Horacio Espinosa, James N. and Nancy J. Farley Professor in Manufacturing and Entrepreneurship at the McCormick School of Engineering at Northwestern University.

NEM switches, which can be designed to function like a silicon transistor, could be used either in standalone or hybrid NEM-silicon devices. They offer both ultra-low power consumption and a strong tolerance of high temperatures and radiation exposure.

Given their potential, the past decade has seen significant attention to the development of both hybrid and standalone NEM devices. This decade of progress was reviewed by Espinosa's group and was published April 29 in the journal *Nature Nanotechnology*. Their review provided a comprehensive discussion of the potential of these technologies, as well as the primary challenges associated with adopting them.

For example, one longstanding challenge has been to create arrays of millions of the nanostructures, such as carbon nanotubes, that are used to make these NEM devices. (For perspective, modern silicon electronics can have billions of transistors on a single chip.) The researchers' review describes the methods demonstrated to date to create these arrays, and how they may provide a path to realizing hybrid NEM-CMOS devices on a mass scale.

Similarly, while individual NEM devices show extremely high performance, it has proven difficult so far to make them operate reliably for millions of cycles, which is necessary if they are to be used in consumer electronics. The review details the various modes of failure and describes promising methods for overcoming them.

An example of the advances that facilitate improved robustness of NEM switch technologies was published in the journal *Advanced Materials*. Here Espinosa and his group showed how novel material selection could greatly improve the robustness of both hybrid NEM-CMOS and standalone NEM devices.

"NEM devices with commonly-used metal electrodes often fail by one of a variety of failure modes after only a few actuation cycles," said Owen Loh, a PhD student at Northwestern University, currently at Intel, and co-author of the paper.

Simply by replacing the metal electrodes with electrodes made from conductive diamond-like carbon films, the group was able to dramatically improve the number of cycles these devices endure. Switches that originally failed after fewer than 10 cycles now operated for 1 million cycles without failure. This facile yet effective advance may provide a key step toward realizing the NEM devices whose potential is outlined in the recent review.

The work reported in *Advanced Materials* was a joint collaboration between Northwestern University, the Center for Integrated Nanotechnologies at Sandia National Laboratories, and the Center for Nanoscale Materials at Argonne National Laboratories. Funding was provided by the National Science Foundation, the Army Research Office, The U.S. Department of Energy, and the Office of Naval Research.

"Ultimately, realizing next-generation hybrid NEM-CMOS devices will enable continued scaling of the electronics that power numerous systems we encounter on a daily basis," Espinosa said. "At the same time, it will require continued push from the engineering, basic sciences, and materials science communities."

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Professor Horacio Espinosa

Colleague's Therapy Robot Aids McCormick Professor's Rehabilitation

When mechanical engineering expert and National Academy of Engineering and National Academy of Sciences member Ted Belytschko was recuperating from a stroke last year, his physical therapists recommended that a robot named "KineAssist" accompany him on his treadmill exercises. The device, they explained, would sense when Belytschko was losing his balance and catch him if he fell.

"I came into the office and said, 'Guess what? I'm using that device you designed.'"
Professor Ted Belytschko

Belytschko was already familiar with the KineAssist. It was borne of the human/robot interaction program just down the hall from his office, in the laboratory of his fellow academics, mechanical engineering professors Michael A. Peshkin and J. Edward Colgate.

"I came into the office and said, 'Guess what? I'm using that device you designed,'" said Belytschko.

Since suffering a blockage on the right side of his brain in April 2010, Belytschko has been visiting the Rehabilitation Institute of Chicago's Northbrook location to regain motor function in the left side of his body. The rehabilitation center is home to one of four KineAssists created by Peshkin, Colgate, and physical therapy professor David Brown.

In a traditional physical therapy model, a human therapist helps to balance a patient as he walks and catches him if he begins to fall, Peshkin explained. But a fall could injure both patient and therapist, so rarely is the patient allowed to get off balance.

"People learn when they're challenged beyond the point of comfort," Peshkin said. "You don't learn through caution, you learn through taking chances."

Over the course of four therapy sessions with the KineAssist Walking and Balance Exercise System, Belytschko learned to take those risks. "I could get off-balance, but I knew I'd get caught," he said. While he continues to work on his strength and balance, Belytschko's mobility has improved and he has returned to teaching.

The KineAssist was developed and commercialized through Kinea Design LLC, a McCormick spin-off founded by Peshkin, Colgate, and Brown. The company was recently purchased by HDT Robotics, based in Fredericksburg, Va.

KINEASSIST

Professors J. Edward Colgate (left) and Michael A. Peshkin demonstrate a device in their human/robot interaction laboratory. Above, a figure shows a patient resting on the KineAssist, walking, and working with the aid of a physical therapist.

FROM THE CHAIR, continued

page: Ted Belytschko was elected to National Academy of Sciences, and a medal for young researchers in structural health monitoring was established in Jan Achenbach's name. These are both honors of the highest degree and demonstrate the strength of these faculty and their research in our department.

Our next newsletter will highlight our new strategic plan and related recent initiatives. In the meantime, enjoy the great stories and highlights in this newsletter and check out our website for breaking news. Your affiliation with the Department of Mechanical Engineering continues to help us in our goal of providing the highest quality education and research in the interdisciplinary mechanical engineering domain for engineers and engineering of the future.

L. Cate Brinson, Chair

McCormick Celebrates National Robotics Week 2012

Robots reigned for a week in April as the Museum of Science and Industry celebrated National Robotics Week, and the McCormick School of Engineering played an important part in the festivities.

On Saturday, April 14, Kevin Lynch, professor of mechanical engineering, Todd Murphey, associate professor of mechanical engineering, and their students shared highlights of their robotics work with kids and adults at the museum.

Spectators marveled at several displays from Northwestern, including a "Humanoid Robot," a small humanoid demonstrating various capabilities; "Robotic Marionettes," a scaled-down automated marionette system (created in collaboration with Disney); and "Friction in Robotics and Automation," an interactive display that demonstrated how friction is important for manipulation and locomotion.

Murphey gave a talk, "Making Marionettes Move," while Lauren Miller, a graduate student in McCormick's Laboratory for Intelligent Mechanical Systems, presented on "Biological Systems as Inspiration for Autonomous Robotics." Graduate student Andrew Wilson also gave a talk, "Engineering Robotic Prosthetics for the Human Arm."

The day-long event — the "Big 'Bot Blow-Out!" — was part of the larger week of festivities at the museum, which included displays and lectures by some of the top experts in the robotics field, as well as student talks and demonstrations.

More than 160 events were held in all 50 states for the third annual National Robotics Week.

Northwestern students give demonstrations at the "Big 'Bot Blow-Out!" on Saturday, April 14. The event, held at the Museum of Science and Industry, was part of the third annual National Robotics Week.

PATENTS, AWARDS, continued

the company's current model paint roller and those made by Zibra's competitors. They set to work painting the off-campus bedroom of one of the team's members, but before long, the rollers began to break.

"The quick-release mechanism wasn't very robust," said Graham, now an engineering team leader for GE Energy in Greenville, South Carolina.

The team started by making a model from Lego-like pieces, toilet paper rolls, and pipe cleaners; a second, more sophisticated model was crafted from Delrin. Finally they came up with a design that worked: a two-prong model that held the roller solidly in place with two spindles.

Zibra was impressed and submitted a patent application for the team's paint roller with the students listed as co-inventors. Inevitably, Pyle said, the product underwent two more rounds of changes before the design was finalized. Still, the student's design had a significant impact on the new product that is in the marketplace today.

"We have a whole team of professional designers and engineers working to mold these designs into products for the marketplace," Pyle said. "But the mechanical engineering class provides another fresh perspective. They come in with no blinders, open to all new ideas. It's been a great experience for me and the company."

Department News

FACULTY

Jan Achenbach was elected an honorary foreign member of the National Academy of Sciences of the Republic of Korea. He was also awarded an honorary doctorate from China's Zhejiang University. Achenbach is the seventh individual—and first engineer—to receive an honorary doctorate from Zhejiang University. In addition, Achenbach was recognized at the International Meeting on Structural Health Monitoring by the establishment of the Achenbach Medal. The medal, which was awarded for the first time in September 2011, is for young investigators for a contribution within 10 years of receiving their PhD.

Ted Belytschko was awarded the prestigious William Prager Medal from the Society of Engineering Science and was elected to the National Academy of Sciences.

Jian Cao was elected president of the North American Manufacturing Research Institution of Society of Manufacturing Engineers. Cao was also named one of five new fellows to the Society of Manufacturing Engineers College of Fellows. She was appointed an editor for *International Journal of Precision Engineering and Manufacturing* as well as the editor for the new ASME transaction journal, *Journal of Micro- and Nano-Manufacturing*.

Wei Chen was awarded the Chang Jiang Lecture Professorship through the Chang Jiang Scholars Program, administrated by the Chinese Education Ministry. She was also reappointed as an associate editor of the ASME *Journal of Mechanical Design* and was elected chair of technical committees in the executive committee of the ASME Design Engineering Division.

Kuniaki Dohda received the JSTP Medal in May 2011 from the Japan Society for Technology of Plasticity, the highest honor for an academic researcher in the field.

Kori Ehmann received the 2010 SME/NAMRI Outstanding Lifetime Service Award.

Horacio Espinosa was elected for a second term to the Society of Engineering Science Board of Directors and was appointed to the U.S. National Committee for Theoretical and Applied Mechanics. He was also elected to the Russian Academy of Engineering

Sandip Ghosal was elected a fellow of the American Physical Society (Division of Fluid Dynamics), and he was appointed a member of the editorial board of the newly launched *Open Journal of Fluid Dynamics*.

Mitra Hartmann was selected to participate in the Defense Science Study Group. Approximately 15 scientists are selected nationwide to participate in this program every two years. She was also elected to the Associated Student Government honor roll.

Walter Herbst was awarded two Red Dot awards in an international product design competition. Herbst was also invited to join the board of the Edison Awards, which recognizes and honors excellence in innovation and innovators, and he was selected to receive the University of Illinois, Distinguished (Design) Alumni Award.

Dean Ho was awarded the Wallace H. Coulter Foundation Phase II Translational Research Award.

Yonggang Huang has been appointed as the editor-in-chief for the journal *Theoretical and Applied Mechanics Letters* as well as the editor of ASME Transactions – *Journal of Applied Mechanics*.

Leon Keer received the ASCE Engineering Mechanics Institute 2011 Raymond D. Mindlin Medal.

Elmer Lewis was appointed to the nine-person Science Council for the Department of Energy's Consortium for Advanced Simulation of Light Water Reactors.

Kevin Lynch was named co-director of the Northwestern Institute on Complex Systems (NICO).

Neelesh Patankar received the International Conference on Multiphase Flow (ICMF) Junior Award presented once every three years for "breakthrough(s) in the field of multiphase flow research." Patankar was one of approximately 15 to recently complete the Defense Science Study Group, and was appointed as an associate editor of the *Journal of Computational Physics*.

Michael Peshkin was awarded the Charles Deering McCormick Professorship of Teaching Excellence for 2011.

John Rudnicki has received the 2011 Daniel C. Drucker Medal from the American Society of Mechanical Engineers (ASME).

Cheng Sun was honored as the first recipient of the Chao & Trigger Young Manufacturing Engineer Award (2011).

Jane Wang received the Edmond E. Bisson award for the best written contribution published in the year by STLE.

GRADUATE STUDENTS AND PRE-AND POST-DOCTORAL RESEARCHERS

Christie Barbosa won a Fulbright Award to go to the Politecnico di Torino in Italy for the 2011-12 school year.

Tiffany Davis was one of seven students awarded a 2011-12 Presidential Fellowship by The Graduate School. The most prestigious fellowship presented by Northwestern, this award includes membership in the University's Society of Fellows.

Andrew Long won the Best Technical Paper Award at the Conference on Climbing and Walking Robots in Paris.

Joe Mullenbach and Professor J. Edward Colgate accept the Best Poster Award at the Haptics Symposium 2012.

Joe Mullenbach and **Dan Johnson**, along with professors J. Edward Colgate and Michael A. Peshkin, won the "Best Poster Award" at the Haptics Symposium 2012.

Tom Vose was a finalist for best student paper at the 2010 International Conference on Robotics and Automation.

Aaron Greco, **Anthony Martini**, and **Yu Liu**, along with Chih Lin and Prof. Q. J. Wang, won the "2010 Best Paper Award" by the STLE Surface Engineering Technical Committee (SETC).

Hiding Objects with a Terahertz Invisibility Cloak

"This demonstrates that we have the freedom to design materials that can change the refraction index. By doing this we can manipulate light propagation much more effectively."

Professor Cheng Sun

Researchers at Northwestern University have created a new kind of cloaking material that can render objects invisible in the terahertz range. Though this design can't translate into an invisibility cloak for the visible spectrum, it could have implications in diagnostics, security, and communication.

The cloak, designed by Cheng Sun, assistant professor of mechanical engineering, uses microfabricated gradient-index materials to manipulate the reflection and refraction of light.

Sun's research was published Sept. 1 in *Scientific Reports*, a new online, open-source journal that provides rapid publication and high visibility of research for all areas of science.

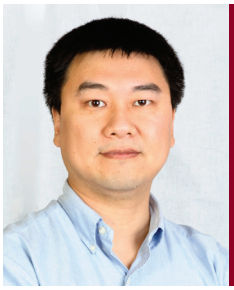
Humans generally recognize objects through two features: their shape and color. To render an object invisible, one must be able to manipulate light so that it will neither scatter at an object's surface nor be absorbed or reflected by it (the process which gives objects color).

In order to manipulate light in the terahertz frequency, which lies between infrared and microwaves, Sun and his group developed metamaterials: materials that are designed at the atomic level. Sun's tiny, prism-shaped cloaking structure, less than 10 millimeters long, was created using a technique called electronic transfer microstereolithography, where researchers use a data projector to project an image on a liquid polymer, then use light to transform the liquid layer into a thin solid layer. Each of the prism's 220 layers has tiny holes that are much smaller than terahertz wavelengths, which means they can vary the refraction index of the light and render invisible anything located beneath a bump on the prism's bottom surface; the light then appears to be reflected by a flat surface.

Sun says the purpose of the cloak is not to hide items but to get a better understanding of how to design materials that can manipulate light propagation.

"This demonstrates that we have the freedom to design materials that can change the refraction index," Sun said. "By doing this we can manipulate light propagation much more effectively."

The terahertz range has been historically ignored because the frequency is too high for electronics. But many organic compounds have a resonant frequency at the terahertz level, which means they could potentially be identified using a terahertz scanner.



Professor Cheng Sun

Sun's research into terahertz optics could have implications in biomedical research (safer detection of certain kinds of cancers) and security (using terahertz scanners at airports). Next Sun hopes to use what he's learned through the cloak to create its opposite: a terahertz lens. He has no immediate plans to extend his invisibility cloak to visible frequencies.

"That is still far away," he said. "We're focusing on one frequency range, and such a cloak would have to work across the entire spectrum."

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