National Science Foundation
WHERE DISCOVERIES BEGIN

ENGINEERS OF THE NEW MILLENNIUM

Welcome to *Engineers of the New Millennium*, a radio series that tells stories from the frontiers of engineering. This radio series, developed as a partnership between IEEE Spectrum Radio and the National Science Foundation, is broadcast on public radio stations across the U.S. We invite you to explore these multimedia pages and learn about the possibilities for the future imagined by engineering researchers.

These researchers are investigating new phenomena, devising new capabilities and designing new technologies. Innovations in engineering can help us overcome challenges in sustainability, launch whole industries and help people enjoy happier and healthier lives. Through their

dedication to creating and discovering cutting-edge solutions, engineers are at the forefront of shaping our new millennium.

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Robots are emerging from industrial settings to help humans perform surgery, catch criminals and even fend off the effects of aging. With new capacities for mobility, sensing and intelligence, robots are augmenting human capabilities in completely new ways. Some researchers are pursuing a vision of robots so smart and sophisticated that they can change their shape and abilities depending on the need at hand.

ROBOTS FOR REAL

The A-Team of Robots

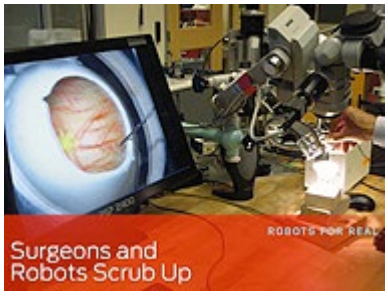
Small reconnaissance robots can stand in for humans in dangerous situations. For instance, the University of Minnesota has developed the Scout robot, which has been deployed by the U.S. military in Iraq and Afghanistan. Now, the lab has set its sights on the next big challenge: how to coordinate its motley teams of robots toward a single goal.

MIT's Shape-Shifting Robots

One day, rolling two tennis balls around in her hand, Daniela Rus wondered why the balls shouldn't be able to roll themselves. Her question led to a decade-long research program to design robots that reconfigure themselves--change shape, move across a surface, and create usable objects at the click of a button.

A Helping Hand From a Robot

The buzzword for robots is "autonomy"--but, at the Quality of Life Technology Center in Pittsburgh, the goal isn't to replace people but to help them do what they want to do. Robots now in development can reach for things in the kitchen, help steer wheelchairs, and even reinforce failing memories.



Surgeons and Robots Scrub Up

At Johns Hopkins University, a group of researchers are taking the operating room into the digital age. With steadier hands, better precision, and less fatigue than a human surgeon, robots are helping make surgery better for patients and doctors alike.

The A-Team of Robots

Nikolaos Papanikolopoulos

Nikolaos Papanikolopoulos serves as director of the Center for Distributed Robotics and SECTTRA and professor in computer science and engineering at the University of Minnesota. See how NSF has supported his research. *Image credit: Nikos Papanikolopoulos, UMN*

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Introduction to the Scout

From the Center for Distributed Robotics at the University of Minnesota, Twin Cities, an overview of the team's star robot, a throwable reconnaissance tool.

Robot Follow-the-Leader

A group of robots can be programmed to follow one another using just the device's onboard cameras as eyes. This could help the robots stick together through unfamiliar territory.

Introduction to the Loper

A stair-climbing robot could be part of an all-terrain search and rescue team.

The Adelopod Tumbling Robot

Not many robots move by tumbling. But a new robot called the Adelopod makes use of the benefits of this form of locomotion.

Shape Shifters


Daniela Rus
Daniela Rus serves as co-director of the Computer Science and Artificial Intelligence Laboratory (CSAIL) Center for Robotics and professor in electrical engineering and computer science at Massachusetts Institute of Technology. See how NSF has supported her research. *Image credit: Daniela Rus*

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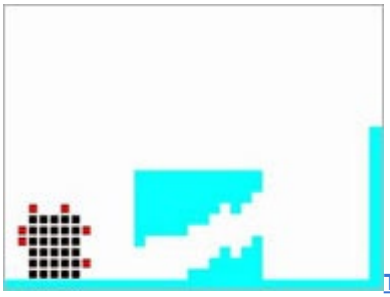
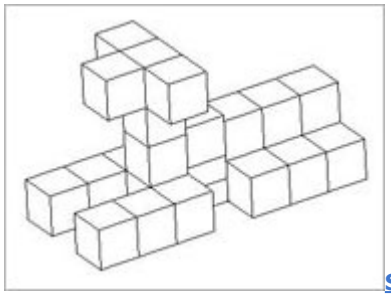
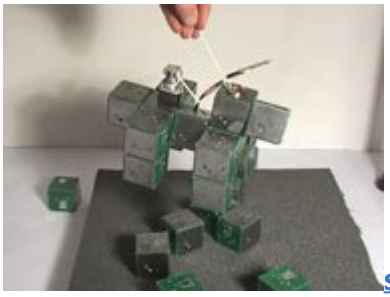

Teaching a Robot to Tunnel
Robots can be made up of many individual modules, each one programmed to act independently. The modules then rearrange to create locomotion. In this algorithm, the robot rearranges to move through the confined space of a tunnel.


Divide and Conquer
Self-reconfiguring robots change shape without human intervention. So the challenge posed to robots is: given a start shape and a goal shape, find the sequence of events to achieve it without self-collision. Here, one robot breaks into four using just expand/contract and detach mechanisms.



Sit, Stay

This conceptual illustration shows how a reconfiguring robot made of cubes could morph from a dog shape to a couch shape. Someday, very tiny cubes could potentially manufacture on command any desired object.



Shape Sculpting

Like a sculptor would remove extra marble to create a statue, an arrangement of robots can be commanded to self-disassemble in an organized manner to create a shape. First, the initial amorphous shape is assembled by hand. Then the modules communicate to establish their location and the goal shape. Finally, unneeded modules disconnect to create, in this example, a dog.

Helping Hands


Takeo Kanade
Takeo Kanade serves as director of the Quality of Life Technology Center and professor in computer science and robotics at Carnegie Mellon University. See how NSF has supported his research. *Image credit: Takeo Kanade*

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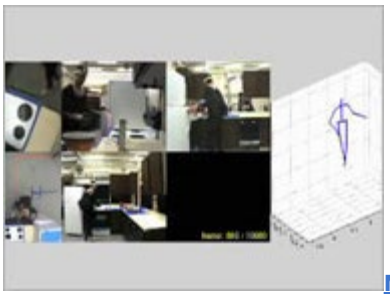
Modeling Humans
This project, called Grand Challenge, aims to collect data on daily activities such as cooking. Here, a user is monitored with video, accelerometers and motion-capture devices. Eventually this data could help robots recognize human activities and assist, if needed.


A Robot Butler
HERB, the robot butler, is part of the Active Home project. That project combines physical assistance with a "smart" environment, monitoring people and objects. The robot can recognize, grasp and move objects of varying shapes and positions.


More Than a Wheelchair
PerMMA is a project that seeks to allow wheelchair users all the mobility and manipulation of an unimpaired person. It's not just a wheelchair with added intelligence and arms--PerMMA is a mobile robotic manipulator with a seat for a person.

Robotic Surgery


Russ Taylor
Russ Taylor serves as director of the Engineering Research Center for Computer-Integrated Surgical Systems and Technology and professor in computer science at Johns Hopkins University. See how NSF has supported his research. *Image credit: Russell H. Taylor*

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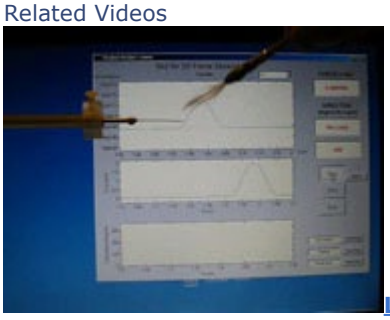
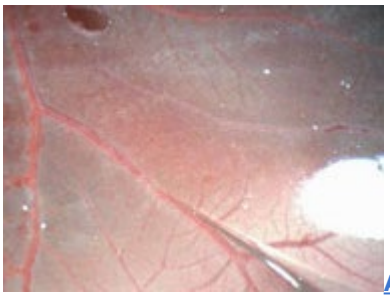

Light as a Feather
Robot-guided needles can perform delicate tasks such as eye surgery. This video shows how sensitive such needles are to just the touch of a feather.


Robot "Feeling"
When using a robot, surgeons can't directly feel the force they're applying. So researchers at Johns Hopkins are trying out different means of audio and tactile feedback for the surgeons using eye surgery robots.


A Steady Hand
The robotic manipulator is specially designed for surgery on the retina, which requires very delicate movements and steady hands. Here, using a chicken embryo to stand in for a human retina, you can see the advantage of using a robot. First, video of a surgeon inserting the needle by hand, and second, footage of a robot-assisted needle.

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In a time of growing water demands and aging water infrastructure, engineers are exploring how our limited supplies of water can be used--and reused--more efficiently. They are creating new tools for sensing, purifying and modeling water. And they are reshaping water systems for our homes and communities, so that clean water isn't wasted. All of which in turn will help communities make more sustainable water choices.

THE GLOBAL WATER CHALLENGE

How Atlanta Outsmarted Its Drought
Drought has been called the "creeping disaster" for its tendency to arrive unnoticed but with full force. Earlier warning of drought could help water managers cut water use and redirect water to the most crucial uses. A drought-monitoring system in Georgia helped the state do just that during its latest drought, from 2005 to 2009. Meet three women--an engineering professor, a water manager and an industry advocate--who played a role in outsmarting Atlanta's drought.

Mopping Up the Purest Water
It takes approximately 10 gallons of some of the purest water on Earth to create one computer chip. A single manufacturing plant can use as much water as a medium-sized town. And many of those plants are located in water-strapped cities of the Southwest U.S. That all has chip manufacturers very interested in cutting back their water use--both to green their plants and to save some green.

Tucson Spins Sewage Into Gold
The philosophy of America's water systems is, treat everything to be drinkable. But there are lots of uses for water that don't need such high standards. Tucson is one of many southwestern cities that have turned to recycled water--partially treated wastewater--for irrigation. As Tucson continues to grow, its groundwater levels drop further. Now some researchers are considering what it would take to bring recycled water to toilets and fire hydrants in the city, and give water a second swirl.

When Water Systems Crumble
America's drinking water systems are almost failing. The 2009 Report Card from the American Society of Civil Engineers gives the U.S. drinking water infrastructure a D-minus. The report estimates the U.S. is facing an annual shortfall of 11 billion dollars needed to replace aging facilities. How do we move forward? Improving water planning and technology are part of the solution--and changing our attitudes about water is the other part.

SERIES NAVIGATION

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Energy Revolution

Atlanta Drought


Anne Steinemann
Anne Steinemann serves as professor of civil and environmental engineering and professor of public affairs at the University of Washington. See how NSF has supported her research. *Image credit: Anne Steinemann*

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The Deserts of Nebraska
The Sand Hills region of Nebraska may today look like a grassland, but in the recent past it was a "sand sea." Desertification 800 years ago was caused by a severe drought. If such a megadrought ever came again, it could well return the region to desert.


Science Nation: Lord of the Tree Rings
Researcher David Stahle travels to ancient forests around the world, collecting tree rings to learn more about major droughts and other climate events dating back hundreds and thousands of years. Stahle can even determine the socioeconomic impact of droughts. In 1998, he made the front page of the *New York Times* with his discovery that drought could have contributed to the disappearance of colonists on Roanoke Island.


Drought-Resistant Wheat
"Dwarfing" is the breeding process that produced most of today's wheat plants. Dwarf wheat plants are shorter and thicker, and therefore hardier. However, they don't cope as well with stressors such as drought. That's why researchers at Washington State University are trying to find a new technique to dwarf wheat plants while making them more drought-resistant, so future droughts don’t decrease our food supply.

Semiconductors

Farhang Shadman

Farhang Shadman serves as director of the Engineering Research Center on Environmentally Benign Semiconductor Manufacturing and professor of chemical and environmental engineering at the University of Arizona. See how NSF has supported his research. *Image credit: From video produced by Will Holst, Video copyright: Arizona Board of Regents*

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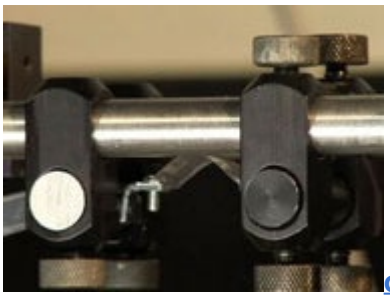
Sustainable Semiconductors

Water is one of the main sustainability challenges for making semiconductors--which go into everything from computer processors to video games and cars. One reason making semiconductors requires so much water is that the chips have to be extensively cleaned. Engineers at the University of Arizona have developed a real-time sensor to tell when chips are clean, which means less water wasted.



Chips That Twist

Engineers at the National Institute of Standards and Technology have developed a flexible memory chip, able to be bent or twisted while still functioning. One benefit could be in the area of health: flexible chips could serve as wearable sensors to track blood pressure or heart rate.

Recycled Water

Kevin Lansey, Robert Arnold and Guzin Bayraksan (not pictured - Christopher Choi and Christopher Scott)
Principal investigator (PI) Kevin Lansey serves as professor of civil engineering and engineering mechanics at the University of Arizona. Robert Arnold, Guzin Bayraksan, Christopher Choi and Christopher Scott are Co-PIs. See how NSF has supported their research. *Image credit: Gwen Woods, University of Arizona*

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Keeping Water Knowledge Flowing
The deserts of Arizona are only habitable because water is carefully managed there. The Water Resources Research Center at the University of Arizona works to keep it that way, by providing educational seminars for kids, supporting water managers, and bringing together water research across the university to solve real-world problems.

Tour the Water Sensing Facility
From the outside it looks like a shed. But inside, the Water Sensing lab at the University of Arizona's Water Village is a high-tech mini water-treatment plant. Researchers there are purposefully dropping contaminants into their water lines to test sensors that can detect not just chemical contaminants but biological ones too.

The Nose Knows
Researcher Ryan Sinclair is studying how to use human senses of taste and smell as scientific instruments. Using human volunteer sniffers and tasters, Sinclair is looking for the threshold at which most people can taste or smell a certain molecule, to better set limits on these things in our drinking water.

Taking the "Fingerprint" of Water

In the Water Sensing lab at the University of Arizona's Water Village, a humble metal tube is one of the most powerful pieces of equipment. The S::CAN uses ultraviolet light to take a "fingerprint" of water as it flows through, and could someday be widely used at water treatment plants to detect introduced bacteria or other contaminants.

Crumbling Systems


John Crittenden
John Crittenden serves as director of the Brook Byers Institute for Sustainable Systems and Hightower Chair and Georgia Research Alliance Eminent Scholar in environmental engineering at Georgia Tech University. See how NSF has supported his research. *Image credit: John Crittenden*

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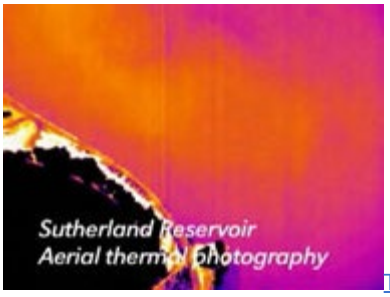

Tracking Water Flows by Temperature
Using a thermal imaging camera, engineers at University of Nebraska-Lincoln can visualize patches of warm water, such as discharge from power plants, as well as the flows of water on a large scale using aerial photography.


Dirty Snow
The Colorado River is one of the most stressed rivers in the U.S., and about 80 percent of its water comes from snowmelt. Research shows that dark-colored dust out of the Southwest now makes melt come earlier in the year--ultimately causing the river to lose more of its precious water annually.


Students Build Water Systems
The student organization Global Water Brigades is devoted to helping developing countries that lack basic water sanitation. At Northwestern University, students have been working with a village in Honduras to build pilas, a traditional water storage unit used by many Honduran families, and to provide water quality education.

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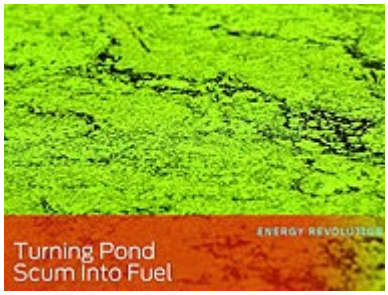
Engineers of the New Millennium

THE ENERGY REVOLUTION

What will our energy future look like? We'll still need light, electricity and fuel for our cars. But the light could come from super-efficient sources, now possible after decades of research. And much of our electricity will come through a reinvigorated grid, pumped up with intelligence and flexibility. And our engine fuel could be produced by tiny algae, designed to pump out exactly the hydrocarbons we need. Engineers are envisioning this future, and making it happen.

THE ENERGY REVOLUTION



Turning Pond Scum Into Fuel

Corn ethanol has become the ubiquitous biofuel in the U.S. But first-generation biofuels like ethanol are problematic. For one thing, they divert land from food crops. They're also chemically different than gasoline, so you can only blend them in limited amounts. But waiting in the wings is the second generation of biofuels--made from non-food material, like algae. And most amazingly, researchers think they'll be able to make an algae fuel you could put straight into the car you drive today.

Note to Smart Grid: Heal Thyself

The future electricity grid may well be a "smart grid," where electricity lines provide not just power, but communication. Now, some researchers are taking that idea a step further. They call their plan the "energy internet," and it would make energy distribution as participatory as sharing photos with friends. It would also pave the way for widespread electric vehicles and distributed energy generation.

What Can We Do to End LED "Droop"?

You've seen them light up computers and electronic displays, and they're now making their way into flashlights, indoor lighting and televisions. They're LEDs--ten times as efficient as incandescent bulbs, and twice as efficient as compact fluorescents. With new materials, LEDs are overcoming past problems with color and "droop." And with new manufacturing methods, LEDs are being produced by major lighting companies. As they become more affordable, they'll likely become the light of the future.

Algae Fuel


Phil Savage
Phil Savage serves as professor in chemical engineering at the University of Michigan. See how NSF has supported his research. *Image credit: From video, Department of Chemical Engineering, University of Michigan*

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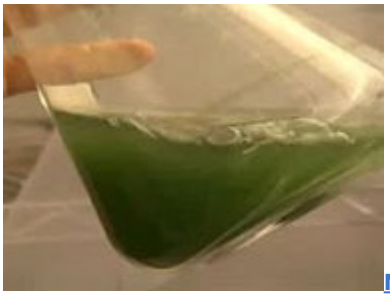
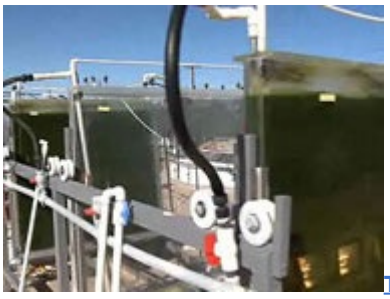
Efficient, Aquatic Biofuel
Chemical engineer Phil Savage envisions a future where instead of being hunter-gatherers for energy, we're cultivators of it. And what he's cultivating is algae. Savage's lab grows the algae, then "pressure cooks" it, resulting in a thick, oily bio-crude. That crude can then be catalyzed to create hydrocarbons that could replace gasoline.


Innovators: Oil of Algae
Algae fuel may be coming to a gas tank near you, if aerospace engineer Bill Roberts has anything to say about it. Roberts's lab at North Carolina State University is genetically modifying a specific strain of algae to produce drop-in replacements for different kinds of transportation fuels.


Making Algae Fat
Researchers at the Scripps Institution of Oceanography are looking to the oceans for the next generation of biofuels. They're trying to understand what genes lead algae to produce lipids as opposed to carbohydrates--because it's lipids that will ultimately be refined into algae biofuel.



The Diversity of Algae

At Arizona State University, scientists are screening many species of algae for their "lipid profile." Each species will have a unique assortment of lipids, and different lipids produce different kinds of fuel--everything from kerosene to jet fuel to gasoline.

Smart Grid


Alex Huang
Alex Huang serves as director of the FREEDM Systems Center and professor of electrical engineering at North Carolina State University. See how NSF has supported his research. *Image credit: Alex Huang*

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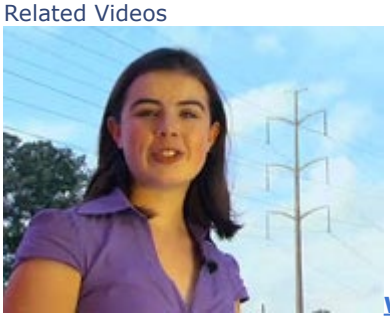
What Is the Smart Grid?
If energy is like a faucet, at the moment, the grid doesn't allow any way to turn off the flow. But wouldn't it be nice to stop the flow when you weren't using it, to store the extra energy, or to divert it to the most important things? Those are all part of the design of the future smart grid.


Who's Building the Smart Grid?
Meet the students, of all ages and from all different disciplines, who are working on smart grid research with the FREEDM Systems Center.


Why Do We Need a Smart Grid?
Renewable energy, electric vehicles, and distributed electricity generation and storage--all would be enhanced by the smart grid, and all are part of the future FREEDM system.

LED Droop


P. Daniel Dapkus
P. Daniel Dapkus serves as director of The Photonics Center and professor in electrical engineering at the University of Southern California. See how NSF has supported his research. *Image credit: P. Daniel Dapkus*

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Do You See What I See?
Changes in lighting affect the way we perceive the world around us. NIST, the National Institute of Standards and Technology, has built a "Vision Lab" to scientifically test how different light sources are perceived by people. One of their special interests is LED lighting--particularly important because LEDs' great energy-saving possibilities won't be realized if they aren't liked and adopted by users.


What Consumers Want
To test consumers' taste in lighting in a realistic setting, researchers at Oklahoma State University equipped rooms in actual houses with incandescent bulbs, compact fluorescent bulbs and LEDs. Students were essential too, "gridding" each of the rooms as to their light level, and educating study participants about the costs and benefits of each lighting type.


Light's Give and Take
Since 2009, P. Daniel Dapkus has been leading a project on both solar cells and LED lighting at the University of Southern California. The connection between the two? Harnessing light and emitting it are similar processes in different directions. The researchers' goal is to make solar cells as cheap as coal-powered electricity.