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Massachusetts Institute of Technology

MechEConnects

News from the MIT
Department of Mechanical Engineering

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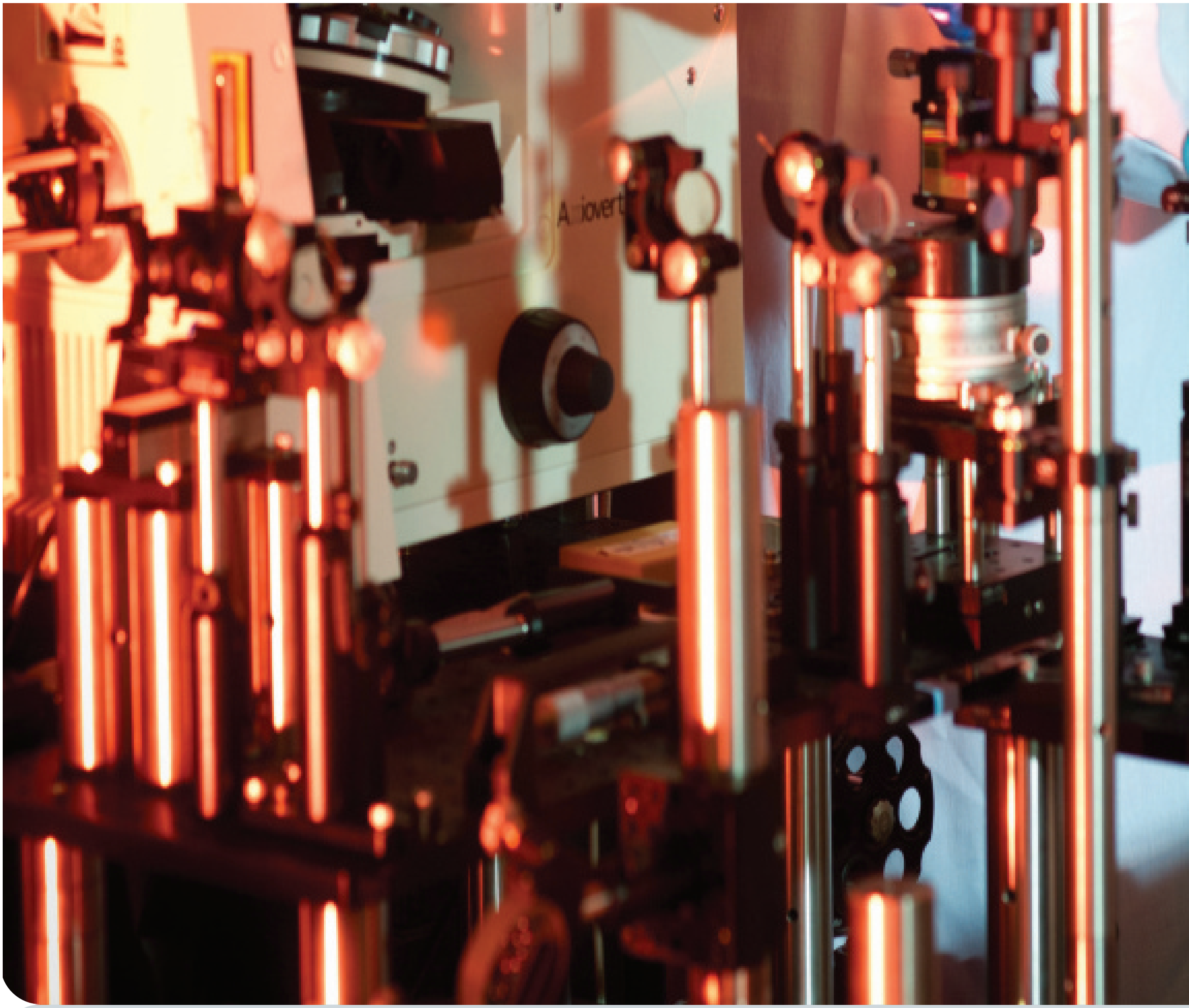

Bioengineering: A Mechanical Engineering Crossroads

MechE continues its tradition of pushing boundaries and discovering new frontiers in bioengineering

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Innovation at the Interfaces

Dear Friends,

Education and research innovations in mechanical engineering are increasingly occurring at the interfaces of our disciplines. This is true not only within our department but also between MechE and other broad disciplines, such as materials science, chemistry, and electrical engineering. This issue of *MechE Connects* focuses on the exciting advances being made in bioengineering — the interface between mechanical engineering and biology.

The MIT Department of Mechanical Engineering was at the vanguard of bioengineering research before it was even recognized as an academic field. In the 1960s Robert Mann developed the first EMG-controlled prosthetic arm, and Ascher Shapiro and C. Forbes Dewey produced remarkable breakthroughs in the understanding and treatment of cardiovascular disease. In the 1970s Ioannis V. Yannas developed the first artificial skin.

Today we continue to bridge the boundaries between biology and mechanical engineering. Research continues not only in the medical sphere, where you will read about advances in bioinstrumentation and biomedical devices, but also in bio-inspired design, where we look to snails and cheetahs for mechanical solutions, and in the emerging field of biomolecular and cellular control systems.

In this issue, we showcase the immense impact our faculty research has had on human health and comfort, consumer empowerment, and fundamental biological understanding. We recognize the lifetime achievement of two incredible bioengineers in our department, Professor Ioannis V. Yannas and C. Forbes Dewey Jr, and highlight current faculty members who are defining new frontiers in biology and inventing life-changing technologies.

For more information on our faculty's areas of research focus, I invite you to visit our interactive faculty grid at http://meche.mit.edu/people/cloud.

Thank you, as always, for your continued support of the Department of Mechanical Engineering.

Sincerely,

Mary C Boyce

Mary C. Boyce, Ford Professor of Engineering and Department Head

Massachusetts Institute of Technology

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News from the MIT
Department of Mechanical Engineering

► mecheconnects.mit.edu

About MechE

Mechanical engineering was one of the original courses of study offered when classes began at the Massachusetts Institute of Technology in 1865. Today, the Department of Mechanical Engineering (MechE) comprises seven principal research areas:

- **Mechanics: modeling, experimentation, and computation**
- **Design, manufacturing, and product development**
- **Controls, instrumentation, and robotics**
- **Energy science and engineering**
- **Ocean science and engineering**
- **Bioengineering**
- **Nano/micro science and technology**

Each of these disciplines encompasses several laboratories and academic programs that foster modeling, analysis, computation, and experimentation. MechE educational programs remain leading-edge by providing in-depth instruction in engineering principles and unparalleled opportunities for students to apply their knowledge.

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ON THE COVER: A high-throughput/high-content 3D imaging bioinstrument developed by the So BioInstrumentation Lab, led by Professor Peter So, is featured on this issue's cover. Photo by Tony Pulsone.

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Bioengineering: A Mechanical Engineering Crossroads

by Alissa Mallinson

MIT's Department of Mechanical Engineering has been at the forefront of cutting-edge bioengineering since before its inception, with renowned MIT MechE faculty members like Ioannis V. Yannas developing the first artificial skin, Robert Mann creating the first EMG-controlled prosthetic arm, and Ascher Shapiro and C. Forbes Dewey Jr. uncovering the mysteries of cardiovascular disease.

A short 40 years later, many groundbreaking discoveries have been made that moved the field forward by leaps and bounds – levels of fundamental understanding and technological advancements that could barely have been imagined when MechE first began research activities in bioengineering. Professor Roger Kamm has developed *in vitro* microfluidic devices into a class of their own, advancing the understanding of cancer metastasis and paving the way for life-changing drug delivery. Associate Professor Anette "Peko" Hosoi and Assistant Professor Amos Winter have created robots that burrow and anchor in the ocean inspired by the natural burrowing of clams, and Professor Harry Asada has developed light-activated artificial muscles for robotic movement. Professor Peter So has developed super microscopes that allow 3D single-cell visualizations of *ex vivo* animal organs, and Associate Professor Domitilla Del Vecchio is designing feedback controllers in cells to realize biological operational amplifiers.

Bioengineering is a field with tremendous opportunities for impacting human health. It is rich with mystery and possibility, and has opened the flood gates for exploration and exploitation, for engineers in particular, who are now applying biological principles to mechanical design and, conversely, mechanical engineering principles to the understanding of biology, advancing both fields dramatically in the process. "Engineers reveal nature's principles by building," says Professor Ian W. Hunter. "The act of building forces you to pose questions you might not have asked yourself otherwise, and bioengineering is no exception."

Our faculty are focused on multiple facets of bioengineering, including bio-inspired design, bioinstrumentation, biomedical devices, and biomolecular systems and control. Major new trends continue to arise from and influence their research, such as bio-integrated engineering and consumer empowerment.

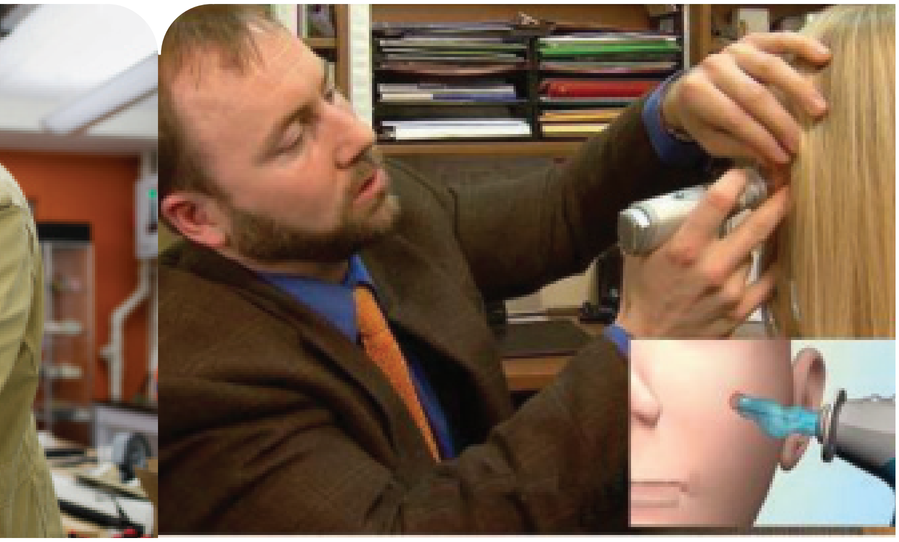
Assistant Professor Sangbae Kim works on his lab's current bio-inspired project, the robotic cheetah.

Bio-inspired Design

Although recently coined as "bio-inspired design," the idea of applying nature's refined designs to man-made creations is one that can be traced back to the time of Leonardo da Vinci, whose observations of biology informed much of his work. Several noteworthy inventions were created in much this same way: the airplane, from studying the flight of winged animals, and Velcro, from noticing burrs attached to dog hair, to name two well-known examples.

These days, that same principle is being used to design more efficient, flexible robots, such as Professor Sangbae Kim's robotic cheetah or Professor Hosoi's robotic snail.

"Technology maturity has reached a certain threshold at this point that encourages people to apply the principles we learn from animals and nature," says Kim.



An audiologist demonstrates the Lantos Scanner, developed by Professor Douglas Hart and commercialzed by his company Lantos Technologies.

"We're not copying biological systems," adds Hosoi, "but rather understanding their physical principles and applying those to engineering design."

As the field of bio-inspired design progresses, a new field of synthetic biology is unfolding alongside it. "Synthetic biology – such as producing methanol from something like switch grass – would be a great way to produce drugs," says Dewey, "because it's very efficient and reproducible."

That, in turn, leads to even further development. Professor Kamm explains:

"Through recent advances in regenerative medicine and synthetic biology, the possibility of creating multicellular biological machines has come onto the horizon. Our vision is that these fully biological, cell-based systems will someday function side-by-side with traditional machines created from inert materials, opening up an exciting new opportunity in which biological and inert materials function together seamlessly to perform their designed function."

According to Kamm, one example of this new field, termed bio-integrated engineering, would be the ability to produce "hyper-organs." Consider an ultra-sensitive nose that "smells," then feeds the information it gathers via a network of neurons to a conventional CPU that analyzes it (see page 16 to read more about bio-integrated engineering).

Bioinstrumentation

Professor Hunter and Dr. Brian Hemond's micro mass spectrometer is representative of another upcoming bioengineering trend: consumer empowerment. "People are getting tired of relying on experts for everything," says Hunter. "They want to empower themselves with the ability to measure things on their own. In the past, people would have their blood pressure measured at a doctor's office, but now there's no reason you can't do this at home. But what else would people like to measure? You could have portable diagnostic devices in the home that would analyze blood samples, or you could even look through the tissue to analyze blood, ultimately bringing the instrument to the specimen instead of the other way around. I see the miniaturization of advanced diagnostic instruments as an important trend of the future."

An inextricable part of that trend is lowering the cost of manufacturing, as well as incorporating ways of analyzing the data, he says.

On the flip side of consumer empowerment is expert empowerment, another trend that bioinstrumentation has a big hand in developing. Scientists and medical doctors also need smaller, more precise instruments to get the job done. They need to get closer, less invasively, and more easily if they are to continue necessary progress. To this end, Professor So has exploited advances in photonics to develop game-changing high-throughput/high-content 3D imaging bioinstrumentation.

Professor Slocum teaches the hands-on Course 2.75, focused on developing biomedical devices in partnership with Boston-area clinicians.

"Basic biology is important," says So, "and advanced technology enables the study of something much more basic than you could study before. If you have a better understanding of basic biology, you can make positive contributions to human health, food production, environmental protection, and other important sociological problems that are biological in origin."

Biomedical Devices

In the biomedical device field, lowering costs is a concern as well. As high health care costs continue to rise, people will continue to look for cheaper, faster, and more accurate health care.

"There's going to be this large push for people to look for ways to cut health care costs, and you'll see medical devices actually boom because of that," predicts Professor Douglas Hart. "If we can make diagnostics more accurate, easier, and cheaper, then why wouldn't we?"

But it's not just diagnostics that benefit from improved devices. Quality of life could be an area of significant improvement as well. Advanced surgical devices (such as the flexural laparoscopic grasper designed by MechE students), for example, can cut down on surgery and recovery time as well as decrease likelihood of infection and speed up wound healing time (see Alumni Spotlight on Danielle Zurovcik PhD '12 on page 21), or monitor patient vitals in the comfort of their own home (exemplified by the Sombus Sleep Shirt developed by Rest Devices, a medical device company started by three MechE students in Professor Alex Slocum's 2.75 course).

On the research side, 3D *in vitro* microfluidic devices, such as those first developed in the laboratory of Professor Kamm, are helping our faculty discover effective ways of preventing the spread of disease – for example, cancer metastasis in Professor Kamm's case – and enabling engineers to unveil new methods of drug delivery – for example, through leaky endothelial vessels (see Faculty Research, page 14).

> **"Basic biology is important, and advanced technology enables the study of something much more basic than you could study before."**
>
> **-Professor Peter So**

Biomolecular Control Systems

Biomolecular control systems may not be officially labeled as "biomedical," but their potential for controlling cells is quickly being recognized as a crucial element of solving several societal problems, including energy and health care. Through biological control systems, engineers are able to use and develop control theory to craft modular designs of biomolecular circuits that can be inserted into living cells to control their behavior.

"The ability to control cell behavior," explains Associate Professor Del Vecchio, "has set the stage for groundbreaking applications ranging from biofuels and biosensing to molecular computing and targeted drug delivery. We envision a near future in which programmable cells will transform waste into energy and kill cancer cells in the bloodstream."

Biomolecular circuitry is limited by its size and complexity, and for

Associate Professor Domitilla Del Vecchio conducts research on biomolecular control systems in her lab.

the most part current research is focused on establishing design principles to overcome these limitations and enable larger, more complex circuits.

Some mechanical engineers such as Professor Jean-Jacques Slotine are utilizing mathematical principles and abstract control theory to identify the characteristics of a network that would make it more or less easy to control, and determine which nodes and locations in the network need to be controlled to make it all work.

The Sum of its Parts

"We were scratching the surface of bioengineering for a long time with something slightly beyond taxonomy," says Dewey. "Obviously some brilliant things have already come along, but as we learn more and more, new opportunities continue to arise. The detective work to get through that is daunting, but once you get there, the question is, 'how do you use it?'"

The answer must include extensive cross-disciplinary collaboration to fulfill its potential. The best solutions and discoveries utilize and integrate the many facets of mechanical engineering: mechanics, manufacturing, design and prototyping, nanotechnology, computation, robotics, and controls. As is often the case with mechanical engineering, it's the sum of its parts, working together, that will change lives for the better.

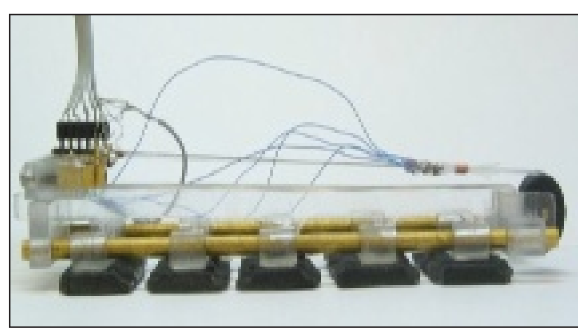
****

Professor Anette Hosoi

Taking their lead from nature, MechE faculty members like Professor Peko Hosoi and her team are developing significantly improved robotic devices to tackle modern challenges. With a background in physics and fluid mechanics, Hosoi gets her inspiration from lower-level organisms. "There are a couple of key things we look for," she says. "Simplicity, a system grounded in mechanics, and significantly better performance than can already be achieved in engineered systems."

With that in mind, she led her research team in an effort to create the most versatile crawler and landed upon the snail – "nature's ultimate all-terrain vehicle," as she calls it. Upon further investigation, they found that when a snail crawls, a trail of slime is left behind that allows it to climb up almost anything. This yield-stress fluid is in a solid-like state during the climb, sticking snails to the wall like glue, but when they start to shear it with the bottom of their foot, it begins to flow like a liquid. "But if you only have one foot and you are sitting on a layer of glue, how do you move?" asked Hosoi. "The answer isn't obvious."

The Hosoi team discovered that snails' muscles contract to create a wave of compression along the bottom of the foot, and invented a way to utilize this naturally occurring technique to design a highly advanced crawler. In their design, a non-Newtonian fluid reacts with two solid pads on the main body – one consisting of a series of small pads that act as one large pad, and a single smaller pad. The difference in force based on varying sizes breaks the symmetry and allows



Professor Hosoi's RoboSnail

one pad to stick and the other pad to slide, thus moving the RoboSnail forward.

The Hosoi team's invention is currently being used in the oil industry as a way to move instruments along pipes in "down-hole environments"; however, RoboSnail can be useful on any terrain.

Professor Sangbae Kim

Assistant Professor Sangbae Kim is also inspired by nature's ideal solutions. He and his team have been building a robotic cheetah in their lab and recently completed the design and prototype of a robotic earthworm. Like Hosoi, they aren't interested in unraveling the mystery of intelligence but rather in understanding the mobility of accomplished animals and borrowing their successful characteristics to create advanced mobility in robots.

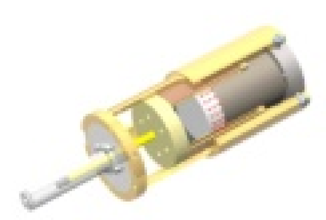
"Our core motivation is to understand how biological systems are designed," says Kim. "People make a lot of assumptions about what animals are designed and optimized for. We're fascinated by that – people think it's the ideal design, but we're not sure. Our research is centered around the idea of testing and proving those hypotheses, and using those findings to form the basis for a new perspective."

The team's newest perspective came from analyzing a simple earthworm. Similar to the Robosnail's wave of contractions, the earthworm also moves forward by squeezing and stretching its muscles, a mechanism called peristalsis. Kim's resulting Meshworm is made of an artificial muscle constructed from nickel and titanium wire that stretches and contracts multiple segments of its body using heat from a small current. Kim and his team developed algorithms to carefully control the wire's heating and cooling, directing the worm's movement.

Professor Ian Hunter

When Professor Ian Hunter initially had the idea for a needleless jet injector that could provide various dose amounts of differing drugs at multiple depths, he doubted if it would even be possible. But years later, the injector, uniquely controlled by a Lorentz-force actuator, is an elegant and easy option for otherwise difficult drug delivery. Needleless injection isn't a new idea, but Hunter's creativity, combined with the vision and expertise of his team – Dr. Cathy Hogan, Dr. Andrew Taberner, and recent PhD graduates Dr. Brian Hemond and Dr. Adam Wahab – has hoisted it to a new level. The team is the first to use a lab-made Lorentz-force actuator to control velocity, volume, and pressure to deliver drugs at a rate equivalent to the speed of sound in air. It can deliver drugs superficially into skin, deep into muscle, through the eye into the retina, through the tempanic membrane into the middle ear, and even into interstitial fluid. The device – which, at 10 to 20 milliseconds per dose (anywhere from 105 micro liters to 500 micro liters), is speedy and almost silent – can also utilize its wide bandwidth to vibrate drugs in solid powder form to create a fluidized drug, thus solving the cold chain problem of delivering refrigerated liquid vaccines to third world countries. Receiving the 10 to 100 Joules needed to power a single-dose delivery from a small lithium polymer battery, the device is also bidirectional, allowing for the option of sucking biomaterials out of the body – including DNA and proteins. The injector uses a 32-bit microcontroller for controlling its operation and a digital nonlinear feedback control system running at up to 100,000 samples per second. The newest version of Hunter's injector includes a double Halbach magnet array designed by recent PhD graduate Dr. Brian Ruddy. It is expected to deliver a dose of drugs with a precision of less than one microliter.

Professor Hunter's needleless injector (see page 30)



Professor Peter So

The question of what differentiates alternate paths of diseases, or why one type of biomaterial more successfully regenerates tissue than another is directed by many cellular and molecular factors that are very difficult to decipher.

Professor Peter So's team is getting to the answers by mapping tissue morphological structures and biochemical organizations of small animal organs with subcellular resolution. The high-throughput/high-content 3D imaging bioinstrumentation they developed as a result of this focus is based on high-speed multi-photon microscopy that enables them to study tissue structures that span five orders of magnitude in scale.

Instead of exciting fluorescence using a single blue photon, So's team uses a lower-energy infrared light to ensure that the probability of photointeraction is limited to a volume on the order of one femtoliter. Outside of this spot, the photon flux is lower and there is no excitation, thus providing unique 3D resolution.

Professor Douglas Hart

Professor Douglas Hart's development of the first 3D ear canal scanner for making perfect-fit hearing aids was actually the result of a happy accident in an auto shop. While measuring oil-film thickness and temperature in seals on the cylinder wall of engines, one of Hart's students ran into a problem: He couldn't get the oil thickness out of the equations. Instead of getting frustrated, Hart took advantage of the problem. "We started realizing that if we could measure the thickness of the liquid that we could also get a 3D image of it," says Hart.

Post-doc Christopher Rowland does work in the So Bioinstrumentation Lab.

Mechanical engineers are applying biological principles to mechanical design and, conversely, mechanical engineering principles to the understanding of biology.

Currently the only 3D ear canal scanner available, the portable Lantos Scanner provides safe, comfortable and fast mapping of the ear canal for perfect hearing aid fits, as well as custom ear plugs and internal headphones.

The soft membrane at the end of the scanner has a visible odoscope tip that is guided deep into the ear canal by a video feed. Once inserted the membrane is filled with a water-based optical dye, expanding the membrane until it conforms perfectly to the patient's unique inner ear. Using a dual wave-length algorithm, the scanner takes thousands of 2D digital images as it exits the ear and stitches them together in real time to create a highly accurate 3D image of the ear.

The scanner can even measure canal wall elasticity by varying the pressure inside the membrane and recording the results. An on-site laptop computer processes all the data and sends it directly to the manufacturer.

"Ears are very small and don't have texture to them, so you can't use stereoscopic imaging to get images of them, nor structured light systems because of skin translucency," explains Hart. "People have tried interferometry and other similar ideas, but that's too sensitive and expensive. What we have designed is one of a kind, utilizing color absorption ratios to determine distance."

Because of the scanner's incredible accuracy, not only can it notably improve patient comfort and hearing aid quality, but it also significantly cuts down on manufacturing cost by eliminating the need to remake hearing aids that weren't fitted correctly the first time.

Professor Alexander Slocum

Professor Alexander Slocum has been guiding senior undergraduates as well as graduate students interested in biomedical device design since 2004, when he founded Course 2.75 upon the famous MIT credo *mens et manus* ("mind and hand"). The 14-week course is focused on biomedical device design projects that match teams of students with Boston-area clinicians. Each team of three to five students works on a real problem, from brainstorming and designing a proof-of-concept device, to building and testing a prototype – all along the way constantly challenged by Slocum to identify risks and viable countermeasures to the design and its production.

One look at the list of devices and start-up companies that have spun off from the work done by 2.75 students, and it's easy to see that Slocum's hands-on approach to the course works. For example, Robopsy, a robotic device to assist radiologists during percutaneous tumor biopsies, won the 2007 $100K Entrepreneurship Competition and the first-place award at the 2008 ASME Innovation Showcase. In 2011, the Somnus™ Sleep Shirt, which monitors patient respiration at home, won a prize at the prestigious Three-in-Five Competition at the Design of Medical Devices Conference. Upon graduation, the shirt's creators formed Rest Devices (www.restdevices.com) to commercialize their technology and secured $500,000 in angel financing. Following both a clinical and a consumer path, they are simultaneously developing the Somnus sleep monitoring shirt as an alternative to in-hospital sleep studies while preparing to launch an infant monitoring onesie. Several other devices from the class have been licensed and are expected to be in production soon.

Slocum's former TA for the class, Dr. Nevan Hanumara, is now a post-doc in his lab, working to expand the course and create an industry outreach program that gets more of the course's products into production.

Professor Domitilla Del Vecchio

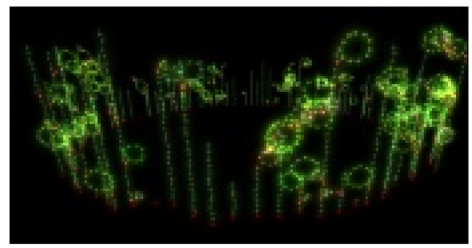
The term "network" has become a standard metaphor for describing the system of arteries and synapases and other areas of flow and synergy in the body, but there's another, less common image that illustrates the connectivity perhaps even better: circuitry. As with electrical circuits, you get effects similar to impedance called "retroactivity," says Professor Domitilla Del Vecchio, who was one of the first to apply control theory ideas to biomolecular design systems that are impervious to such impedance.

"The main problem is how one can use the specific mechanism you have in biological systems to modify or create new control techniques that are useful in this new domain," says Del Vecchio.

Del Vecchio's team is currently focused on the development of biomolecular feedback circuits that are robust to retroactivity and function like operational amplifiers in electronics. "Biological components are already there," says Del Vecchio, "so our focus is on making the ensemble of these parts suitable for modular design, which will enable the creation of complex new functionalities."

Professor Jean-Jacques Slotine

One area of Professor Jean-Jacques Slotine's focus is the theory of biological control systems. He's researching ways to control and exploit synchronization mechanisms in neurons and cells, and utilizing mathematical principles to answer the question of which nodes and locales in a biological circuit network need to be controlled to gain control of the entire network. Now that biological models are precise enough to be controlled, says Slotine, we can begin to develop circuit diagrams and dynamical systems that might be able to do the job of controlling the large, nonlinear, and complex networks that exist in biology.



His recent work with colleagues points toward the origin and characteristics of a network that would allow for easy control. He has discovered that there are specific characteristics that make a biological network easy or difficult to control, and that more connections equate to greater control of the network as a whole.

Although his work is very theoretical at this stage, Slotine suspects that such fundamental knowledge about how to control biological networks could be very useful in the future for drug delivery and synthetic biology.

Faculty Spotlight: Professor Ioannis V. Yannas

A Lifetime of Biomaterials Engineering Achievement

by Alissa Mallinson

In 1969, Professor Ioannis V. Yannas was an expert on fibers and polymers at MIT when Dr. John F. Burke approached him with a request for help. A surgeon, Burke had made significant strides in burn treatment but was still missing a piece of the puzzle.

"He wanted something to keep the bacteria out," said Yannas, "and keep the moisture in."

Human skin and pig skin, which were often used in burn treatments, were commonly rejected by the body's immune system, and the immune suppressants given to patients left them vulnerable to infection. The other obstacle was dehydration. No one had yet found a way of building skin that could absorb and maintain moisture.

With a bachelor's degree in chemistry from Harvard College, a master's degree in chemical engineering from MIT, a second master's degree in physical chemistry from Princeton University, and a PhD in physical chemistry from Princeton, Yannas was a good choice to help Burke with his mission.

Weaving together their collective expertise in engineered polymers and biology, the two teamed up to create the first artificial skin.

But getting there wasn't easy. The skin's delicate intricacies were difficult to replicate, and the recipe for success was incredibly specific. A patient's real skin couldn't regenerate if the artificial skin's pores weren't between 20 and 120 millionths of a meter, for example. It also had to naturally degrade in a specific time frame – too long and it would block growth of new skin; too short and the new skin wouldn't have enough time to fully regrow.

As it turned out, Yannas's skin did more than just block infection and retain moisture – it actually helped to regenerate the skin. The trick was adding a synthetic layer of silicone on top of a layer of organic "scaffolding" – a combination of molecular material from cow tendons and shark cartilage. The synthetic layer protects the skin from bacteria and infection and keeps the moisture in, while the organic layer acts as a cornerstone on which new healthy skin cells can grow.

The artificial skin was a lifesaver for many patients – not just those fighting significant burns, but those with chronic skin problems too, such as diabetics who have wounds that won't heal due to poor circulation.

Since then Yannas has built on his regenerative breakthroughs, applying some of the principles he discovered in the process of developing artificial skin to other areas of medicine as well, such as tissue, cartilage, bone, and nerve regrowth.

Harvard Medical School Professor Myron Spector, a close collaborator of Yannas for more than 20 years and an expert in biomaterials and tissue engineering, says, "In addition to resulting in a highly successful treatment for a broad spectrum of skin injuries and diseases, which alone would have been a life's achievement, the research that Yanni has conducted over the past three decades in developing a collagen-based regeneration template has led to many significant advancements. He has proved the validity of certain principles guiding regeneration and has provided a groundbreaking model for medical device development and what is now termed 'translational research.'"

Yannas's regeneration principles and the collagen scaffolding he invented have spawned at least four start-ups founded by prior students, postdoctoral fellows, and residents, with products to treat defects in the meniscus of the knee, articular cartilage, bone, and the eye.

Professor Ioannis V. Yannas is a member of the National Academy of Sciences (Institute of Medicine) and the Association for the Advancement of Science, a founding fellow of the American Institute of Medical and Biological Engineering, and a charter member of the Biomedical Engineering Society, among others. He has won numerous awards, including the Doolittle Award of the American Chemical Society and the Clemson Award for Applied Science and Engineering from the Society of Biomaterials.

A Customizable Curriculum

The 2-A Flexible Degree Program Offers In-Depth Undergraduate Study

by Alissa Mallinson

As is often the case, the MIT Department of Mechanical Engineering is leading the way. This time, it's in the area of undergraduate education, with the newly revamped flexible degree program 2-A.

One of the first mechanical engineering programs in the world to offer a customizable curriculum alongside a rigorous core in mechanical engineering and the ability to concentrate in one of several modern engineering areas, the Department's 2-A program is garnering a lot of attention in the US and around the world.

"The key is hitting the right balance between rigor and flexibility," says Undergraduate Education Officer Professor Anette "Peko" Hosoi. "Once 2-A became accredited in 2002, students knew they'd be getting the same engineering rigor they would get in Course 2, as well as the freedom to focus on topics that are specifically interesting to them, like energy or robotics or manufacturing. So I think it's that particular combination that's appealing to the students."

Since 2002, enrollment in the program has increased 10-fold to the point where 45% of mechanical engineering majors are currently enrolled in 2-A. Meanwhile, Course 2 enrollment remains steady, indicating a growing interest in mechanical engineering more broadly.

The Mechanical Engineering core requirements for both degree programs are exactly the same in the sophomore year; then changes start to occur in the junior year, when Course 2 students are required to take four specific courses, but Course 2-A students only two, allowing them to begin honing in on an area of focus for their remaining third-year credits. From there, Course 2-A students are given the flexibility to take 6 12-credit upper-level courses in a concentration area they choose in conjunction with the Course 2-A advisor.

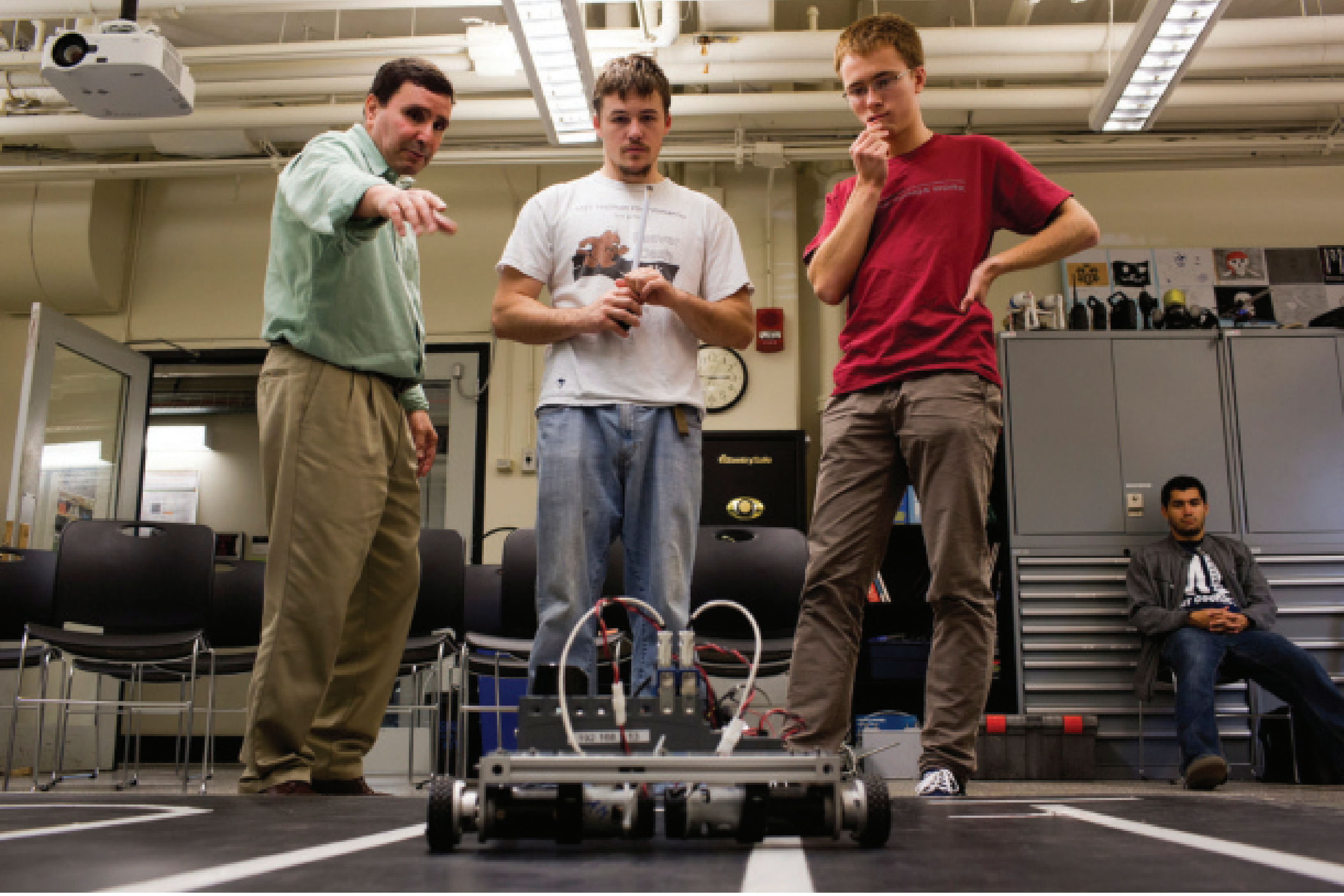
Students love the choice, especially those who go into it with a very targeted career plan – they know they want to go into the energy or robotics field when they graduate, for example. They can focus in on what they're most interested in, which is often difficult to do in a traditional accredited engineering program.

Choices, Choices

Based on the numbers, what are students choosing? With more than 20% of 2-A students concentrating in robotics, the area of Control, Instrumentation, & Robotics is currently the clear winner.

However, Management and Product Development aren't far behind, with 15% to 20% of students focused in

> "This program shows that you can provide an extrememly rigorous engineering education while still adapting to modern engineering themes."
>
> -Professor Hosoi



Professor Youcef-Toumi directs students in one of MechE's robotics courses, Course 2.12 Introduction to Robotics.

each of those areas. Data also shows that Manufacturing, Biomedical, Industrial Design, Entrepreneurship, and Transportation are all on students' radar.

To make it even easier to concentrate on a particular mechanical engineering area, this year the program has implemented even more flexibility. Instead of offering 6 12-credit core courses, students can now build a core from 13 different options, three of which are traditional 12-credit courses, and 10 of which are 6-credit course modules.

But are they getting a less thorough understanding of the material?

No, says Hosoi. "I think the students in 2-A are actually getting a more in-depth education," she says. "Normally if someone is interested in robotics, for example, they have very little space in their schedule to squeeze the electives in. But now students can put together a substantial group of classes that allows them to focus on their field of interest. Robotics is a great example because, in addition to the Course 2 electives, they can also take upper-level classes in Course 6 (Electrical Engineering and Computer Science).

"It's a very important program," says Hosoi, "because it shows that you can provide an extremely rigorous accredited engineering education while still adapting to the modern themes that are emerging in real engineering jobs."

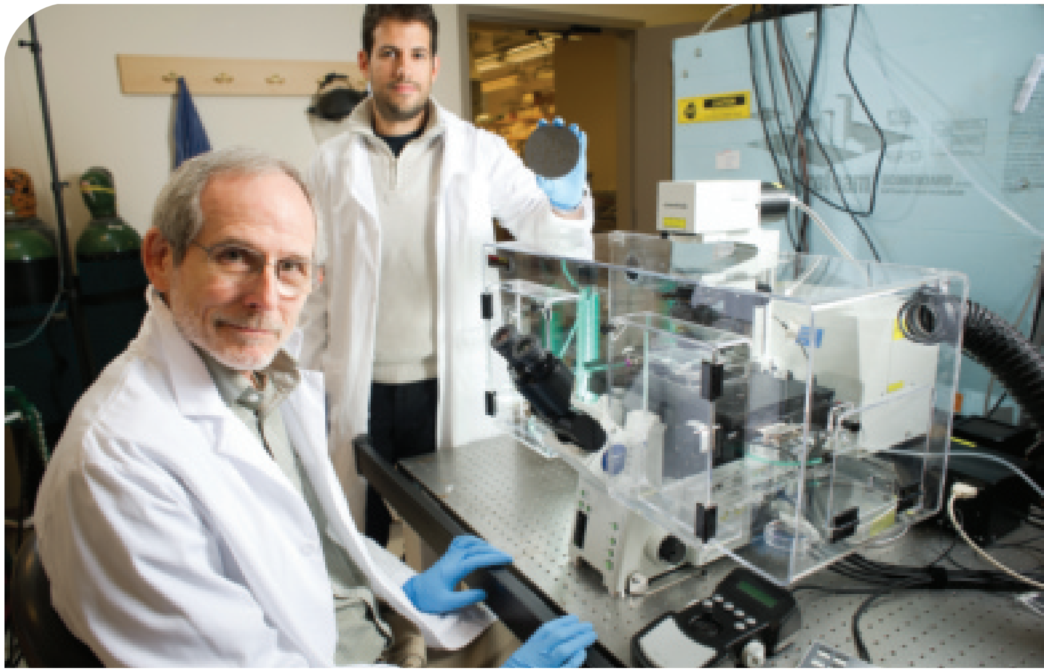
"The key is hitting the right balance between rigor and flexibility."

Faculty Research: Visualizing Sneaky Tumor Cells

3D *in Vitro* Microfluidic Devices Allow Never-Before-Seen Tumor Cell Movement

by Alissa Mallinson

Not many people have watched as a single tumor cell sneaks its way through a blood vessel wall and out the other side.



But Roger Kamm, the Cecil and Ida Green Distinguished Professor of Biological and Mechanical Engineering, and his doctoral student Ioannis Zervantonakis are two of the few who have. They are studying the mechanics of metastasis, the process of cancer cell migration from one location in the body to another and the cause of more than 90% of cancer deaths.

Professor Kamm has studied several aspects of metastasis over a period of several years using a 3D *in vitro* microfluidic device developed in his lab, including a recent study on the effect of flow on tumor cell migration. This time, the team used a device designed and developed by Zervantonakis to look at the importance of signaling between tumor cells and macrophages, a type of white blood cell with a versatile role in the immune system. They found that when macrophages are absent, it is extremely rare for tumor cells to migrate across the cell layer that lines the blood vessels (a process called intravasation), but, conversely, when they are present, the rate of entry increases significantly.

"It's very exciting to have developed one of the first systems to image this process in real time and be able to characterize transport across the endothelial barrier," says Zervantonakis. "Previous designs in our group allowed for endothelial cell and tumor cell cultures, but because intravasation is so rare — only about 5% of cells achieve it — it was hard to capture it in the two to four regions we had. So I designed a new device that would allow us to observe at least 200 cells, using 40 regions of observation."

Zervantonakis also included in his design the ability to measure permeability while quantifying tumor cell invasion by using fluorescently labeled proteins and incorporating a y-junction to balance the fluid flow. Combined with the significant increase in number of regions and the integration of the gel matrix that enables 3D culture, Kamm and Zervantonakis studied tumor cell intravasation as no one has ever done before.

This unprecedented ability to visualize intravasation confirmed several theories about the intricate mechanics taking place – which they published this year in the journal *Proceedings of the National Academy of Sciences.**

First, Kamm and Zervantonakis confirmed the importance of the presence of bacteria-fighting macrophages. Because a lonely few tumor cells can cross through the endothelium even without the help of macrophages, the duo determined that their presence wasn't essential; but they identified a strong positive correlation.

Second, they detected cell-to-cell communication between both invasive tumor cells and normally protective macrophages, and, subsequently, between traitor macrophages and the blood vessel. The result is increased leakiness of the vessels and tumor cells that can enter them.

Additional experiments – which involved replacing macrophages with a tumor necrosis factor called TNF-α, which is known to increase vessel leakiness – helped to determine the mechanisms more specifically and confirm a causal relationship. By performing these control experiments, they determined that macrophages alone were instrumental in increasing the blood vessel diffusive permeability and were at least causal in an increase in the migration of the tumor cells, if not the primary trigger.

“Experiments that included macrophages alone and then only TNF-α – a factor that macrophages secrete – both resulted in increased intravasation,” says Zervantonakis. “Because we have this method of measuring permeability in real time, we saw over the course of eight hours that the endothelium becomes leaky. We proved that when we make the endothelium leaky, more intravasation occurs. When we decrease the leakiness by blocking antibodies, less intravasation occurs.”

Kamm and Zervantonakis’s work provided support for the theory of John S. Condeelis, from the Albert Einstein Medical Center in New York, whose studies on mice had suggested that macrophages were important in this migration process. Being limited to live cell models only, Condeelis contacted Kamm after hearing news of his 3D *in vitro* microfluidic assay, which allows not only imaging of the cell movement but also the ability to consequently infer this crucial element of signaling between cells, something that no one had been able to incorporate into their *in vitro* assays. Unlike other systems, Kamm and Zervantonakis’s device enables them to visualize the cells at very precise locations within the system, even allowing them to discover that macrophages do not need to be in physical contact with the tumor cells but simply close enough to communicate with them.

“This is good news not only for the fundamental understanding of how metastasis occurs, but also because intact endothelial vessels block intravasation,” says Zervantonakis. “Although leaky vessels can be a positive thing when you want to distribute cancer-fighting drugs, tumor cells may utilize these same leaky vessels to enter the blood stream and travel to another part of the body. Additional studies are needed to investigate ways to target the role macrophages have in making blood vessels leaky.”

*I.K. Zervantonakis, S. K. Alford-Hughes, J. L. Charest, F. B. Gertler, J. C. Condeelis and R. D. Kamm (2012). “Three-dimensional microfluidic tumor-vascular interface model: Tumor cell intravasation and endothelial barrier function.” PNAS, 109 (34), 13515-13520]. *Read the published paper here: http://bit.ly/UkPzTk*

Student Snapshots

Faculty Research: Professor Harry Asada

Engineering Light-Activated Muscles

by Jennifer Chu, MIT News Office

Many robotic designs take nature as their muse: sticking to walls like geckos, swimming through water like tuna, sprinting across terrain like cheetahs.

Now, scientists at MIT and the University of Pennsylvania are taking more than inspiration from nature – they're taking ingredients. The group has genetically engineered muscle cells to flex in response to light, and is using the light-sensitive tissue to build highly articulated robots. This "bio-integrated" approach, as they call it, may one day enable robotic animals to move with the strength and flexibility of their living counterparts.

Harry Asada, the Ford Professor of Engineering in MIT's Department of Mechanical Engineering, says the group's design effectively blurs the boundary between nature and machines.

"With bio-inspired designs, biology is a metaphor, and robotics is the tool to make it happen," says Asada, who is a co-author on the paper. "With bio-integrated designs, biology provides the materials, not just the metaphor. This is a new direction we're pushing in biorobotics."

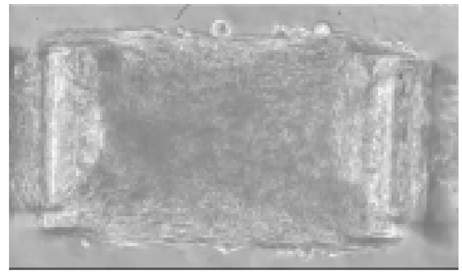
Seeing the light

Asada and MIT postdoc Mahmut Selman Sakar collaborated with Professor Roger Kamm to develop the new approach. In deciding which bodily tissue to use in their robotic design, the researchers set upon skeletal muscle – a stronger, more powerful tissue than cardiac or smooth muscle. But unlike cardiac tissue, which beats involuntarily, skeletal muscles – those involved in running, walking, and other physical motions – need external stimuli to flex.

Normally, neurons act to excite muscles, sending electrical impulses that cause a muscle to contract. In the lab, researchers have employed electrodes to stimulate muscle fibers with small amounts of current. But Asada says such a technique, while effective, is unwieldy. Moreover, he says, electrodes, along with their power supply, would likely bog down a small robot.

Instead, Asada and his colleagues looked to a relatively new field called optogenetics, invented in 2005 by MIT's Ed Boyden and Karl Deisseroth from Stanford University, who genetically modified neurons to respond to short laser pulses. Since then, researchers have used the technique to stimulate cardiac cells to twitch.

Asada's team looked for ways to do the same with skeletal muscle cells. The researchers cultured such cells,



or myoblasts, genetically modifying them to express a light-activated protein. The group fused myoblasts into long muscle fibers, then shone 20-millisecond pulses of blue light into the dish. They found that the genetically altered fibers responded in spatially specific ways: Small beams of light shone on just one fiber caused only that fiber to contract, while larger beams covering multiple fibers stimulated all those fibers to contract.

A light workout

The group is the first to successfully stimulate skeletal muscle using light, providing a new "wireless" way to control muscles. Going a step further, Asada grew muscle fibers with a mixture of hydrogel to form a 3D muscle tissue, and again stimulated the tissue with light – finding that the 3D muscle responded in much the same way as individual muscle fibers, bending and twisting in areas exposed to beams of light.

The researchers tested the strength of the engineered tissue using a small micromechanical chip – designed by Christopher Chen at UPenn –

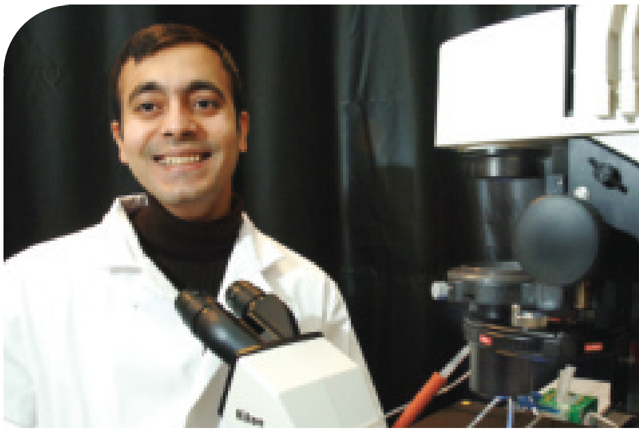
(continued on page 18...)

Find out more ► **Read the full MIT News article:** **http://bit.ly/SopT1y**

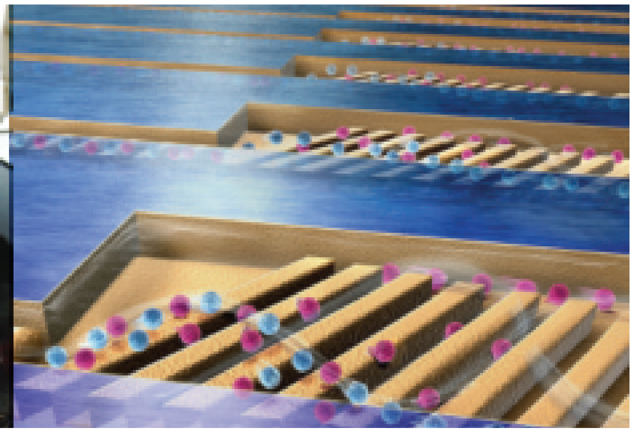
Faculty Research: Professor Rohit Karnik

In a New Microchip, Cells Separate by Rolling Away

by Jennifer Chu, MIT News Office



Associate Professor Rohit Karnik in his lab.



Karnik's new microfluidic device isolates target cells (in pink) from the rest of the flow by getting them to stick weakly to the device's ridges then roll through trenches and into a collection chamber.

Cell rolling is a common mechanism cells use to navigate through the body. During inflammation, for example, the endothelial cells that line blood vessels present certain molecules that attract white blood cells just enough to divert them from the rest of the vessel's cellular traffic. White blood cells then roll along the vessel wall, slowing down to help in the healing of inflamed areas.

Researchers at MIT and Brigham and Women's Hospital – including MIT Professor Rohit Karnik, postdoc Sung Young Choi of MIT, and Jeffrey Karp, Associate Professor at Harvard Medical School and co-director of the Center for Regenerative Therapeutics at Brigham and Women's – have now designed a cell-sorting microchip that takes advantage of this natural cell-rolling mechanism. The device takes in mixtures of cells, which flow through tiny channels coated with sticky molecules. Cells with specific receptors bind weakly to these molecules, rolling away from the rest of the flow and out into a separate receptacle.

The cell sorters, about the size of postage stamps, may be fabricated and stacked one on top of another to sift out many cells at once – an advantage for scientists who want to isolate large quantities of cells quickly.

"We're working on a disposable device where you wouldn't even need a syringe pump to drive the separation," says Rohit Karnik, Associate Professor of Mechanical Engineering at MIT. "You could potentially buy a $5 or $10 kit and get the cells sorted without needing any kind of [additional] instrument."

While current cell-sorting technologies separate large batches of cells quickly and efficiently, they have several limitations. Fluorescence-activated cell sorting, a widely used technique, requires lasers and voltage to sort cells based on their electric charge – a complex system requiring multiple parts. Researchers have also used fluorescent markers and magnetic beads that bind to desired cells, making them easy to spot and sift out. However, once collected, the cells need to be separated from the beads and markers – an added step that risks modifying the samples.

Going with the flow

Karnik's team designed a compact cell sorter that requires no additional

Find out more ► **Read the full MIT News article: http://bit.ly/woqWvg**

(...Asada, continued from page 16)

that contains multiple wells, each housing two flexible posts. The group attached muscle strips to each post, then stimulated the tissue with light. As the muscle contracts, it pulls the posts inward; because the stiffness of each post is known, the group can calculate the muscle's force using each post's bending angle.

The light-sensitive muscle tissue exhibits a wide range of motions, which may enable highly articulated, flexible robots. One potential robotic device may involve endoscopy, a procedure in which a camera is threaded through the body to illuminate tissue or organs. Asada says a robot made of light-sensitive muscle may be small and nimble enough to navigate tight spaces – even within the body's vasculature.

"We can put 10 degrees of freedom in a limited space, less than one millimeter," Asada says. "There's no actuator that can do that kind of job right now."

Another possible use may be in drug screening for motor-related diseases. Scientists may grow light-sensitive muscle strips in multiple wells, and monitor their reaction – and the force of their contractions – in response to various drugs.

Read the published paper here: http://rsc.li/UbM1Ak

(...Karnik, continued from page 17)

parts or steps. In concert with MIT's Robert Langer and others, the team built upon their 2007 work in which they first came up with the sorting-by-rolling principle. The initial proof-of-principle design was relatively simple: Cells were injected into a single inlet, which gave way to a large chamber coated on one side with sticky, roll-inducing molecules. The incoming cells flowed through the chamber; the cells that bound to the molecules rolled to one side, then out to a collection chamber.

However, the researchers found that in order to allow target cells to first settle on the chamber's surface, long channels were required, which would make the device too large. Instead, Choi came up with a surface pattern that causes cells to circulate within the chamber. The pattern comprises 10 parallel channels with 50 ridges and trenches, each ridge about 40 microns high. The researchers coated the ridges with P-selectin, a well-known molecule that promotes cell rolling. They then injected two kinds of leukemia cells: one with receptors for P-selectin, the other without.

They found that once injected, the cells entered the chamber and bounced across the top of the ridges, exiting the chip through an outlet. The cells with P-selectin receptors were "caught" by the sticky molecule and flipped into trenches that led to a separate receptacle. Through their experiments, the team successfully recovered the cells they intended to sift out with 96 percent purity.

Karnik says the device may be replicated and stacked to sort large batches of cells at relatively low cost. He and his colleagues are hoping to apply the device to sort other blood cells, as well as certain types of cancer cells for diagnostic applications and stem cells for therapeutic applications. In the future, Karnik envisions tailor-made cell rolling, designing molecules and surfaces that weakly adhere to any desired type of cell.

"It's really the ability to design molecules to separate cells of interest that will be powerful," Karnik says. "There's no reason to believe it cannot be done, because nature has already done it."

Read the published paper here: http://rsc.li/UkPpvd

Alumni Spotlight

Davide Marini, PhD '03; CEO and Cofounder, Firefly BioWorks

What was missing in the biomedical market that inspired you to cofound Firefly?

Many of the technologies currently available to life sciences researchers require dedicated instrumentation and consumables. As a consequence, scientists typically develop assays that are only usable on the platform on which they were designed. When I saw Daniel Pregibon (who at the time was finishing his PhD in the Department of Chemical Engineering, under the supervision of Professor Patrick Doyle) present the technology he had invented at a conference sponsored by the Deshpande Center, I was immediately captured by the elegance of the idea: a very flexible method for rapid micro-fabrication of hydrogel microparticles for biological analysis. We started Firefly BioWorks with a desire to offer scientists a completely open, flexible method for developing biological assays. The full potential of our technology became apparent after talking with several instrument manufacturers. It became clear that our products had the power to shift the complexity from the instrument to the consumable, allowing existing equipment to perform more sophisticated tasks than those for which it was designed.

Please describe your product suite.

Our core technology, Optical Liquid Stamping, allows rapid production of individually encoded hydrogel microparticles that can be easily bio-functionalized by embedding DNA, antibodies or other biologically relevant molecules within their matrix. We've designed our particles to be mixed with a biological sample to reveal the presence of specific biomarkers of interest. Our first product, FirePlex miRSelect™, is designed to detect microRNAs, an important class of biomarkers that regulate gene expression and has shown great potential for cancer diagnostics. The particles

in miRSelect™ are designed to be read on standard flow cytometers, so users don't need to purchase additional equipment to use our products. These hydrogel particles are more sensitive than existing microarrays and solid polystyrene beads, because they are made of a porous, flexible hydrogel that mimics aqueous conditions. Firefly particles allow for target molecules to diffuse into a 3D scaffold, increasing the number of target molecules that bind and therefore producing a more intense fluorescence signal. Furthermore, their porosity is precisely tuned to size-exclude certain species from the particle interior.

Where did the idea come from?

The idea came from a failed experiment. The inventor, Daniel Pregibon, was trying to develop a new method for coating a surface with a structured hyrodgel pattern. A change he made to the setting allowed individual patterns to float away after polymerization. After noticing this unexpected behavior and talking to his advisor Professor Doyle, they realized they had created an entirely novel combination of UV photolithography and microfluidics – a powerful new method for microfabrication.

How does your optical liquid stamping fill the void in the market?

Existing solutions for miRNA detection typically fall within two categories: either high-throughput/low-multiplexing, or high-multiplexing/low-throughput. But according to several opinion polls among scientists, there is a strong need for solutions allowing them to profile "100 targets over 100 samples in the same day." Our technology was designed to address exactly this need. Additionally, each one of our products is customized for a specific user. All you need to do is type the names of the miRNAs you wish to profile on our web site, and we will ship you a product built specifically for your purpose. We have also just launched a web-based method for automated product customization, based on relevance of microRNA targets as published in the scientific literature. As a startup, we can make decisions very rapidly and integrate a wide spectrum of technologies into our production work flow.

What are you most proud of?

Our team. This is by far the most important ingredient in a startup company. It is so important that investors typically assume the technology won't work, but that if the team is driven and resourceful enough, they will find their way out. We have established a culture of trust-based open conflict, where criticism is encouraged. We also do not tolerate arrogance, as it is a big obstacle to absorbing new information. We greatly value passion and admire people that love excellence for its own sake.

How did your PhD work in MechE inspire you to start Firefly?

My PhD adviser, Professor Roger Kamm, allowed me the freedom to explore uncharted territory. This was a very precious opportunity. I was working on the mechanical properties of a biomaterial, and eventually found myself deeply immersed in the molecular structure of the fibers clotting the brain of Alzheimer's patients. The years I spent at MIT were the most exhilarating of my professional life. Having the opportunity to interact with many different departments was an extraordinary and invaluable experience. I particularly enjoyed the interaction with the biology department. It is through this interaction that I became captivated by the complexity of living systems, and by ion channels in particular – the biological equivalent of transistors. This window into the world of biology kindled my passion for developing products designed to make the life of scientists easier.

MIT's Department of Mechanical Engineering has historically attracted very entrepreneurial, hands-on students. It was through my interaction with these friends that I came to appreciate the importance of applying theoretical principles to building useful products. In Italy, where I grew up, the emphasis is more on learning the theory and proving theorems. At MIT I learned the beauty of applying first principles to creating real products. In a sense, I re-discovered what my ancestors enjoyed during the Renaissance in Florence, where small workshops of talented artists produced remarkable works of art and developed their skills to absolute excellence.

How has your time at MIT influenced your professional decision-making?

MIT has shaped my thinking in such a deep way that I cannot even imagine who I would be without this experience. The Institute offers an environment that I have never found anywhere else. When I make important decisions, I always bring to mind the most extraordinary people I met here and how they would think in front of the same challenge. I also remind myself of the words of Teresa of Avila, a 16th-century Spanish nun: "Humility is the bread that must be eaten at every meal."

Alumni Spotlight

Danielle Zurovcik (SM '07, PhD '11); CEO and Founder, WiCare

By Alissa Mallinson

Danielle Zurovcik (SM '07, PhD '11) conducted her doctoral research on a high-tech medical device, but in her free time, she followed her passion for a low-tech wound therapy device that led her to start a global medical device company called WiCare.

Negative pressure wound therapy (NPWT) is a relatively new technique that applies a vacuum pressure to an open wound. It stresses the cells and causes them to divide, brings blood to the area, removes infectious fluids, and provides a healthier healing environment. It's been shown to significantly decrease healing time from months to just weeks. It prevents infections and requires less care and materials than traditional wound therapy, decreasing dressing changes from once a day to once every three to five days and requiring less nursing support as a consequence.

According to Zurovcik, current NPWT devices cost $100 a day to rent and 70 watts of power. For a typical 6-week therapy timeframe, that comes to more than $4,000. But how could a device with such simple mechanics be so expensive?

"If you look at it from a fundamental physics-based perspective, you have to question why it costs so much to apply a low-vacuum pressure to a wound," says Zurovcik. "The answer is based on the fact that you're putting a planar system on contoured skin, causing many wrinkles and bends to develop that create air leaks. As a result, the device is continuously sucking in air, up to 13 liters per minute, and the patient is paying for the device to constantly overcome its own inefficiencies."

As part of her master's degree research in the MIT Department of Mechanical Engineering, Zurovcik was one of the first to identify the significance of the air leak – not only its relationship to NPWT success but also to the unnecessary amount of energy needed to power it. After years of research, experience, and experimentation, she understood that the most important elements of maintaining an airtight seal were material and, even more importantly, application method. But if you can overcome these obstacles, she says, you can decrease power usage from 70 watts to 20 microwatts.

Zurovcik did exactly that.

"Current dressings on the market have freedom of application, meaning they allow for the possibility of air leaks," she says. "So application method is very important to address even before you create a design. If you have the freedom to apply it incorrectly, the design could be rendered useless."

When she arrived in Rwanda to conduct clinical trials, Zurovcik was able to visualize problems and adjust the device immediately.

"I was hand making all my dressing designs at night and applying them in the field the next day, visualizing any issues and promptly using the data I gathered that day to make a better one that very night, while staying within the limits of our protocol," she explains. When she returned to MIT that fall, she was able to finalize her best design, which in part consisted of a new way of making wound dressings from scratch without using electricity. She invented a new dressing material – a new polymer mixture that eliminates the necessity of a fixed shape and conforms to the skin, utilizing its natural properties to create a stronger bond. Just as importantly, she also invented a new application method that eliminates the risk of bridges over the skin contours and subsequent air leaks.

Having found the perfect recipe of airtight application method and effective, inexpensive design,

(...Zurovcik, continued from page 21)

Zurovcik, who also has a minor in business from the MIT Sloan School of Management, started WiCare as a means of distributing her product to emerging markets. She plans to first prove the device in the US market – which, at $2 billion, still only treats a fraction of patients who could benefit from NPWT – but a key element of her design is a price point that fits emerging markets.

“My goal with WiCare is to design global medical devices that are affordable for the bottom of the pyramid but are just as effective as those created for the top of the pyramid,” says Zurovcik.

Faculty Spotlight: C. Forbes Dewey

A Lifetime of Bioengineering Achievement

By Alissa Mallinson

Professor of Mechanical Engineering and Biological Engineering C. Forbes Dewey Jr. first came to MIT’s Department of Mechanical Engineering in 1968 as an associate professor, bringing with him a BS in mechanical engineering from Yale University, an MS in mechanical engineering from Stanford University, and a PhD in aeronautics from California Institute of Technology. Between his PhD at Caltech and his position at MIT, he did a five-year stint at the University of Colorado and the Joint Institute for Laboratory Astrophysics in Boulder, where he struggled to tame unstable plasmas in the hopes of achieving controlled fusion.

“Back in 1968,” remembers Dewey, “there were a few very forward-looking faculty members here at MIT, including Professor Ascher Shapiro, who believed that bioengineering was a great new field that was going to integrate biology, chemistry, physics, and engineering, and transition into something miraculous. I thought that was very interesting.”

With a background in fluid mechanics, Dewey was a perfect fit for this great new field. The number of engineers studying biomedical fluid mechanics at the time was miniscule, and many very challenging problems were being discussed. “I said to myself, ‘I’m an engineer, this is biology. How can I make a difference?’

“But then I got to thinking about blood flow, as exemplified by the flow past an atherosclerotic artery constriction, and the question of where the sound comes from was a very interesting physics problem to me,” he recalls. “You have blood flow through a restricted artery, and you should be able to at least get a theory for what that looks like and try to understand where the sounds come from.”

He eventually transitioned from fluid-mechanical problems to the cells themselves in order to study atherosclerosis. At branch points, arteries are more prone to developing disease. Dewey knew it was a function of their geometry and blood flow, and suspected that the underlying mechanics of the problem were related. But he quickly realized that external engineering studies couldn’t get to the answers he was seeking, because the key phenomena were all biological in nature, and that he’d have to find a way to get a closer look.

Partners in Discovery

Dewey partnered with Dr. Michael Gimbrone, a pathologist at Brigham and Women’s Hospital who had developed new techniques for growing cells in culture. Together they designed a laboratory apparatus that would first grow the cells, then subject them to fluid flow, mimicking what they would experience in the artery. The apparatus was modeled after a cone-and-plate viscometer, well known to the fluid

mechanics field for producing a constant shear force over a large surface area. This allowed large samples of cells to be exposed to shear and make them available to biological assays.

The cone-plate apparatus allowed Dewey and Gimbrone to make the first controlled *in vitro* laboratory measurements of the effects of fluid flow on vascular endothelial cells. Today there are a number of different apparatuses to perform such experiments, and the response of cells to fluid shear stress is studied in hundreds of laboratories around the world, but at the time, it was a groundbreaking invention.

Now with the ability to visualize blood flow, Dewey and Gimbrone began to look closely at the cell mechanics. They were able to look at the interior of the cells to see how the force of the blood flow not only changes the cells' orientation to align with the flow direction, but also changes the arrangement of the internal structural members in the cell and brings about dramatic changes in cell crawling speed and morphology. The endothelial cells that were subjected to disturbed flow [flow that oscillated and had a low magnitude] became compromised, shedding from the surface and leaking at the joints between the cells. Dewey and Gimbrone realized that they were likely visualizing the very same phenomena that occurred *in vivo* in the very regions of bifurcations subjected to disturbed flow.

In 1988, Dewey ran into a problem. "Using various methods, we went looking for the actual mechanism that couples the fluid force to the cell, and came up with a blank," he says. He felt that early theories explaining that shear stress acted directly on the cell membrane were inadequate. How could a "fluid membrane" resist a continual force without being totally distorted, he thought? Frustrated, he turned his attention to other interesting problems, becoming heavily involved in the development of medical imaging standards, such as the DICOM standard, as well as nonlinear optics. He and Lon Hocker developed novel devices for broadly tunable wavelength laser systems and, with the help of MechE Professor Roger Kamm, pollution device detection systems based on resonant opto-acoustic spectroscopy.

There and Back Again

With such life-changing discoveries already under his belt, Dewey could have easily stopped there. But instead he returned to the mystery of the fluid-force-cell connector. He ran across a paper published by Professor Brian Duling of the University of Virginia showing that on top of the cell membrane is a very thin layer of gooey material about 0.5 microns thick called the glycocalyx.

"All of a sudden, that layer became all important to me," says Dewey. "Now you had your mechanism for getting the force from the fluid flow to the inside of the cell." With this missing piece of the puzzle finally in place, Dewey's research team was the first to directly measure the mechanical stiffness of glycocalyx in an ongoing and as-yet unpublished experiment using super-resolution microscopy and a quantum dot florescence technique.

"It all made perfect sense," says Dewey, "and for the first time it was possible to visualize how the shear stress actually acted on the glycocalyx and its support structure, which reached completely through the cell membrane and attached to the cytoskeleton. It was also clear that if the glycocalyx was missing, the effects of fluid shear stress on the cells would be compromised. The potential for understanding how fluid flow and cell biology worked together to modulate arterial disease seems at hand."

Just as he did in earlier years, Dewey is simultaneously working on data collection and analysis as well – specifically, highly complex models for characterizing drugs for development. Back in 1981, Dewey was a founder of the Massachusetts Computer Corporation, a successful venture to develop microprocessor-based laboratory computers for science and engineering. That love for computational problems was triggered in Dewey again when it became obvious that the drug development process was eating larger and larger chunks of the health care budget, with poor results.

"Many people have created elegant small- and mid-scale models for drug characterization, but they eventually become so large and complex that they are impossible to deal with," he says. "There are too many species and reactions, and no simple way to modify the data when new information comes to light. So what we've done is to treat each of these individual pathways for combination as a black box, characterize the black box, and then program the computers to put the black boxes together." A desire to solve the problem led Dewey to found another new company, CytoSolve, Inc., with a former student, Shiva Ayyadurai.

"The challenge of making a positive impact on increasing the success of drug development – helping many people with cancer and cardiovascular disease lead better lives because of more intelligent drug design – is very exciting."

Professor Dewey is a founding fellow of the American Institute of Medical and Biological Engineering, an inaugural fellow of the Biomedical Engineering Society, a fellow of the American Physical Society, and a foreign fellow of the Royal College of Engineering (UK). He is also a vice president and trustee of the Fidelity Nonprofit Management Foundation.

Faculty Promotions

We are pleased to announce the promotions of Professor Daniel Frey and Professor Nicolas Hadjiconstantinou, both from the rank of Associate Professor with Tenure to Full Professor; Professor Pierre Lermusiaux, from the rank of Associate Professor without Tenure to Associate Professor with Tenure; and Professor Tonio Buonassisi, Professor Franz Hover, Professor Rohit Karnik, and Professor Kripa Varanasi, each from the rank of Assistant Professor to Associate Professor without Tenure. Each brings a unique signature to the Department and the Institute in terms of their individual achievements and contributions to research, education, mentorship, and service.

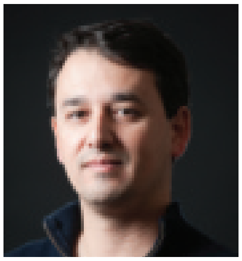
Daniel Frey

Full Professor

Professor Dan Frey is a researcher in the fields of robust design and design pedagogy. He brings depth and precision to the design process and has made significant contributions to the sub-field of Design of Experiments. His research has rigorously shown that an adaptive one-factor-at-a-time (aOFAT) approach to robust design, when coupled with informed engineering choices and used in an ensemble manner, offers key advantages over widely used fractional factorial design approaches, enabling engineers to effectively utilize engineering knowledge to engage with the design process in contrast to experiencing a loss in intuition and disengagement in "black box" approaches. Professor Frey is also strongly engaged in design pedagogy. His classroom teaching is well recognized in both ESD and ME as being amongst the best. In particular, since 2008, Dan has taken on the lead role in 2.007, a signature undergraduate design subject in MechE. He is also widely recognized for his work in K-12 outreach, and, with Professor David Wallace, he played a role in developing the WGBH television program "Design Squad." He worked with a team who helped to start a major International Design Center at MIT and at the new Singapore University of Technology and Design.

Nicolas Hadjiconstantinou

Full Professor



Professor Hadjiconstantinou is a recognized international leader in numerical simulations of micro/nanoscale transport. His interests lie in the scientific challenges that arise from the failure of the traditional macroscopic descriptions when the characteristic length scales become sufficiently small, and in exploiting the opportunities provided by the novel behavior of matter at the nanoscale to develop new concepts, devices, and systems with improved engineering performance. His group has developed a fundamentally new class of methods for simulating nanoscale transport phenomena, referred to collectively as "deviational simulations," which significantly outperform traditional simulation methods in a wide variety of nanoscale applications without introducing any additional approximations. In addition, Professor Hadjiconstantinou is contributing to nanoscale engineering education in the ME Department and beyond. He is a strong teacher and pedagogical developer of new course materials in the micro/nano engineering areas that have rapidly been integrated into our core undergraduate and graduate curriculum. He has demonstrated leadership in the ME Department through his chairmanship of our graduate admissions committee, his leadership of graduate programs within the Computation for Design and Optimization program (CDO) and, at the Institute level, his chairmanship of an Institute-wide task force assigned to updating and streamlining our graduate admissions processes.

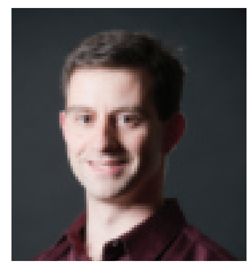
Pierre Lermusiaux

Associate Professor with Tenure

Over the past five years at MIT, Professor Lermusiaux has established a world-renowned research group at MIT in the broad area of regional ocean data assimilation. He is a nationally and internationally recognized scholar whose research has already profoundly influenced the fields of ocean data assimilation and real-time ocean modeling and forecasting, enabling the quantification of regional ocean dynamics on multiple length and time scales. His group creates and utilizes new models and novel methods for multiscale modeling, uncertainty quantification, data assimilation and the guidance of autonomous vehicles, applying these advances to better understand physical, acoustical, and biological interactions in a wide variety of different regional ocean domains. Many of his group's innovations are being integrated into large-scale ocean forecasting programs and real-time naval coastal monitoring operations. Lermusiaux is recognized as an outstanding lecturer at both the graduate and undergraduate level and has been recognized with the MechE Department's Spira Award.

Tonio Buonassisi

Associate Professor without Tenure

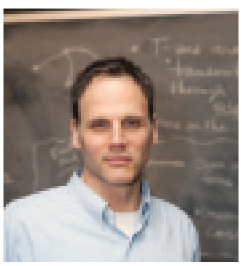


Professor Buonassisi is an emerging leader in solar energy conversion. His goal is to increase the efficiency of energy conversion and to make solar energy cost-competitive with fossil fuels. He spearheads the use of "defect engineering" to achieve dramatic enhancements in efficiency in common semiconductor materials such as multicrystalline silicon, which are cost-effective but defect-laden. Using sophisticated multiscale experimental characterization, Buonassisi's group has revealed the processing history dependence of iron distribution in PV silicon and its governing role on performance. Informed by data and modeling of the underlying diffusion and gettering mechanisms, his group has developed simulation tools that predict how process parameters vary the defect structure and device performance.

These tools enable design of cost- and time-efficient processing histories needed to achieve performance and have already had industrial impact, reducing processing times for one partner by more than 75%. Professor Buonassisi is now initiating new research directions within his group and with collaborators to bring his signature defect engineering approach to hyperdoped silicon as well as thin-film Earth-abundant semiconductors.

Franz Hover

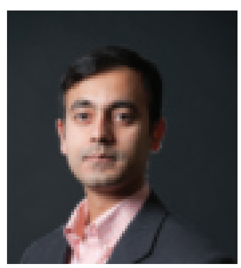
Associate Professor without Tenure



Professor Hover is an established leader in the field of complex marine systems design. He is widely respected for his depth and breadth across a range of disciplines, including fluid dynamics, control theory, robotics, mechanical design, sensor systems, and data processing, as well as for his ability to synthesize this multidisciplinary background into innovative new technologies. With autonomous inspection of naval ships having become a high priority for the US Navy as a means to manage the safety and security of the fleet, Professor Hover has pursued the challenge of developing a vehicle system capable of autonomously mapping a complete ship hull. The primary technology enablers include the breakthrough idea of using Doppler velocity and image sonar sensors to locate the vehicle relative to the ship, which in turn enabled innovations in navigation, mapping, control, and motion planning. The success and impact of his work is dramatic: the underside of a 163-meter ship hull, including details of the propeller region, have recently been imaged using his technology. While continuing to push the frontiers of marine robotics, Professor Hover also initiated and developed computational tools for early-stage design of power systems for the All Electric Ship.

Rohit Karnik

Associate Professor without Tenure



Professor Karnik's research is in the interdisciplinary field of micro/nanofluidics, dealing with fundamental studies of fluid flows at submicron length scales, as well as the design of microscale systems that exploit such flows. Within this field, his research focuses on the discovery and elucidation of novel transport phenomena that can enable micro/nanofluidic systems with superior performance in the areas of health care, energy systems, and biochemical analysis. His group has made a number of key contributions to the advancement of micro/nanofluidic systems, including the demonstration of a new paradigm in cell separation by the steering of cells in continuous flow via cell-surface molecular interactions involving both chemical and topographic patterning strategies. They have also led the development of microfluidic systems for controlled nanoprecipitation of polymeric drug-delivery nanoparticles. This enables high-throughput and precise tuning of their properties, something that cannot be achieved by bulk mixing. Karnik's group is also building on a core expertise in the design and fabrication of nanofluidic channels to create a new class of osmosis membranes that employ vapor-trapping nanopores to provide selective transport of water molecules. Professor Karnik is a co-recipient of the Keenan Award for Innovation in Education and is also a recent recipient of the Department of Energy Early Career Award for the study of fundamental transport properties of graphene membranes for water purification.

Kripa K. Varanasi

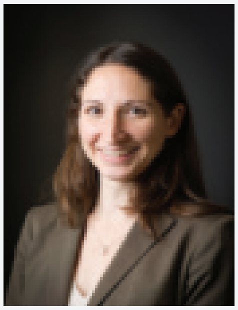
Associate Professor without Tenure

Professor Varanasi is recognized as an emerging leader at the crossroads of thermal sciences, nanotechnology, and manufacturing.

The principal theme of his research is the discovery and development of novel nano-engineered surfaces and coating technologies that can fundamentally alter thermal-fluid-interfacial interactions for transformational efficiency enhancements in various industries, including energy, water, agriculture, transportation, electronics cooling, and buildings. His activities are embodied in an interdisciplinary research framework focused on nano-engineered interfaces, thermal science, and new materials discovery combined with scalable nanomanufacturing that will have impact on multiple industrial segments. His group's work spans various thermal-fluid and interfacial phenomena, including phase transitions, thermal and fluid transport, separation, wetting, catalysis, flow assurance in oil and gas, nanomanufacturing, and synthesis of bulk and nanoscale materials guided via computational materials design. His group's studies involve insightful combinations of (i) how surface morphology at multiple scales can be used to control interfacial interactions and scalable manufacturing of such structures, (ii) fundamental studies of the physical chemistry and transport processes at the interface, and (iii) atomistic- and electronic-structure-level understanding of interfacial interactions guiding the synthesis of new materials. This work has been recognized by an NSF CAREER Award as well as by a DARPA Young Investigator Award. Professor Varanasi is also respected for his teaching in the core undergraduate design, mechanics, and thermal sciences courses.

New Faculty

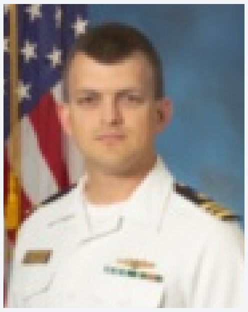
We are pleased to introduce two new faculty members to the Department, Lieutenant Commander Jerod Ketcham and Assistant Professor Alexie Kolpak.



Alexie Kolpak, Assistant Professor

Professor Alexie Kolpak graduated from the University of Pennsylvania, where she earned a BA in biochemistry, an MS in chemistry, and a PhD in physical chemistry. She worked as a postdoctoral associate in the Department of Applied Physics at Yale University, and then in the Department of Materials Science and Engineering here at MIT.

Dr. Kolpak's research employs atomic and electronic structure modeling techniques such as density functional theory (DFT) to elucidate fundamental chemical and physical principles of surface and interfacial phenomena. Her research is interdisciplinary in nature and includes collaborations with experimentalists aimed at the engineering of interfacial structures for a variety of applications, including renewable energy, novel electronics technologies, and integrated nanoscale medical devices.



Jerod W. Ketcham, Associate Professor of the Practice

Lieutenant Commander (LCDR) Jerod Ketcham earned a BS in mechanical engineering from Wichita State University, an MS in materials science and engineering from MIT, and a Naval Engineer's degree from MIT. He has served in the US Navy for 15 years, most recently working in the OHIO Replacement Program Office at the Naval Sea Systems Command.

Ketcham is an expert in designing, building, overhauling, and operating submarines, having been involved in several submarine projects. He has extensive experience in naval architecture and systems engineering. He is also a registered Professional Engineer for Naval Architecture in Massachusetts.

Department News

Zhang Baile Named One of Top 35 Innovators Under 35

Assistant Professor Zhang Baile of Nanyang Technological University (NTU) in Singapore has recently been recognized by *Technology Review*'s highly regarded TR35 Global list of the world's top 35 innovators under the age of 35.

Zhang, who earned an undergraduate degree from Tsinghua University in the People's Republic of China and a PhD in electrical engineering and computer science at MIT, is internationally recognized for his work with MechE Professor George Barbastathis on a groundbreaking invisibility cloak.

The cloak, which was named No. 4 of the top 10 breakthroughs in 2010 by Physics World and published in *Physical Review Letters*, works by placing a wedge of calcite crystal – a crystalline form of calcium carbonate, the main ingredient in seashells and stalactites/stalagmites in caves – over an object. When the object is then illuminated by visible light and viewed from the direction perpendicular to the wedge, it "disappears" from sight because the observer perceives the wedge as flat and thus nonexistent. And it's not just a simple illusion. The cloak is designed so that any scientific instrument would also be "fooled" into thinking the crystal surface is flat.

To see the full TR35 list, go to http://www.technologyreview.com/tr35.

Inaugural Cummins-Tsinghua Fellowship Recipient Announced

We are pleased to announce a new graduate fellowship offered by MechE and Cummins Incorporated to outstanding Chinese women who have earned a degree from Tsinghua University and been admitted to the MechE master's degree program.

The inaugural Cummins-Tsinghua Fellowship for the 2012-2013 academic year has been awarded to Qifang Bao. This past year, Bao graduated No. 1 in her class from Tsinghua University in Beijing, China, earning a bachelor of science degree in micro-electron-mechanical system engineering. She earned several awards during her time there, including the Excellent Student Scholarship (twice), second prize in the Sony New Product Ideas Collecting Competition, and second prize in the 26th National Undergraduate Competition of Physics.

IDA Awards 2012 Channabasappa Memorial Scholarship

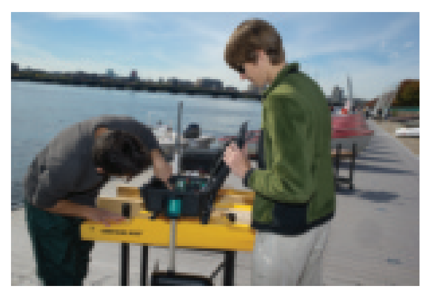
The International Desalination Association has awarded this year's Channabasappa Memorial Scholarship to PhD candidate Ronan McGovern, a member of Professor John H. Lienhard V's research group in the Department of Mechanical Engineering.

A native of Ireland, McGovern earned a bachelor's degree from the University College Dublin, and a master's degree in mechanical engineering at MIT. His PhD research is focused on emerging technologies for water desalination. He is currently the president of the Graduate Association of Mechanical Engineers (GAME).

The IDA names one recipient per year from a large pool of international applicants.

Read the IDA's news announcement here: http://bit.ly/P38RcQ

Renovated Sailing Pavilion is One in a Million



With a sailing pavilion steps away from MIT's campus, ocean engineering students have always been a lucky bunch. But last year, they got even luckier when the Department renovated the MIT Sailing Pavilion, which proudly sits on the Cambridge side of the Charles River. Last year, the Sailing Pavilion received new docks, which allow researchers and students to keep boats and underwater vehicles at the ready, as well as new research stations, updated and expanded building infrastructure, and brand new underwater vehicles. As a result of the extra storage and research space and updated equipment, students of new course 2.680 Unmanned Marine Vehicle Autonomy, Sensing, and Communication and MechE researchers can skip the hours of hauling they previously had to do and get right to work, knowing that everything they need is awaiting them at the pavilion.

Marine Robotics Team

Led by junior Jacqueline Sly, the Marine Robotics Team is making a comeback after most of its members graduated a few years ago. One of several MIT student teams supported by the Edgerton Center, and funded in large part by Chevron, as well as the Department, the new Marine Robotics Team isn't a competitive force but rather is fueled by a passion for research and discovery. This past summer, the group, including team members David Wise, Tommy Moriarty, and Adrian Tanner, a student at Boston University, traveled to Alaska to help mentor middle school students in the areas of science and engineering and get them excited about technology. While they were there, they also had a chance to test out their new and improved glider, the primary focus of the team's efforts.

MechE Wins Big at this Year's MassChallenge

On October 23, the world's largest accelerator program, MassChallenge, announced the winners of $1.1 million in prizes. The MIT Department of Mechanical Engineering was a big winner, with MechE-connected teams taking home two of the four top prizes.

Global Research Innovation and Technology (GRIT) was one of four winners of the major $100K prize. GRIT is the social enterprise incorporated last year to bring the Leveraged Freedom Chair (LFC), developed by Department of Mechanical Engineering Assistant Professor Amos Winter, to market in the developing world.

The LFC, a first place winner of the 2008 MIT IDEAS competition, takes advantage of simple physics and geometry principles to create a variable mechanical advantage drivetrain controlled by the rider's upper body strength and hand placement. The rider changes gears by either choking up on the lever to increase the power output or by gripping low to increase speed. Riders can remove and store the levers when they're maneuvering indoors and need less power. Built with bike parts, the low-cost wheel chair is easy and inexpensive to repair anywhere.

GRIT's LFC was also a recipient of Fast Company's Innovation by Design Award this year. The judges noted that part of its ingenuity comes from its low-tech simplicity.

Another MechE MassChallenge winner of a $100K prize was LiquiGlide, a nontoxic, nonstick, super slippery coating for condiment bottles developed by the Varanasi Lab. Made from food materials, LiquiGlide is easy to apply to food packaging and prevents stubborn condiments from sticking to the inside of the bottle. LiquiGlide also won earlier this year at MIT's $100K Entrepreneurship Competition, bringing home the Audience Choice Award. It was also just named to TIME Magazine's Best Inventions of 2012 list. Led by Professor Varanasi, the LiquiGlide team is J. David Smith, Christopher J. Love, Adam Paxson, Brian Solomon, and Rajeev Dhiman.

The MassChallenge winners were culled from an initial field of 1,237 applicants from 35 countries and 36 states. One hundred twenty-five teams of entrepreneurs were chosen to spend the past four months in free office space in Boston's Innovation District, working with mentors to refine their startups. Those 125 were further narrowed down to 26 finalists prior to the announcement of the final cash prize winners.

Read more about the Leveraged Freedom Chair at http://bit.ly/VhgrT5. Read more about LiquiGlide at www.liqui-glide.com.

Talking Shop: Professor Ian W. Hunter

The Micro Mass Spectrometer

Professor Ian W. Hunter sat down with us recently to discuss one of his newest inventions, a miniature ("micro") mass spectrometer, which he developed with Dr. Brian Hemond, a former PhD student from his BioInstrumentation Lab. Earlier this year, Hunter and Hemond co-founded microMS around the handheld instrument, together producing a total of 13 separate inventions related to its fundamental technological advancements.

Where did the idea for the micro mass spectrometer come from?

Five years ago, a brilliant PhD student in our lab, Brian Hemond, started looking at all of the sub systems of one type of mass spectrometer and redesigning and combining them as a single miniature system. The result was a handheld mass spectrometer with a manufacturing cost possibly as low as $100.

A typical mass spectrometer is a large instrument for performing chemical analysis, such as determining air quality, composition of car exhaust fumes, or presence of insecticides and growth hormones on fruit or vegetables you buy. Mass spectrometers are also used extensively in forensics, engineering, materials science, biology, and chemistry. But they're very expensive, costing anywhere from $100,000 to $1 million. And because they're so large, samples are currently sent off to a laboratory that houses one for analysis. With our device, you bring the spectrometer to the sample as opposed to the other way around.

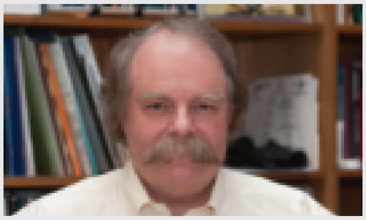
What does it do?

My favorite example is to imagine that you're in a restaurant. The wine server (sommelier) brings you some wine and you swirl it around and sniff its bouquet, but actually you have our micro-mass spectrometer hidden in your pocket that analyzes its chemical compounds and displays its results on your cellphone. You could confirm that it is indeed the wine you ordered, but perhaps note that the grapes were grown on the Northern slope rather than the optimal Southern slope.

It could potentially be used for health-related reasons too. For example, when you're shopping for fruit and vegetables, you might actually analyze the fruit and vegetables before you buy them to make sure they don't have pesticides or insecticides on them. You could also imagine that you might have one of these in every refrigerator to detect when food is going bad. You could even cook using our micro mass spectrometer to determine how well done the meat is or if a particular sauce is ready.

Anything you can smell, this device can potentially quantify. The nose is sensitive to molecules up to a mass to charge ratio (m/z) of about 300, and this device can measure up to 350 m/z – and in a special "tuned" mode can measure up to 500 m/z.

There is also a growing interest in using mass spectrometers to try and deduce health status from your breath. There's some evidence that certain diseases give off a chemical signature in your breath that is correlated with different disease states, so you could imagine a patient using this device at home for early detection. Of course it also brings new meaning to the breath analyzer. We make the joke that with this device, when your breath is analyzed for alcohol, you can not only estimate the alcohol content but also deduce that what you actually drank was a whiskey and two bourbons.



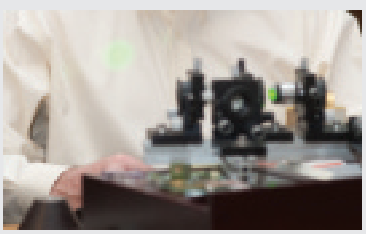
Hatsopoulos Professor of Mechanical Engineering Ian W. Hunter is a distinguished inventor. He has invented numerous biomedical instruments, holds several patents, and has started more than 20 companies. He received his BSc, MSc, DCP, and PhD from the University of Auckland in New Zealand, where he is an honorary professor, and has been a Professor of Mechanical Engineering at MIT since 1994. Professor Hunter's passion for teaching has been recognized with the Keenan Award for Innovation

All of these examples enable a very important trend of empowering individuals with the ability to measure things about themselves and about their environment using personal instrumentation, as opposed to relying on an expert or sending it off and waiting a week for it to be analyzed.

How do you allow for subjectivity for more personal uses, such as identifying a great glass of wine or your favorite cup of coffee?

When you smell a flower, you probably know which smells you like and which smells you don't. We might use the micro mass spectrometer to measure the spectra associated with those different flowers, but that's not going to tell us which ones you like and which ones you don't. So we plan to build a model that correlates the spectra the mass spectrometer measures with people's subjective analysis using themselves as a measuring instrument. For example, if you were trying to quantify the smell of a wonderful fresh cup of coffee, we can measure the spectra from freshly ground coffee beans, but there's an additional step to then correlate that to what people consider to be a marvelous aroma or a bad smell. Our plan is to create a set of aficionado user groups to build up that relationship between the chemical spectra as quantified by our micro mass spectrometer and the perceptional nature of that particular thing.

In fact, we already use ourselves as a measurement instrument, smelling food when cooking, smelling wines and cosmetics, but the difficulty is that the only way to report those interactions is to give words to the things you're smelling to describe their qualities. But how do we know that when an individual is talking about the fine bouquet of a wine that they're talking about the same fine bouquet of a wine that another individual is describing? This instrument will extend people's use of themselves as a measuring instrument and augment their ability to measure things around them, from air quality or the carcinogen and lead levels in a toy, to a type of cheese or the freshness of a fruit – or even to identify what it is exactly they like about the smell of their favorite perfume. We are even enabling the idea of sharing the spectrum of a wine you like, for example, with a friend, as well as sending the data users collect back to us anonymously to identify trends and build up collective wisdom about ourselves and the world around us.



in Undergraduate Education, the Amar Bose Award for Excellence in Teaching, and the Den Hartog Distinguished Educator Award. He is a fellow of the American Institute for Medical and Biological Engineering, and a member of the American Association for the Advancement of Science and the Institute of Electronic and Electrical Engineers. He is the director of MIT's BioInstrumentation Lab.

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Coming in the next issue:

► Innovation and entrepreneurship in the Department of Mechanical Engineering

This past fall, Course 2.009 teams competed in a team-building challenge using human-powered "snow-ball" launchers to hit targets and reveal their team flag. Teams had 10 minutes to generate ideas for launchers and one hour to build the best one from a pre-determined kit. The winning team won the prestigious 2.009 cup. This exercise reinforces the cycle of exploration students use throughout the semester to develop real products.