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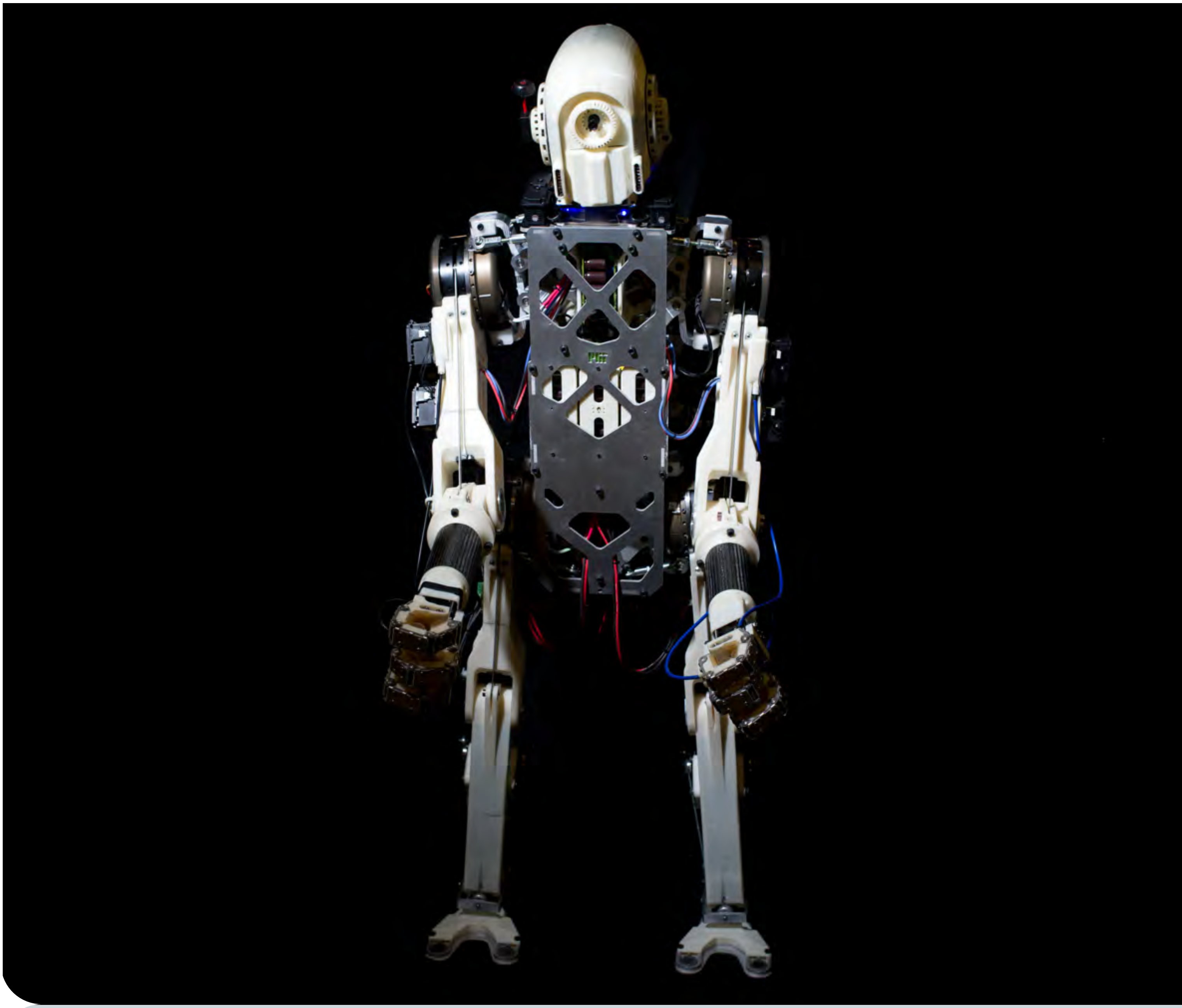
Massachusetts Institute of Technology

MechEConnects

News from the MIT
Department of Mechanical Engineering

In This Issue:



Robotics in the 21st Century

MechE researchers are transforming the roles of robots in our daily lives

| ► p. 4 |

"MechE robots are complex machines built to make people's lives healthier, safer, and more comfortable."

Dear Alumni and Friends,

The progress that's been made in the field of robotics over the past 50 years is nothing short of remarkable. From Professor Robert Mann's Boston Arm to Associate Professor Hugh Herr's bionic limbs, the technology that's been developed – some of it right here in the MIT Department of Mechanical Engineering – has transformed the way we view the role of robotics in our daily lives.

The robots being designed today in MechE aren't the manifest fantasies of Hollywood writers and directors, but rather are complex machines built to make people's lives healthier, safer, and more comfortable. Through advanced programming, clever mechanics, and optimized dynamics, we are developing the robots we need for the real 2015 and beyond, on our way to fulfilling our technological aspirations while at the same time providing valuable assistance to those who need it most.

For example, Professor Harry Asada is building wearable robotics that work as extra fingers, arms, and legs, extensions of the wearer's own body; Professor Kamal Youcef-Toumi is developing a collaborative robot that can sense the needs and goals of humans working in tandem and support them; Professor John Leonard is creating robots that can simultaneously locate and navigate themselves in both known and unknown territory; Associate Professor Domitilla Del Vecchio is developing algorithms for on-board vehicle safety systems that take control of automobiles when necessary to avoid collisions; and Associate Professor Sangbae Kim is building a disaster-response humanoid robot that can run and jump on uneven terrain and yet pick up an ax and break down a door.

In this issue, you will also read about Professor Neville Hogan, who has developed a robotic aid for stroke victims; Professor Peko Hosoi, who is developing robots that can quickly change phase from rigid to squishy and back again; and Assistant Professor Alberto Rodriguez, who is building a dexterous robotic hand that can pick out and grasp small objects amidst various obstacles.

I hope you enjoy reading about the many aspects of our robotics research as much as I have.

As always, thank you for your ongoing support and friendship.

Sincerely,

Gang Chen, Carl Richard Soderberg Professor of Power Engineering and Mechanical Engineering, and Department Head

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► 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**
- **Micro and nano science and technology**

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

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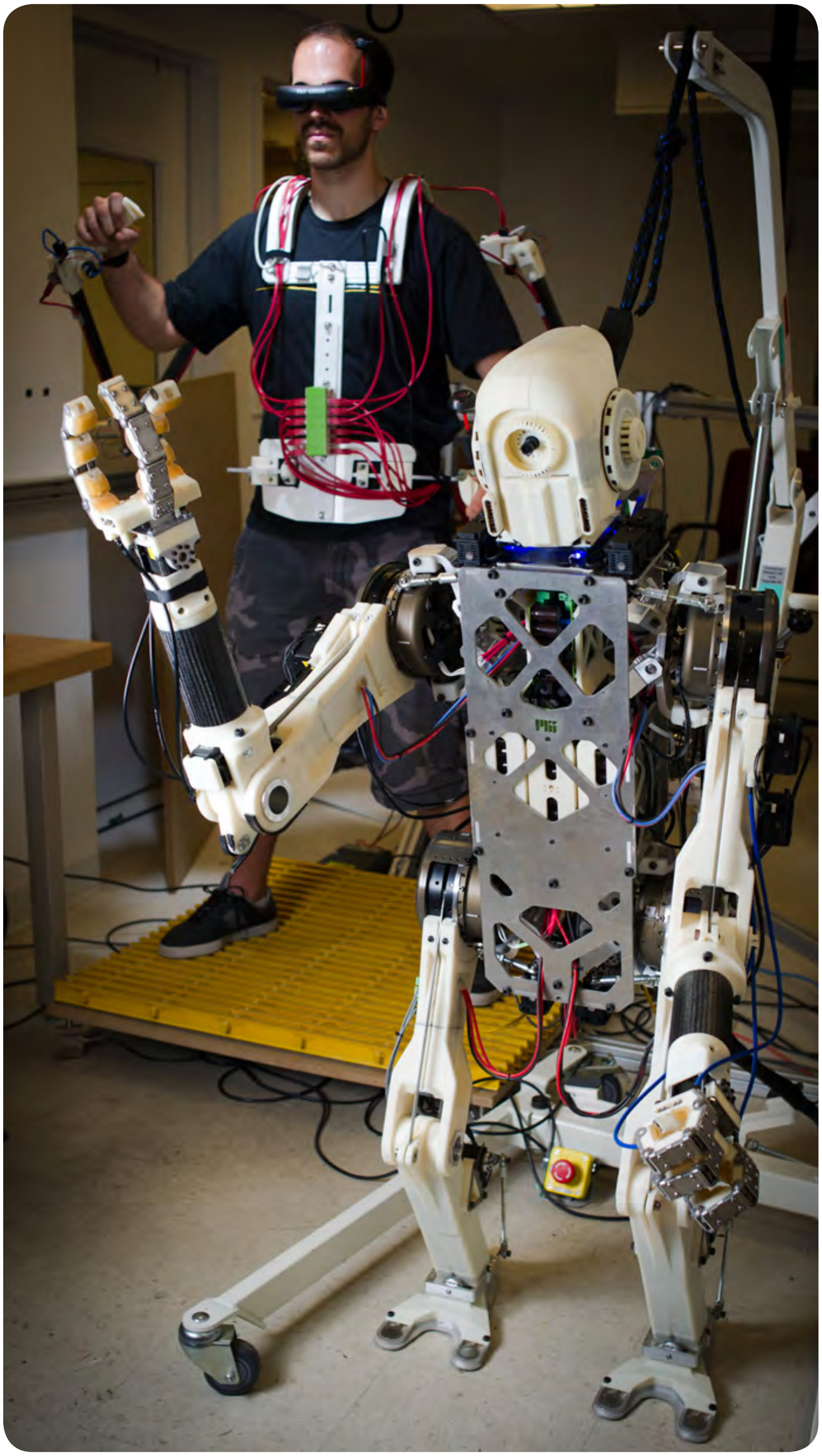
Robotics in the 21st Century

Building Robots for the People

by Alissa Mallinson

! Watch a video about Professor Kim's cheetah: http://bit.ly/1sauLNN



The image that comes to mind when you hear Professor John Leonard describe his dream of developing a robot that is what he calls "a lifelong learner" is so cinematic it's almost hard to believe:

"Maybe it operates for six or eight hours a day," he begins. "It plugs itself in overnight, recharges its batteries, and 'dreams' about all the experiences it had that day. It does that same thing night after night, building models up over time so that it gradually gains a better understanding of the world and a better decision-making capability for taking the right actions."

That something like this might be possible in our lifetime prompts us to ask ourselves if we're not the ones who are dreaming.

It begs another question too: To what end? What place do advanced robotics have in the timeline of human progress? What do we really gain from these advancements? Is it simply a nerdy satisfaction that comes from knowing it can be done? Is it just a self-fulfillment of our science-fiction fantasies and fears?

Faculty in the MIT Department of Mechanical Engineering believe there is more to it than that. There is human progress to be made, and not just in the areas of first-world conveniences and national defense, although those possibilities exist too. But the potential for significantly improved human health and safety is significant – particularly in the field of assistive technologies for those suffering from paralysis and immobility, and in our ability to deal with or avoid emergencies, such as a threatening fire, a devastating nuclear disaster, a tragic car crash, or a dangerous police or military situation.

"I look at where robots can be really valuable," says Associate Professor Sangbae Kim. "There are a lot of people looking for jobs, but we're not interested in taking their jobs and replacing them with a robot. If you think seriously about where you can use a robot, where you really need a robot, it's in environments where humans could not survive, such as where there have been nuclear disasters. There are many power plants in Europe that have had to shut their doors because people can't get in to them, or where they need to dispose of waste but can't because it is too dangerous for a human."

In situations such as these, where robots can deliver aid that isn't otherwise accessible, robots can be incredibly helpful. In a hot fire, a humanoid robot like the one Professor Kim is creating could walk into a building, find someone who is trapped, break down the door, pick them up, and carry them safely out. In a hostage situation or a police shootout, a robot could enter an uncertain circumstance, survey the scene, and report back to the police about how many people there are, whether they are carrying weapons, and so on, similar to what happened during the aftermath of the Boston Marathon bombing in 2013 when police found the suspects' abandoned car and sent PackBots – developed by iRobot, a company co-founded by MechE alumna Helen Greiner – in for reconnaissance.

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Associate Professor Sangbae Kim: Disaster Response and Rescue

For many, Professor Kim's robotic cheetah needs no introduction. The nature-inspired quadruped machine is as graceful and nimble as it is strong and powerful, like the cheetah itself. Built with electric motors – as opposed to hydraulic motors – and self-designed actuators, in collaboration with Professor Jeff Lang in MIT's Electrical Engineering and Computer Science Department, the robotic cheetah can bear the impact of running for more than an hour at speeds up to 13 mph, can autonomously jump over obstacles and land smoothly, and is powered by an 8-kilogram battery that lasts for two hours.

But you may be surprised to hear that the cheetah is only half of the picture. The other half is HERMES, a quadruped humanoid robot that can stand up on two legs and use its other two limbs for hard mechanical work and object manipulation.

"If you look at all of the current robots in the world, very few of them can do anything that involves dynamic interaction with environments," says Professor Kim. "Our cheetah is constantly interacting dynamically with the environment, but it is not doing any of the delicate position control tasks that manufacturing robots do. So I'm focused on bringing this dynamically interactive capability and infrastructure from the cheetah to the manipulation world. This will allow our robot to tackle unstructured and unexpected situations in disaster sites."

HERMES and the cheetah will soon merge to become a life-saving disaster response robot. That unity will result in a robot that looks like a mix between a monkey and a human, and will be able to autonomously direct itself to a dangerous scene where it could, for example, use an ax to break down a door or find a trapped child, instead of sending a firefighter into a life-threatening situation. Or where it can walk into a nuclear disaster to inspect the situation and take emergency action.

> **"If you think seriously about where you really need a robot, it's in environments where humans could not survive."**
>
> **-Associate Professor Sangbae Kim**

Modern-day robots have the physical speed in motion to carry out such tasks – in fact, they're even faster than humans, who, according to Professor Kim, take about 100 to 200 milliseconds to physically respond, whereas robots can respond in a millisecond or two and generate speed much higher than humans can. But what about the quick thinking that is required in emergency situations?

"If a door is jammed and the robot needs to break it down using an ax, there is the question of what strike pattern to use," says Professor Kim. "It becomes a very complex task, and developing autonomous algorithms for such a variable, complex task can be extremely challenging at this point."

To overcome this intelligence limitation in robots, Professor Kim is designing a system that incorporates a human operator in the loop. In a virtual reality-type scene, the human operator wears a sensor suit and views the situation through a camera installed on the robot, then gives the robot instructions by simply moving his or her own body in response to the robot's surroundings and goals, like a "surrogate," as Professor Kim calls it.

And here is where we meet the one major technical challenge standing between Professor Kim and a saved life: the question of balance – how an operator feels the balance of the robot. Professor Kim and his research group are working now on how to answer this missing piece of the puzzle by developing a force feedback system that informs the human operator about the robot's balance, allowing the operator to "feel" whether it is going to fall or slip and then virtually correct its center of mass.

He estimates that within five years the technology will be ready for action, and within another five, the disaster bot – part cheetah, part human – will be properly tested and suited up with fireproof materials, ready to jump into the fray.

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Professor John Leonard: Simultaneous Localization and Mapping (SLAM)

There are some feats, such as quick decision-making, that robots simply aren't well suited for – and many technical questions have yet to be answered. Science-fiction movies and mainstream media might lead us to believe that we're so close to full robot autonomy that we can reach out and touch it, but according to faculty members in MechE, we're not as close as it may seem.

"Abilities such as object detection and recognition, interpreting the gestures of people, and human-robot interactions are still really challenging research questions," says Professor John Leonard. "A fully self-driving car, able to drive autonomously in Boston at any time of year, is still quite a long time away, in my opinion, despite some of the predictions being made to the contrary."

Professor John Leonard was one of the first researchers to work on the problem of simultaneous localization and mapping (SLAM). The question was how to deal with uncertainties in robotic navigation so that a robot can locate and navigate itself on a map that it's still in the process of building.

SLAM asks three questions: How do you best represent the environment? What trajectory best fits the collected data? What are the constraints of the physical system?

Professor Leonard has been working on the most effective ways of answering these questions since his graduate student days at Oxford University. Back then, he says, the sensors to collect data were primitive and the ability to compute large amounts of data was limited. There was – and still is – a lot of uncertainty as a robot moves in space and time toward a future that is completely unknown to it – unknown terrain, unknown objects, unknown twists and turns.

He gives the example of a robot car moving through the world. "If you just count the wheel rotations and try to integrate the change in position, accounting for the changes in heading, there is noise in those measurements. And over time as you integrate that you get increased error. The robot becomes less sure of where it is relative to where it started.

"Also," he continues, "when a robot measures the world, there are errors in those measurements. Some of the sensor readings are totally sporadic. There is ambiguity. So measurements are uncertain both in how the robot moves and its perception of the world."

Even in places where the uncertainty is decreased, such as a location where the robot has already been – there is the issue of "dead reckoning error," meaning that the map the robot develops as it moves is slightly off from its actual trajectory so that when the robot comes back to a known location, identified by the camera's position, the map shows that it's slightly adrift from its actual location. Without finding a way to close the loop, the robot becomes lost and can no longer progress in an accurate way.

Professor Leonard, along with collaborators in Ireland, has developed an advanced algorithm that can correct for drift to close loops in dense 3D maps.

In his earlier days when image-processing power was rather weak, Professor Leonard's solution was focused on sparsity – the idea that less data was more. Instead of collecting entire sets of data, researchers gathered points intermittently, and filled in the gaps with estimations. But now, he says, thanks to video game console developers, GPUs (graphical processing units) are so advanced that, instead of settling for sparse data, he's gathering data sets that are as dense as possible.

And it's this improvement in technology – along with techniques to close the loop – that led Professor Leonard to realize that, in combination, the two could enable something that had never been done before in autonomous mapping: an expanded map that wasn't restricted to a small area.

"If you can accrue the information from a big area," he explains, "then when you come back to where you started, you can use all that information as a constraint—and propagate that back through your trajectory estimate with improved confidence in its accuracy."

His current work is the integration of object recognition into SLAM. "If you can represent the world in terms of objects, you will get a more efficient and compact representation of all the raw data. It's also a way to gain a more semantically meaningful means of presentation for potentially interacting with people. If you could train a system to recognize objects, then the robot could detect the objects and use them to map their locations, and even perhaps manipulate them and move them through the world."

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Professor Domitilla Del Vecchio: On-Board Vehicle Safety Systems

Considering, then, that humans are strong in areas such as intelligence where robots are not, and vice versa, it makes sense that several MechE faculty are focusing on ways to combine their best characteristics into one effective human-robot system. (MechE's own Professor Emeritus Thomas Sheridan – who, in 1978, established an eight-level taxonomy of human-machine interactions that became the basis for understanding how people interact with products and complex systems – was a pioneer in this field.)

Associate Professor Domitilla Del Vecchio is creating on-board safety systems that provide semi-autonomous control for commercial vehicles, particularly in congested situations prone to crashes such as highway merges, rotaries, and four-way intersections. Her system is programmed to take control of the car as needed in order to achieve safety.

"Full autonomy on the road is probably not going to be realistic for the next five to 10 years," she says. "We are developing a system that can monitor the driver, monitor the situation in the traffic, and intervene only when it is absolutely necessary."

You're probably familiar with a scene like this: A car that was waiting at a four-way intersection starts accelerating. Almost at the same time, another car starts moving toward the first, out of turn, trying to make a left. Before surrounding drivers can even consciously process what is happening, brakes screech and a loud crash pierces the air. Automobile pieces go flying.

Professor Del Vecchio is developing onboard safety controls to help prevent a situation just like that. Her group is designing a safety system that would anticipate this type of collision – before you do – and initiate automatic action on your behalf to prevent it. An extremely complex computation would go on behind the scenes to consider all the facts of the situation – placement of cars, speeds, and angles to determine the probability that the crash will take place.

But there's a problem: The algorithms to do those computations are incredibly complex, and to do them online would take minutes, which of course you don't have.

"So many of these algorithms that have been developed are beautiful," says Professor Del Vecchio. "You can run them in simulation, and they work very well. But if you want to implement them on a real-time platform, it's never going to work."

Instead of developing algorithms that do the full computations, she has determined where approximations can be made in the algorithms to save time. Since there are certain monotonic aspects of a car's behavior – break harder, and the speed decreases; increase the throttle, and the speed increases – she has been able to develop algorithms that scale, and calibrate them for a reasonable range of uncertainties, which can also be modeled from data.

"With approximations," she says, "of course you lose something, so we are also able to quantify those losses and guarantee a certain success rate, a probabilistic safety. In return, we gain quick autonomous decision-making in polynomial time."

Her research group is also working to find ways of decreasing the uncertainty. If communication is possible from vehicle to vehicle, then a considerable amount of uncertainty is removed and vehicles can cooperate with each other. Although there is a delay that usually renders the information old by the time it arrives, she has developed an algorithm that uses the old information and makes a useful prediction about the present based on it.

Professor Del Vecchio's group has been collaborating with Toyota since 2008 and with Chrysler since 2013. They have tested their safety systems on full-scale vehicles in realistic scenarios and have found them to be successful. Their ultimate goal is to enable vehicles to become smart systems that optimally interact with both drivers and the environment.

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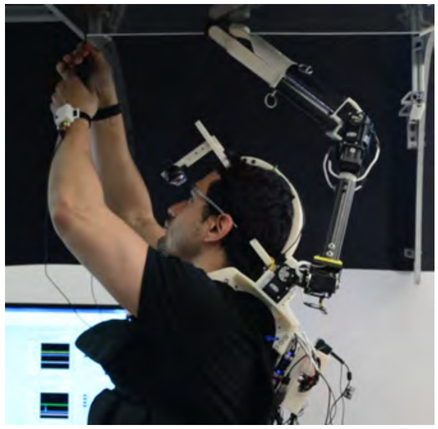
Professor Harry H. Asada: Wearable Robotics

Since Professor Emeritus Sheridan discovered decades ago that humans aren't particularly good at monitoring otherwise autonomous robots, faculty members like Professor Harry Asada want to take the interactions even further. He has a long-term vision of creating a wearable robot that is so well attuned to its operator through advanced sensing and interpretation that it becomes an extension of their mind and body.

Professor Asada and his research group are focused on developing robotic fingers, arms, and legs to help stroke victims or persons with a physical handicap to compensate for lost functionality, or to enhance human capabilities. It may sound a bit supernatural, but for Professor Asada, it's anything but. His goal is to build wearable robots that can be perceived as an extension of human limbs. To achieve this goal, his robots must work naturally, through implicit direction from the user, rather than through explicit commands.



For his work on robotic fingers, his team started with neuromotor control theory.

"There are 600 muscles and 200 degrees of freedom in the human body," says Professor Asada. "Our brain does not control all 600 muscles individually. When it sends a command for movement, each command coordinates a group of muscles working together. When you grasp something, the brain is telling the muscles to move according to certain patterns."

Applying that theory to their development of wearable extra fingers, they found that there are three main patterns of motion that, when used in various combinations, make up 95% of common hand movements. The first is the opening and closing of the fingers in sync with each other; the second is an out-of-phase movement; and the third is a twist or rotation of the fingers.

Next, they conducted studies with patients and doctors at Spaulding Rehabilitation Hospital and analyzed users' placement and orientation of their hands while they performed approximately 100 common daily chores, then asked them where additional fingers would be most useful.

Outfitting their test subjects with sensor gloves to detect various combinations of bending joints, Professor Asada's team was able to design a set of control algorithms based on the resulting data and the known hand-motion patterns, and ultimately program robotic fingers to be prepared for a variety of tasks.

On their functioning hand, users wear a glove with embedded sensors that detect their movements. Based on those movements, Professor Asada's robotic hand, which adds two extra fingers (and six joints), can interpret that data as a certain task and coordinate its two fingers to complement the healthy hand. Professor Asada has also embedded force sensors in the robotic fingers to determine if a stable grasp has been achieved.

This gets to the core of Professor Asada's research: a robot that can sense which task a user is about to tackle based on their posture, and intuitively and naturally complement it in real time. His ultimate goal is for users of his wearable robotics to forget that they're wearing them altogether – the robots would be so intuitive and self-sustaining that they would feel like a natural part of the body.

It's this same principle that drives his other research in wearable robotics as well. His group is also developing extra arms that could be used in manufacturing scenarios where the labor is strenuous, such as work that is consistently done with ones' arms over their shoulders, or work that would normally require two people. He's using similar sensors to detect the placement and movement of shoulders, so that the robot arms can determine the task – for example, soldering – and support it; he's even pursuing the use of a camera that can scan eye movements to determine where a person is looking.

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Professor Kamal Youcef-Toumi: Advanced Safety and Intelligence

How many times have you wished aloud to an empty room for some help with a task – to assist with a car repair, clean up the house before a dinner party, or contribute to an assembly line? You probably said it in vain, resigned to the fact that it would never happen in your lifetime, but Professor Kamal Youcef-Toumi has something that will change your mind.

Like Professor Asada, Professor Kamal Youcef-Toumi is developing robots that can sense a gesture or expression from a human collaborator and understand the subtle complexities in meaning – and then "instinctively" understand how best to proceed.

Along with his research group, he is working to implement high-level sensing capabilities of robots that can aid in industrial fields such as manufacturing. One of these capabilities is, well, let's call it "sensitivity." He is developing robots that will quite literally "sense" subtle cues from a human who is working by its side, and then through a complex web of algorithms, decipher those cues and adapt to them. To say nothing of the fact that some humans have trouble sensing implicit cues through body language or hand gestures, the thought of a robot picking up on such non-verbal hints is impressive indeed.

"The robot is a machine, so we have to give it information," says Professor Youcef-Toumi, "but we want it to also have some intelligence of its own so that it's building on the information we've given it, and we don't have to tell it every little step.

"Imagine we are sitting in a restaurant," he continues. "We order tea. We don't have to say to the server, 'Please bring two cups, two spoons, two napkins, and two saucers.' All of that is implied. This is similar. The robot starts with some information and uses new information to keep building on that."

In Professor Youcef-Toumi's demonstrations, his research group will present the concept using well defined tasks and environments, but his final robot will be able to make decisions about new interactions and environments in real time. He says that the robot – which is not being designed as a humanoid robot at this point – will sense tools or objects, their placement, and human gestures and motion, among other things – to paint a picture for itself about what it is expected to do.

"In the end," says Professor Youcef-Toumi, "we want the robots and humans working together as if the robot is another human with you, complementing your work, even when you leave the scene and come back. It should adjust to resume complementing you and proceed in that way."

Professor Youcef-Toumi has also been working on a robot that can swim through water or oil in a pipe system, or crawl through one filled with natural gas. The robot his group has designed leverages pressure changes to detect particularly small leaks (down to approximately 1mm) in a pipe made of any material, carrying any product. The robot can pinpoint a tiny leak that a current system would miss, determine exactly at what angle and location on the pipe's circumference it exists, and navigate there on its own with knowledge of where it is in context of the whole system. All of this data is collected, recorded, and transmitted wirelessly via relays to a control center.

"Small leaks that go undetected for a long time can weaken the foundation of a building, or collapse a street or sidewalk. Contamination is also a big safety concern. Most of the time the water is going from the pipe to the outside, but there are times when the pressure changes and the water flows outside, mixes with whatever is around the pipe, and then flows back in," he says.

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It's hard to predict whether or not full automation will happen in our lifetimes, but it's not a stretch to say that here in MechE, we get a little bit closer every day. We can see the benefits to humankind at each step, from prevention to response, and we wait for the day when robots become dreamers themselves.

2.12: Introduction to Robotics

The MechE World Cup

! Watch a video about 2.12: Introduction to Robotics: http://bit.ly/1EmdJ4C

By Alissa Mallinson

It's an introduction to robotics – for some students, that's all they need to know to get excited about the popular class that goes by the number 2.12. For a mechanical engineering student, it's a fun hands-on convergence of design, manufacturing, kinematics, controls, mathematics, mechatronics, problem-solving, and computer science.

"This course is an introduction," says instructor Professor Harry Asada. "We don't assume anything about the students' backgrounds. We just assume we share one thing in common: a love of complex motion. Motion is important in any area of mechanical engineering, but it's particularly important in robotics – we wouldn't have robotics without it."

An elective class for upperclassman, 2.12 goes beyond abstracts, providing students with a way to visualize complex mathematical concepts and a chance to build on their foundation in mechanical engineering basics.

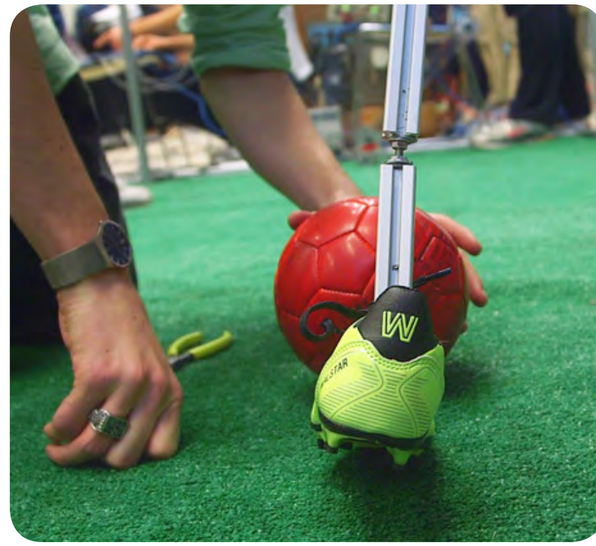
Students spend the first five weeks learning about controls, and programming, and relevant mathematics, but during the final seven weeks, they split into teams and focus on building a robot that will compete in the final challenge. Each member of the team focuses on a different element of their robot – controls, manufacturing, or computer vision.

"This is a very difficult challenge for students," says Professor Kamal Youcef-Toumi, a co-instructor of the class, "and we provide a lot of support for all 80 students to reach the goal: two faculty members, four teaching assistants, undergraduate assistants, and a post-doc. We all feel like part of each student team and want to see them build robots at the highest levels of performance and operations."

The student teams design, build, and test a robot that will debut its skills in a themed competition. The themes, chosen by Professor Asada and Professor Youcef-Toumi, are based on a recent world event that will be relevant for students, such as the Fukushima nuclear disaster or the Summer Olympics.

Last year's Soccer World Cup was the inspiration for this year's 2.12 final project. The students had to design, build, test, and compete two complex, automated soccer robots, one that played the position of striker and one that played goalie.

"Every year, we raise the bar," says Professor Youcef-Toumi. "We add new challenges, and this year was no exception. The robots had to be able to receive or kick a ball, and withstand the associated impact forces. These reaction forces had to be born by the structure of the robot and not by the servos."



The students also used cameras that enabled their robot to intercept the ball and then save or strike it. The robots had to conduct real-time processing of the images and then predict the trajectory of the ball while simultaneously generating their own motion plan to meet and intercept it, regardless of whether the ball was rolling or bouncing.

"This is not an easy thing to do," says Professor Youcef-Toumi. "But we all had a lot of fun."

"Every day in this class is an experiment and a new discovery," says Professor Asada. "If we assign a project to which we already know the solution, it's no fun. We have found that students come up with brilliant ideas and it's so much fun to see that happen.

"We share the joy and pain of it together," he laughs. "That's MIT MechE."

Alumni Spotlight: Associate Professor Hugh Herr (SM '93)

The Body Electric

A condensed version of an article by Courtney Humphries, MIT Technology Review

Hugh Herr (SM '93) believes that technologists can do better. An associate professor of media arts and sciences and leader of the Biomechatronics Group in MIT's Media Lab, Herr is building sophisticated devices that aid human movement by mimicking nature.

It's unusual to find a researcher whose work and personal history are so entwined, and not just because Herr, himself a double amputee, now walks on bionic legs that his lab designed. As both a rock climber and a user of prostheses, Herr has direct experience with frustratingly poor prosthetic design — and an athlete's determination to overcome them. His lab is working to understand the tricks the human body uses for moving efficiently, and then translating that knowledge into robotic devices that can not only restore function to those who have lost it but enhance normal human capabilities.

A Redirected Passion

Herr, 50, describes himself as a focused person, and he speaks with a solemnity that makes it easy for people to miss his dry humor. When he was young, that intense focus was directed at one thing: climbing. "My singular objective was to be the best climber in the world," he says. His academic interests were, he readily admits, nonexistent. In 1982, when he was 17, Herr and a friend were caught in a blizzard while climbing Mount Washington in New Hampshire. They were stranded for three nights before being rescued; one man who was trying to rescue them died. Herr's frostbitten legs were amputated below the knees.

"It's alarming to every person who first receives an artificial limb how low-tech and archaic the technology is — certainly back then," he says. His first prostheses were temporary ones with plaster sockets, and he was instructed not to walk without crutches or another support: the plaster would shatter under his full weight. Later he got permanent prostheses made

Continued on next page

of wood, rubber, and plastic, but they were stiff and painful.

Yet Herr found that he could still excel in the vertical world of rock climbing. In high school, he had trained in tool and die machining at a vocational school; shortly after returning home from the hospital, he set up a workshop in the garage and put those skills to work designing and building his own prosthetic limbs for rock and ice climbing. "I quickly abandoned this notion that the prosthesis has to look like a human limb, and I started to think: what's optimal, what's best for function?" he says. He created tiny feet that could balance on a whisper-thin ledge, and hatchetlike blades that could fit into a crack.

After graduating from Millersville University, Herr came to MIT, where he completed a master's degree in mechanical engineering in 1993. He also received a PhD in biophysics at Harvard, and worked at MIT's Leg Lab, which made advances in building legged robots that could walk and run. The lab was then led by Gill Pratt (SB '83, SM '87, PhD '90) — its founder, Marc Raibert, had already left to work full time at the company he founded, Boston Dynamics. When Herr graduated, Pratt hired him as a postdoc.

Pratt was so impressed with Herr's work that he made him co-director of the lab, though Herr was just a postdoc. "Hugh had tremendous practical knowledge about prosthetics, he had tremendously good intuition about control, and he was also very strong in terms of physics," says Pratt, now a program manager at DARPA. When Pratt left MIT in 2000, Herr took over the lab, which eventually became the Biomechatronics Group within the Media Lab.

The Science of Walking

At the center of the Biomechatronics Group lab space is a raised platform with a treadmill and a set of hip-high parallel bars. Ten cameras trained on the platform capture the motions of subjects as they run and walk on the treadmill. That's because an important part of the lab's work is describing how the human body moves. Walking, though a seemingly simple act, is still largely mysterious, using energy in a very economical manner that is difficult to re-create in robotics.

"We do not entirely understand how the muscles are being controlled, which surprises a lot of people," Herr says.

His lab's work to model the human ankle joint ultimately led to the development of the prosthesis Herr uses today, sold as the BiOM T2 by his startup company BiOM (formerly called iWalk). It is the first foot and ankle prosthesis that behaves, as he puts it, more like a motorcycle than a bicycle, meaning that it puts energy into the system rather than relying solely on human power.

In human walking, the calf muscle and the ankle joint contribute the most power. The BiOM T2 uses a battery to power a system of microprocessors, sensors, springs, and actuators; the joint provides stiffness during a heel strike to absorb shock, then power to help propel the lower leg up and forward during a step.

The goal of such devices is to make prostheses more natural and, by lowering the energy costs of walking, reduce joint stress and fatigue. But bringing bionic devices into the clinic is not easy. Bob Emerson, a prosthetist at A Step Ahead Prosthetics who helps connect patients to research projects in Herr's group, says it's challenging to persuade insurers to pay for devices like BiOM. "It's a far-reaching technological platform; people don't understand it really well," he says. He says it takes vision and persistence to drive major technological innovations in such a small and specialized market.

There are still drawbacks to current bionic designs — ankle prostheses like Herr's go through one or two battery charges a day, for instance — so Herr and his colleagues are working to make prosthetic devices smaller, lighter, quieter, and more efficient. They're also involved in efforts to design more comfortable sockets to attach prosthetic limbs to the body. Humans "are soft and malleable," says Herr, "and we're not static; we change in time, we swell, we shrink. So how you attach the machine world to that is a really hard problem."

Herr has already tackled the problem of giving humans better, more seamless control over artificial limbs; his BiOM ankle prostheses adjust their torque and power in response to muscle contraction. Now he is going a step further, collaborating with surgeons and other researchers on ways to allow bionic limbs to be controlled directly by the nervous system, which he hopes to demonstrate in a human in the next few years.

Alumni Spotlight: Helen Greiner (SB '89, SM '90)

A Cultural Icon

By Alissa Mallinson

MechE/EECS alumna Helen Greiner (SB '89, SM '90) is a household name – quite literally.

She's a co-developer of the famous robot vacuum, the Roomba, and co-founder of the Roomba's producer, iRobot. The Roomba was the first commercial household robot of its kind and, since its introduction in 2002, has become a "cultural icon," to use Greiner's own words. It has appeared on popular TV shows like *Breaking Bad*, *Arrested Development*, and *Saturday Night Live*. The Roomba features an acoustic sensor that detects dirt, responsive navigation around objects and walls, and a homing ability that allows it to return to its base for a recharge as needed, among other things.

If you go back far enough, the truth is that it was the 1977 flick *Star Wars* that swept Greiner happily away into this life of robots. The likable sidekick bot in the movie, R2-D2, stole Greiner's heart and inspired her to apply to MIT to learn how to build something similar. For Greiner, starting iRobot in 1990 with Colin Angle (EECS SB '89, SM '91) and Dr. Rodney Brooks, former director of the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL), was like a dream come true.

iRobot had a vision that encompassed more than just cleanliness and convenience, however, and in fact, Greiner has said publicly that it is another robot, focused on safety and security, that has filled her with more pride than even the success of the quirky Roomba: the PackBot. PackBots were designed to enter uncertain or dangerous environments when humans couldn't – or shouldn't – and Greiner has said that they have saved many lives, citing military reconnaissance missions that would've turned tragic had soldiers approached instead of the PackBot, the Fukushima nuclear disaster in which the PackBot went in when the radiation would've killed human inspectors, and even the man hunt for the Boston Marathon bombers that employed a PackBot to inspect the bombers' car at the height of the chase's tension and uncertainty. The modular, expandable PackBots can climb stairs and traverse rough terrain at up to 5.8 miles per hour. They are small enough to fit into the trunk of a car; accommodate a range of payloads; and relay video, audio, and sensor data – including explosive and HazMat detection – in real time to a human controller operating the robot with a touchscreen tablet.

Greiner, who served as president of iRobot until 2004 and chairman till 2008, later left the company to turn her attention to the development of flying robots with her new company, CyPhy (pronounced "sci-fi") Works, for which she is the chief executive officer. While some people cringe at the mention of "drone," Greiner believes that they hold great potential for human safety, efficiency, and convenience. She envisions them being sent into risky situations to get birds-eye views of a situation and a lay of the land; or flying over rough terrain that would otherwise be challenging or even impossible for a human to bound. She also sees them being used in civil structural inspections that are dangerous for humans, such as visualizing the underside of a bridge. They could even be used, Greiner suggests, by fulfillment centers for one-hour delivery.

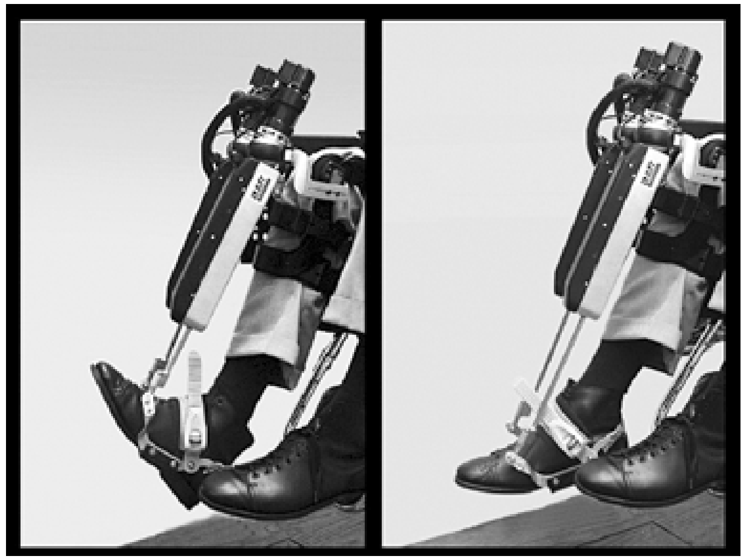
Greiner was named one of America's Best Leaders by the Kennedy School at Harvard in conjunction with *US News & World Report* and Innovator for the Next Century by *MIT Technology Review*. She has received the Pioneer Award from the Association for Unmanned Vehicle Systems International (AUVSI) and in 2003 was named a New England Entrepreneur of the Year by Ernst and Young. Greiner was inducted into the Women in Technology International (WITI) Hall of Fame in 2007. She is a trustee of MIT and of the Boston Museum of Science.

Greiner recently launched a Kickstarter campaign to fund a new commercial drone that shoots video and photography. Read more at http://kck.st/1AAdBhI

Faculty Research: Professor Neville Hogan

'Anklebot' Helps Determine Ankle Stiffness

By David Chandler, MIT News Office



For most healthy bipeds, the act of walking is seldom given a second thought: One foot follows the other, and the rest of the body falls in line, supported by a system of muscle, tendon, and bones.

Upon closer inspection, however, locomotion is less straightforward. In particular, the ankle — the crucial juncture between the leg and the foot — is an anatomical jumble, and its role in maintaining stability and motion has not been well characterized.

"Imagine you have a collection of pebbles, and you wrap a whole bunch of elastic bands around them," says Neville Hogan, the Sun Jae Professor of Mechanical Engineering at MIT. "That's pretty much a description of what the ankle is. It's nowhere near a simple joint from a kinematics standpoint."

Hogan and his colleagues in the Newman Laboratory for Biomechanics and Human Rehabilitation have measured the stiffness of the ankle in various directions using a robot called the "Anklebot."

The robot is mounted to a knee brace and connected to a custom-designed shoe. As a person moves his ankle, the robot moves the foot along a programmed trajectory, in different directions within the ankle's normal range of motion. Sensors record the angular displacement and torque at the joint, which researchers use to calculate the ankle's stiffness.

From their experiments with healthy volunteers, the researchers found that the ankle is strongest when moving up and down, as if pressing on a gas pedal. The joint is much weaker when tilting from side to side, and weakest when turning inward.

Interestingly, their measurements indicate that the motion of the ankle from side to side is independent of the ankle's up and down movement. The findings, Hogan notes, may help clinicians and therapists better understand the physical limitations caused by strokes and other motor disorders.

A Robotic Walking Coach

Hogan and Dr. Hermano Igo Krebs, a principal research scientist in MIT's Department of Mechanical Engineering, developed the Anklebot as an experimental and rehabilitation tool. Much like MIT-Manus, a robot they developed to improve upper-extremity function, the Anklebot is designed to train and strengthen lower-extremity muscles in a "cooperative" fashion, sensing a person's ankle strength and adjusting its force accordingly.

The team has tested the Anklebot on stroke patients who experience difficulty walking. In daily physical therapy sessions, patients are seated in a chair and outfitted with the robot. Typically during the first few sessions, the robot does most of the work, moving the patient's ankle back and forth and side to side, loosening up the muscles, "kind of like a massage," Hogan says. The robot senses when patients start to move their ankles on their own, and adapts by offering less assistance.

"The key thing is, the machine gets out of the way as much as it needs

(Continued on page 16)

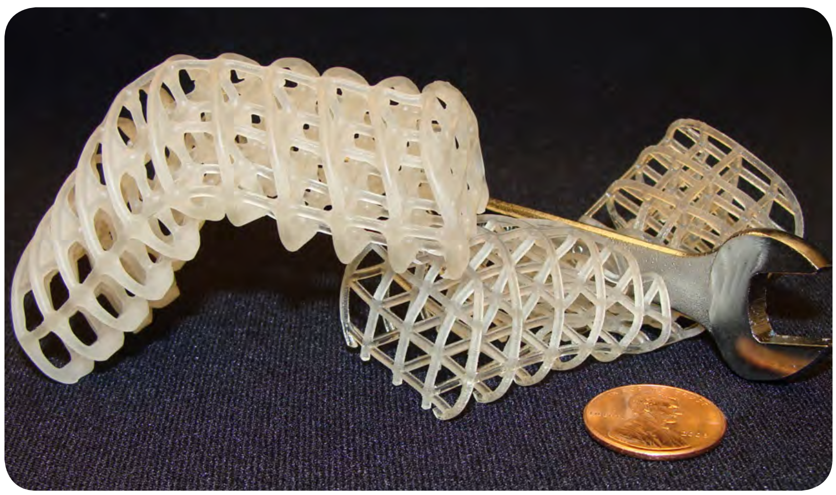
Faculty Research: Professor Anette Hosoi

Squishy Robots

By Helen Knight, MIT News Office Correspondent

In the movie "Terminator 2," the shape-shifting T-1000 robot morphs into a liquid state to squeeze through tight spaces or to repair itself when harmed.

Now a phase-changing material built from wax and foam, and capable of switching between hard and soft states, could allow even low-cost robots to perform the same feat.



The material — developed by Anette "Peko" Hosoi, a professor of mechanical engineering and mathematics at MIT, and her former graduate student Nadia Cheng — could be used to build deformable surgical robots. The robots could move through the body to reach a particular point without damaging any of the organs or vessels along the way.

Robots built from the material could also be used in search-and-rescue operations to squeeze through rubble looking for survivors, Hosoi says.

Follow That Octopus

Working with robotics company Boston Dynamics, based in Waltham, Mass., the researchers began developing the material as part of the Chemical Robots program of the Defense Advanced Research Projects Agency (DARPA). The agency was interested in "squishy" robots capable of squeezing through tight spaces and then expanding again, Hosoi says — much as octopuses do.

But if a robot is going to perform meaningful tasks, it needs to be able to exert a reasonable amount of force on its surroundings, she says. "You can't just create a bowl of Jell-O, because if the Jell-O has to manipulate an object, it would simply deform without applying significant forces to the thing it was trying to move."

What's more, controlling a very soft structure is extremely difficult: It is much harder to predict how the material will move, and what shapes it will form, than it is with a rigid robot.

So the researchers decided that the only way to build a deformable robot would be to develop a material that can switch between a soft and hard state, Hosoi says. "If you're trying to squeeze under a door, for example, you should opt for a soft state, but if you want to pick up a hammer or open a window, you need at least part of the machine to be rigid," she says.

Compressible and Self-Healing

To build a material capable of shifting between squishy and rigid states, the researchers coated a foam structure in wax. They chose foam because it can be squeezed into a small fraction of its normal size, but once released will bounce back to its original shape.

The wax coating, meanwhile, can change from a hard outer shell to a soft, pliable surface with moderate heating. This could be done by running a wire along each of the coated foam struts and then applying a current to heat up and melt the surrounding wax. Turning off the current again would allow the material to cool down and return to its rigid state.

(Continued on next page)

In addition to switching the material to its soft state, heating the wax in this way would also repair any damage sustained, Hosoi says. “This material is self-healing. So if you push it too far and fracture the coating, you can heat it and then cool it, and the structure returns to its original configuration.”

To build the material, the researchers simply placed the polyurethane foam in a bath of melted wax. They then squeezed the foam to encourage it to soak up the wax, Cheng says. “A lot of materials innovation can be very expensive, but in this case you could just buy really low-cost polyurethane foam and some wax from a craft store,” she says.

In order to study the properties of the material in more detail, they then used a 3-D printer to build a second version of the foam lattice structure, to allow them to carefully control the position of each of the struts and pores.

When they tested the two materials, they found that the printed lattice was more amenable to analysis than the polyurethane foam, although the latter would still be fine for low-cost applications, Hosoi says. The wax coating could also be replaced by a stronger material, such as solder, she adds.

Hosoi is now investigating the use of other unconventional materials for robotics, such as magnetorheological and electrorheological fluids. These materials consist of a liquid with particles suspended inside, and can be made to switch from a soft to a rigid state with the application of a magnetic or electric field.

(Hogan, continued from page 14)

to so you do not impose motion,” Hogan says. “We don’t push the limb around. You the patient have to do something.”

Many other robotic therapies are designed to do most of the work for the patient in an attempt to train the muscles to walk. But Hogan says such designs are often not successful, as they impose motion, leaving little room for patients to move on their own.

“Basically you can fall asleep in these machines, and in fact some patients do,” Hogan says. “What we’re trying to do with machines in therapy is equivalent to helping the patients, and weaning them off the dependence on the machine. It’s a little bit like coaching.”

Ankle Mechanics

In their most recent experiments, the researchers tested the Anklebot on 10 healthy volunteers to characterize the normal mechanics of the joint.

Volunteers were seated and outfitted with the robot, as well as surface myo-electrodes attached to the ankle’s four major muscles. The robot was connected to a video display with a pixelated bar that moved up and down, depending on muscle activity. Each volunteer was asked to activate a specific muscle — for example, to lift the foot toe-up — and maintain that activity at a target level, indicated by the video bar. In response, the robot pushed back against the ankle movement, as volunteers were told not to resist the robot’s force.

The researchers recorded each muscle’s activity in response to the robot’s opposing force, and plotted the results on a graph. They found that in general, the ankle was stiffest when toe-up or toe-down, while less stiff from side to side. When turning inward, the ankle was least stiff — a finding that suggests this direction of movement is most vulnerable to injury.

Understanding the mechanics of the ankle in healthy subjects may help therapists identify abnormalities in patients with motor disorders. Hogan adds that characterizing ankle stiffness may also be useful in designing safer footwear — a field he is curious to explore.

“For example,” Hogan says, “could we make aesthetically pleasing high heels that are stiffer in the inversion/eversion [side to side] direction? What is that effect, and is it worth doing? It’s an interesting question.”

For now, the team will continue its work in rehabilitation, using the Anklebot to train patients to walk.

Student Spotlight: PhD Candidate Faye Wu (SB '09, SM '12)

Moving Objects With Your Mind

By Alissa Mallinson

All you have to do is think about it.

Or at least that's what it would look like to someone watching you use the robotic finger system that PhD student Faye Wu is designing in Professor Harry Asada's lab.

Wu – who earned an SB and an SM in mechanical engineering from MIT in 2009 and 2012, respectively, and was the first recipient of the Sonin Graduate Fellowship in 2014 – has been a member of Professor Asada's lab for two years, working on a set of futuristic robotic fingers that look like they just burst through the pages of a graphic novel.

An outside observer would see a user with two hands – and 12 fingers. One of the hands would likely be inactive due to stroke or handicap – as Wu is developing the robotic hand as a wearable assistive device – while the active hand would include its five natural fingers and two robotics ones that extend from a wrist mount. They are designed to work cooperatively with the five healthy fingers to achieve tasks that would otherwise be impossible with just one hand, such as opening a pill bottle or grabbing a heavy object. Users who are rehabilitating an impaired hand could also wear the robotic fingers on their weaker arm to provide improved physical therapy by allowing normal motions despite a lack of function.

Of course, the robotic fingers don't actually read the wearer's mind, but Wu does expect that they will be able to take implicit commands toward a common goal. Those commands

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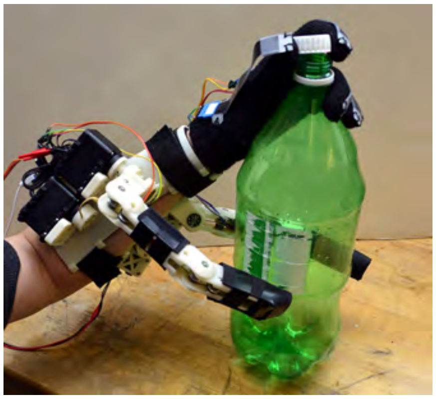

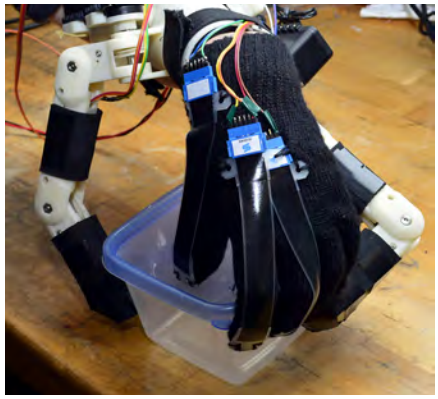

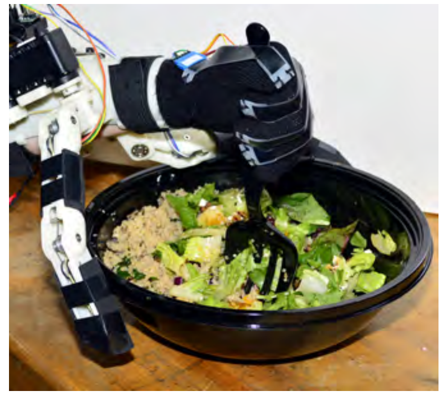

are likely to follow from a set of pre-established triggers for common tasks.

"Human hand motion," says Wu, "as complex as it is, is really just combinations of a few major movements. We were surprised to see that this actually extends out to robotic fingers too. This discovery made us very happy because it means we can create more natural robotic motion quite simply."

How it Works

The wearer's alpha hand fits inside a sensor glove, which gathers data on motion of the fingers, as well as contact forces between the object and the hand. A camera measures the relative positions of the hand with respect to the objects in its grip and records the motion of the adjoining arm. The robot hand, with its own set of sensors, corresponds to movement of the alpha hand in order to support and complement it.

For example, if the commanding hand grasps a bottle cap, it would trigger the robotic hand to grasp the bottle body and provide the opposing force needed to twist off the cap. Another trigger might be a drop of the elbow, which the robot is trained to interpret as the sign for "holding" rather than "moving." Alternatively, the trigger could be something as simple as a tap of the foot or a nod of the head, indicating to the robot that it should prepare for a specific task.

But, says Wu, the best option is for wearers to simply approach an object or perform a task as they normally would. In this scenario, the robot would correctly detect the user's intentions based on their natural movements, which would then trigger the robot to appropriately respond. Wu is interested in the intuitiveness and ease of use associated with this option, and has narrowed her focus on this type of robotic assistive hand for her thesis.

"An algorithm will be continuously running in the background, deciding if you are simply holding an object, if you are manipulating it, in what way the manipulation is being done, and what future actions you may be taking," says Wu.

In addition to the controls techniques associated with the development of a "mind-reading" third hand, Wu is also interested in its design. The comfort and flexibility of "wearables" are crucial to consumer satisfaction, and at the same time, they need to be sturdy and powerful enough to carry out the required tasks. The solution, says Wu, is likely a combination of soft, compliant robotic elements and more classic materials and actuators.

"I'm thinking of what a real human finger is like," she says. "It is soft on the outside, and a combination of soft and hard compliances on the inside, with some stiffness to hold up the structure. I imagine that in the future the robotic fingers will have comparable properties. We can even take it one step further, for example, to enable the robotic fingers to tune the stiffness of their surfaces, so if a wearer's grip is slipping, they could grab a little harder, or if they're gripping something more fragile, they could grab more softly."

Wu, who comes from a family of doctors, hopes to begin official testing of her prototype this summer in cooperation with local hospitals, including the Spaulding Rehabilitation Hospital in Boston.

Student Spotlight: PhD Candidate Albert Wang (SB '10, SM '12)

By Alissa Mallinson

Albert Wang has had robots on his mind for a long time.

"When I was about four years old," he recalls, "I dreamt about building a robot vacuum. I remember wandering around the house, while my parents did chores. They were often vacuuming the floor. It was loud and took time. So I thought about making this round thing that could move around autonomously and vacuum things. I was very happy when iRobot finally came out with the Roomba," he laughs.

MechE alumna Helen Greiner may have beaten Wang to the robotic vacuum punch, but, having been a member of Associate Professor Sangbae Kim's Biomimetic Lab since 2010 – first as an undergraduate, then as a master's student, and now as a PhD candidate – Wang has made up for it. He has been a major contributor to the lab's work on an untethered running and jumping robotic cheetah and, more recently, a humanoid robot designed for disaster and rescue missions.

"We asked ourselves what the requirements would be for a robot to replace a human in those situations. What would they need to be able to do?"

The response robot would need to complete laborious, heavy-load tasks such as opening a door, axing down an obstacle, or picking up and carrying a heavy object.

"We realized that the robot needed to be exactly like a human," he says. "Except immune to things like radiation and fire."

Thus, HERMES was born. A humanoid robot built with powerful but lightweight electric motors and customized actuators, HERMES will be able to walk, run, and jump autonomously toward a specific location, performing any necessary heavy-duty tasks on its way.

But there is something HERMES can't do: make quick on-the-spot decisions – like the kind people have to make all the time in emergency situations.

The system Wang and the rest of the team has designed requires a human operator to play the brain, while the robot plays the brawn.

"You cannot easily program the type of quick thinking you need in emergency situations," says Wang, "so we decided that connecting the robot to a human operator was the easiest way to incorporate the kind of intelligence we need. It would take a computer a long time and a lot of programming to come to the quick conclusions that humans come to almost instantaneously through good instincts."

HERMES was designed to mimic the movements of its human operator through tele-operation and in return to share its vision and physical "feelings" – its proprioception – with him or her. Creating this mapping of bodies between the robot and human and finding a way to share these feelings of force and balance have been the hardest technical challenge the team has had to face. Their solution allows operators to strap into a device that pushes and pulls on them as appropriate to replicate the forces that impact the robot as it moves through the scene. Simultaneously, operators wear a sensor suit that captures their movements and sends that information back to the robot, which then mimics those human movements.

"Physically, humans are slow compared to robots," says Wang. "But the human mind can work much more quickly and at a much more sophisticated level than a robot, so that's why we chose to use a human operator. Instead of sending a robot in with its own intelligence, we just feed all this information back to the person. And if we can achieve this, you could say

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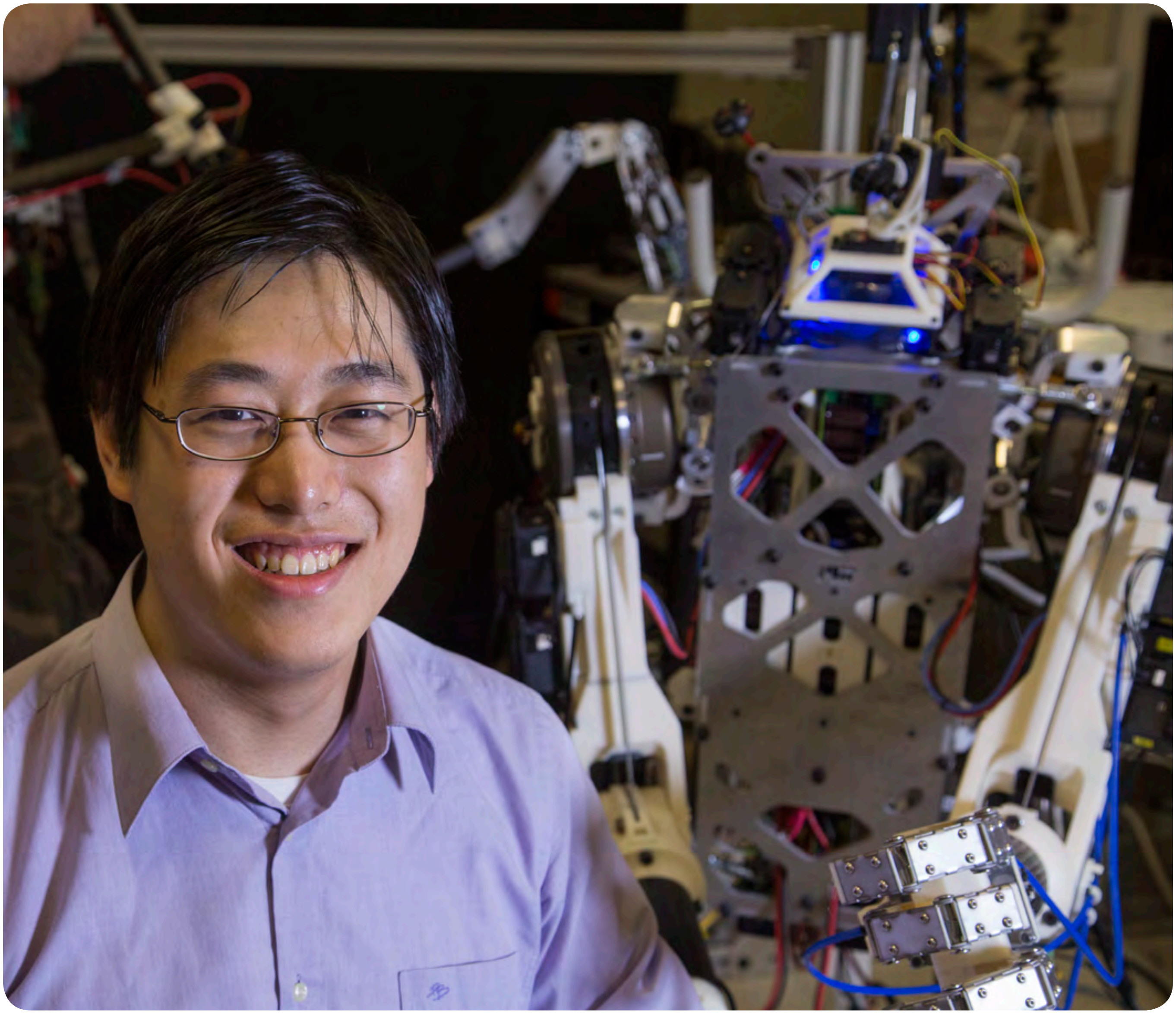


this is the loop closure rate: It would happen so quickly that the human doesn't even subconsciously think about commanding the robot. They are just feeling something and reacting to it. It's so instantaneous, it's almost an extension of themselves."

Wang and the team of researchers in the Biomimetic Lab – Joao Luiz Souza Ramos, Wyatt Ubellacker, John Mayo, and Justin Cheung – eventually hope to evolve their robotic system to the point where the robot and the operator are both learning from each other and building a valuable synergy that helps to save as many lives as possible.

For Wang's part, he's simply following a desire to impact the world for the better.

"Some people are very technology focused," he says. "But I'm more driven by the impact I can make. If the next problem I encounter happens to be completely different, maybe not even in the field of robotics, I'd consider it a privilege and challenge to work on it.

"But there is always going to be that robotics bent in me," he laughs. "I'll find a way to put some automation in it."

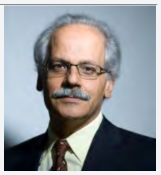
Faculty Awards

Professor John Brisson received the MIT Earll M. Murman Award for Excellence in Undergraduate Advising.

Associate Professor Tonio Buonassisi was awarded the Everett Moore Baker Award for Excellence in Undergraduate Teaching by MIT.

Professor Gang Chen, Department Head and Carl Richard Soderberg Professor of Power Engineering and Mechanical Engineering, received the 2014 Nukiyama Memorial Award from the Heat Transfer Society of Japan, and the 2014 Outstanding Alumni Award from Huazhong University of Science and Technology. He was elected as an academician of Academia Sinica in 2014. In addition, Professor Chen's work on batteries that can capture low-grade waste heat and convert it to electricity was named one of *Scientific American*'s 2014 World-Changing Ideas.

Professor Nick Fang was named a key player in *MIT Technology Review*'s 2015 list of 10 Breakthrough Technologies for his work on nano-architecture.



Professor Ahmed Ghoniem received the 2015 ASME James Harry Potter Gold Medal, which recognizes eminent achievement or distinguished service in the science of thermodynamics and its application in mechanical engineering.

Professor Roger Kamm received the Huiskes Medal for Biomechanics from the European Society of Biomechanics for his significant contributions to biomechanics throughout his career.

Assistant Professor Ken Kamrin received the Eshelby Mechanics Award. This award is given annually by ASME to rapidly emerging junior faculty who exemplify the creative use and development of mechanics.

Associate Professor Sangbae Kim won the Ruth and Joel Spira Award for Excellence in Teaching by the School of Engineering.

Professor John Leonard was appointed to the Samuel C. Collins Chair Professorship.

Professor John Lienhard was named the Abdul Latif Jameel Professor of Water & Food. He also received the 2015 Heat Transfer Memorial Award for outstanding contributions to the field of heat transfer.

Professor David Parks was named an ASME Fellow.

Assistant Professor Themis Sapsis received the 2015 Young Investigator Award from the Office of Naval Research. He was awarded a 2015 Alfred P. Sloan Research Fellow in Ocean Sciences.

Professor Yang Shao-Horn was elected a fellow of the American Association for the Advancement of Science (AAAS).

Professor Alex Slocum received the 2014 Association of Manufacturing Technology Charlie Carter Advanced Manufacturing Award. He also received a NEUP award to develop a seawater uranium extraction system that will work symbiotically with an offshore windmill.

Professor Michael Triantafyllou was named an APS Fellow.

Assistant Professor Amos Winter, along with PhD student Natasha Wright, won USAID's Desal Prize for their photovoltaic-powered

(Continued on page 23)

Student Awards

Undergraduate

Alfred A. H. Keil Ocean Engineering Development Award (For Excellence in Broad-Based Research in Ocean Engineering)
Brian K. Gilligan, Beckett C. Colson

AMP Inc. Award (Outstanding Performance in Course 2.002)
Patricia A. Das, Xiaoyue Xie

Cambridge "Firsts" (Outstanding Academic Performance at Cambridge University)
Teresa Y. Lin, Kirsten B. Lim

Carl G. Sontheimer Prize (Creativity and Innovation in Design)
Nikhil Padhye, Sarah N. Brennan, David D'Achiardi, Iman S. Bozchalooi

Department Service Award (Outstanding Service to the Department of Mechanical Engineering)
Joanna K. So, Tobi G. Rudoltz, Fernando L. Nunez, Tachmajal M. Corrales Sanchez

Ernest Cravalho Award (Outstanding Performance in Thermal Fluids Engineering)
Clare M. Zhang

International Design Competition (Outstanding Performance in Course 2.007)
Allison Edwards

Lauren Tsai Memorial Award (Academic Excellence by a Graduating Senior)
Dacie J. Mainion

Link Foundation Fellowship (Excellence in Study of Ocean Engineering Instrumentation)
Gabriel D. Bousquet

Louis N. Tuomala Award (Outstanding Performance in Thermal Fluids Engineering)
David F. Larson

Luis de Florez Award (Outstanding Ingenuity and Creativity)
Jaguar P. Kristeller, David O. Afolabi

MIT-Lincoln Lab Beaver Works Barbara P. James Memorial Award (Excellence in Project-Based Engineering)
Otto J. Briner, Peter T. Godart, Jaya Narain

Park Award (Outstanding Performance in Manufacturing)
Julia C. Canning, Nicholas W. Fine

Peter Griffith Prize (Outstanding Experimental Project)
Ann M. Huston

Robert Bruce Wallace Academic Prize
Justin W. Carrus

Thomas Sheridan Prize (Creativity in Man-Machine Integration)
Murthy Arelekatti, Margaret M. Coad

2015 Tau Beta Pi Inductees

- Joshua Born
- Laura Jarin-Lipschitz
- Nicholas Kwok
- Felipe Lozano-Landinez
- Jared McKeon
- Morgan Moroi
- Joseph Campion
- Margaret Coad
- Kirsten Lim
- Teresa Lin
- Dacie Manion
- Jaya Narain
- Ernesto Ramirez
- Kelsey Seto

2015 Phi Beta Kappa Inductees

- Sarah Fay
- Kirsten Lim
- Naina Mehta
- Emma Nelson
- Nathan Spielberg
- Spencer Wilson
- Kathy Yang

Whitelaw Prize (Originality in 2.007 Design and Contest)
Amado Antonini, Kodiak D. Brush, Jason Z. Fischman, Diego A. Huyke

Wunsch Foundation Silent Hoist and Crane Awards
David F. Larson, Jimmy A. Rojas, Jonathan T. Slocum, Deborah Ajilo

Graduate

Carl G. Sontheimer Prize (Creativity and Innovation in Design)
Michael Stern

Luis de Florez Award (Outstanding Ingenuity and Creativity)
Michael L. Stern, John W. Romanishin, Jeremy Cho, Gerald J. Wang

Martin A. Abkowitz Travel Award
Jacob S. Izraelevitz, Chengxi Li, Mustafa A. Mohamad

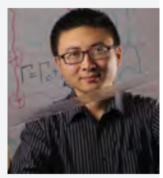
Meredith Kamm Memorial Award (Excellence in a Woman Graduate Student)
Shreya H. Dave, Jocelyn M. Kluger

Wunsch Foundation Silent Hoist and Crane Awards
Michael S. Boutilier, Khalid Jawed, Hussain Karimi, Anshuman Kumar, Brian R. Solomon, Anna Tarakanova, Natasha C. Wright

(Faculty Awards continued from page 21)

electrodialysis reversal system for off-grid regions. He also received the Freudenstein/General Motors Young Investigator Award at the 2014 ASME International Design & Engineering Technical Conferences.

Professor Ioannis Yannas was recently inducted into the National Inventors Hall of Fame for his invention of artificial skin.



Associate Professor Xuanhe Zhao received the 2015 *Journal of Applied Mechanics Award* for his paper "Phase diagrams of instabilities in compressed film-substrate systems."

Faculty Promotions

Professors **Rohit Karnik**, **Kripa Varanasi**, and **Maria Yang** have been promoted from associate professor without tenure to associate professor with tenure. Professors **Cullen Buie** and **Xuanhe Zhao** have been promoted from assistant professor to associate professor without tenure.

Student Snapshots

From top to bottom: Student Robert Katzschmann explains his DeFlorez Award entry to Professor Doug Hart; the top winners of the 2.007 Robot Competition pose with Professor Sangbae "Marty" Kim and Professor Amos "Doc Brown" Winter; MechE students discuss sports technology with company reps at the annual STE@M event; and student mentors for the new ME Maker Works celebrate the new maker space's grand opening.

Department News

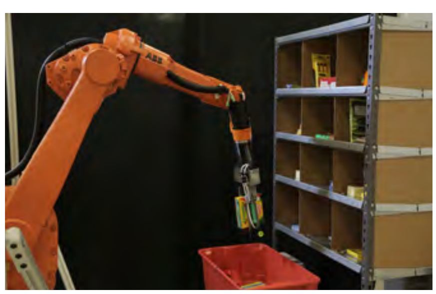
Two Instructors Win Best Paper Award

Dr. Dawn Wendell (SB '04, SM '06, PhD '11), a senior lecturer in the Department of Mechanical Engineering, and Charles Z. Guan (SB ' 11), a technical instructor in MIT-SUTD Collaboration, have authored a paper that will receive the 2015 Best Paper of the ASEE Manufacturing Division Award at this year's American Society for Engineering Education Conference, taking place this June in Seattle, Wash. The paper, titled "2.00GoKart – Using Electric

Go-Karts to Teach Introductory Design and Manufacturing at MIT," introduces an experimental lab section of the introductory design and manufacturing class, 2.007, in which small teams of sophomore students are challenged to build and race a working electric gokart in the span of one semester. Students who have little to no experience in building mechanical and electrical systems develop skills in design concept selection, detailed optimization of select components, CAD software, design for assembly, and design for repair. The paper demonstrates how such a project class can help build students' confidence and their retainment of learned material, and how this structure for project based learning may be applicable to the development of similar programs nationwide.

MIT Team Competes in Amazon Picking Challenge

During this year's International Conference for Robotics & Automation (ICRA), e-commerce giant Amazon hosted the first annual Picking Challenge to uncover commercially viable solutions for the automated picking of goods for warehouse packing and shipping. Assistant Professor Alberto Rodriguez led a team of five MIT graduate students in this challenge this past May. The final set of participating teams, including the MIT team, was narrowed down from 30 entrants, and each team was tasked with building a robot that could pick a particular subset of products and put them on a table in a 20-minute timeframe.



The robots were scored by how many items they were able to pick and place, with $26,000 in prizes being awarded to the winning teams. The winning robot demonstrated an ability to grab and grip small objects in tight spaces amidst a binful of other objects, and its creators presented a solution to object recognition, pose recognition, grasp planning, compliant manipulation, motion planning, task planning, task execution, and error detection and recovery. Read more about Professor Rodriguez's research on page 26.

A Day of MechE Innovation

This past May, the Department of Mechanical Engineering celebrated MechE innovation with a full day of festivities, starting with the annual de Florez Award Competition,

which awarded $20,000 in prizes to undergraduate and graduate students for their innovative engineering science and design projects. Later in the day, the new "Inspiring Engineering" Lecture Series began with a talk by John Hennessey, of Hennessey Performance, maker of the world's fastest production car at 270 mph. Hennessey spoke to a crowd of students, faculty, and alumni about the obstacles and successes he experienced on his journey toward breaking the record speed. This year's 2.007 Final Robot Competition took place later that evening, at Johnson Ice Rink. Students of the class spent most of the spring semester building their robots, then sent them "Hack to the Future" to see who could earn the most points by collecting plutonium, climbing the clock tower, sliding Doc Brown down the cable, and opening the DeLorean door. After an exciting night of tense "Back to the Future"-themed faceoffs, sophomore Ali Edwards took home the gold, followed by Yamile Pariente in second place, Amado Antonini in third, and Brian Yue in fourth.

New Maker Space Opens in MechE in Partnership with MIT Trust Center

This past May, MechE proudly unveiled its new student-run, state-of-the-art maker facility, ME MakerWorks. The new space, located in building 35, will provide MechE students, staff, and faculty with convenient after-hours access to technology, equipment, and mentorship for academic and hobby projects. It hosts multiple 3D printers

and laser cutters, a water-jet cutter, a mill, a shop-bot, a lathe, electronics fabrication, hand tools, and several other maker tools. MakerWorks aims to foster a student community and hands-on learning environment wherein a culture of safety is combined with prototyping resources to attract, motivate, and develop campus makers. MakerWorks hopes to strengthen hands-on learning within the MIT community and act as a spearhead for like efforts around the MIT campus by making the tools, knowledge, and motivation available to students on their schedules. The facility will be managed by MechE students, who will also act as mentors for the MechE community. The Department of Mechanical Engineering opened MakerWorks in partnership with a complementary space, ProtoWorks, in the MIT Martin Trust Center. This partnership creates a synergy among the two spaces, enabling a valuable integration of engineering and entrepreneurship for students of both groups. We are grateful for the support we received in opening MakerWorks from the Richard A. Lufkin Memorial Fund, the Martin Trust Center, and the MIT School of Engineering.

Two MechE Students Win at MIT IDEAS Global Challenge

Graduate student Prithiviraj Sundararaman was part of the Navi-Chem team that won one of two $10,000 grand prizes at this year's MIT IDEAS Global Challenge, a competition that aims "to bring novel technologies and new educational models to the developing world." Navi-Chem won for its novel process of using reactors to convert solid waste into polylactic acid that can be used to make valuable products such as biodegradable cups and medical implants. Graduate student Anshul Singhal, along with his colleagues at Squirrel Devices, a company Singhal co-founded to create simple and effective assistive technology to enable persons with blindness to access STEM subjects, won one of three $5,000 awards. The company is developing a framework to connect assistive technology devices with dedicated output devices over wireless networks to fit users' needs.

Talking Shop: Professor Alberto Rodriguez

Robotic Dexterity for Warehouse Efficiency

Assistant Professor Alberto Rodriguez led a team in the Amazon Picking Challenge that took place this past May in Seattle, Wash. The challenge, whose judging panel included MechE alum Pete Wurman (SB '87) – a senior executive at bot-building company Kiva Systems – tasked competitors with the job of developing a robot that has the dexterity to pick items out of bins and place them onto pallets or into boxes. Professor Rodriguez has been working on this type of problem for years, focusing his PhD at Carnegie Mellon University on robot manipulation and dexterity.

Professor Rodriguez and his team tested their robot's dexterity in preparation for the Amazon Picking Challenge.

MC: What piqued your interest about competing in the Amazon Picking Challenge?

AR: The Picking Challenge is a very simplified version of the real problem, but the question of how to develop robots that can help manage warehouses, deliveries, and grocery shopping is a very hot topic in the field of robotics. Several decades ago, the main economic driver for dexterous robots was the need for manufacturing automation. More recently, the economic incentive was less clear. But now, with the spread of ecommerce, a need to manage warehouses more efficiently has come to the forefront, and there is a very clear economic advantage to solving the problem. It's one that many researchers can connect with, so it's a good place for collaboration. It's also a great project for my students that will progress our research in the lab significantly.

What are some of the technical challenges in developing these types of bots?

There are quite a few challenges in developing a robust automated solution. It doesn't sound like a complex problem, but there are many intricacies when you start looking into the specifics of the different ways in which an object or objects can be arranged in respect to each other and the constraints in the environment. The robots have to be able to pick up objects on shelves or inside bins where there is no clear access, not only in terms of perception but also in terms of the dexterity needed to get inside. These are objects that are clustered with others, so it's challenging for a robot to understand exactly what the right strategy is to get in there and grab the right item without colliding with everything around it. There is a lot of complexity involved in that process, both in terms of dexterity and perception.

How significantly is your group focusing on artificial intelligence?

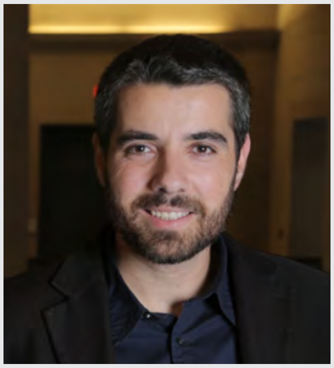
Our focus is more on the physical interaction of what I like to call "the last inch." It is challenging to plan the motion of getting close to things, but there is yet another challenge robots face once they get there and need to make contact. The robot needs to know exactly what to do with its fingers and how to react to unexpected contacts or when something slips. That is "the last inch," and it is the focus of my research. I look at it from several perspectives. One is design: How do you develop grippers that can account for the variability of the different shapes of the object, the different materials, or the different constraints in the environment? Another is perception: There is information that the robot should be able to recover from contact to help it make decisions, such as the weight and inertia of objects, its pose, or other mechanical properties such as friction. Another is control: Once the robot knows enough about itself and the environment around it, it needs to plan and execute a motion that will contact the environment, for example by pushing on or pulling from it.

What possible solutions have you chosen to pursue?

One idea we're working on is to develop a robotic hand that pushes against the environment to manipulate an object. This means that the robot would use the environment as a fixture by pushing against it to obtain some reconfiguration of a grasped object, almost as if using the environment as an extra "finger."

How would you use the environment in that way in a manufacturing environment?

In a manufacturing setting – on an assembly line, for example – there are parts coming in at a certain speed. They might come in on a conveyor belt, or in trays or bins, but either way the robot needs to grab one of those parts for assembly. But the constraints on how it can pick up the part often prevent it from picking it up at the right orientation. So it can pick it up, but now that it's in the hand, the robot needs to do some reconfiguration before it can move it to the next stage. One of the classic ways of doing this reconfiguration is to have a fixture the robot uses to put the thing down and then re-grab it. The problem with that approach is that it tends to be slow. In assembly lines, companies want things that work every second, or every two seconds; that's the throughput that they have. One way to make that process faster would be to replace the act of re-grasping (grab, reposition, re-grasp) with pushing against the environment. So the robot picks up a bolt and pushes it against the environment so that it is in the right orientation, and then screws it in.



Alberto Rodriguez graduated from the Universitat Politecnica de Catalunya (UPC) in Barcelona in 2005 with a degree in mathematics and again in 2006 (with honors) with a degree in telecommunication engineering. He earned his PhD in robotics in 2013 from Carnegie Mellon University, then he spent a year as a postdoctoral associate at the Computer Science and Artificial Intelligence Laboratory (CSAIL) at MIT. Professor Rodriguez is the recipient of La Caixa and Caja Madrid fellowships for graduate studies in the US, as well as the recipient of the Best Student Paper Awards at the RSS 2011 and ICRA 2013 conferences. His main research interests are robotic manipulation, mechanical design, and automation. His long-term research goal is to provide robots with enough sensing, reasoning, and acting capabilities to reliably manipulate the environment.

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Coming in the next issue:

► Water technologies in MechE

PhD candidate Josh Siegel (SB '11, SM '13) won this year's 2015 Lemelson-MIT prize in the $15,000 "Drive it!" graduate category. Josh, who founded a startup called CarKnow that designs software and hardware to utilize vehicle data, earned the prize for his invention of CARduino, a plug-and-play software and hardware system that enables users to access real-time data from their car's hundreds of sensors and actuators, and connect it to a cloud platform.