A Smart Lighting Revolution

The Smart Lighting Engineering Research Center is developing the systems that will transform the way we live, work, and communicate.

Let there be light, for every step we take throughout a building—automatically, without ever having to touch a switch. Let there be light that will brighten, dim, provide any color we want depending on the task at hand, without having to think about it.

Let there be high-quality light shining down from our everyday light fixtures to transmit data to our laptops and cell phones, network our electronic devices via the Internet for better efficiency, and provide wireless access when and wherever we want it, all while saving energy.

This is the vision of the Rensselaer Smart Lighting Engineering Research Center (Smart Lighting ERC). The mission is to develop next-generation solid-state lighting systems that provide tightly knit assemblages of lighting sources, sensors, and controls that have the power to transform the way we live, work, and communicate.

The result will be lighting systems that are not just relegated to illuminating a room. They will be smart systems that create new ways to optimize human health, safety, and productivity.

In hospitals and homes, for example, a smart lighting system could detect when someone has fallen and summon help, without invading their privacy. Such lighting systems also will one day communicate with building control systems to improve heating, ventilation, and air conditioning operation, as well as security, by knowing where people really are, to automatically provide the right lighting-enabled services when and where they need them.
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Robert Karlcek leads the Smart Lighting Engineering Research Center (ERC) at Rensselaer. The center was established in 2008 with an $18.5 million grant from the National Science Foundation and is one of 17 ERCs in the United States.

Researchers are also using the visible light spectrum to build new telecommunication technologies that could exceed the speed of today’s best radio frequency (RF) broadband and wireless capabilities to transmit data in unprecedented ways. There are huge implications simply in the ability to control the color of light at any given time, thanks to the advancements in light-emitting diodes (LEDs).

“At the ERC, we are building smart lighting systems that automatically adjust the right lighting for you at any given time, with light coming from the right direction, with the right color intensity, optimized for human health and productivity,” says ERC Director Robert Karlcek. “At the same time, we are developing smart lighting systems that will provide information to us, directly through the light, which will be faster than the radio frequencies we now use.”

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The purpose of the ERCs is to develop interdisciplinary research and education programs in partnership with industry aimed at accelerating the commercialization of university research. The goal is to advance technology and innovation to address significant societal problems and enhance the foundation for economic competitiveness.

The core research partners of the Smart Lighting ERC are Boston University and the University of New Mexico, along with outreach partner schools Thomas Jefferson and Tufts universities. Howard University, Morgan State University, and Rose-Hulman Institute of Technology serve as educational outreach coordinators.

Twelve faculty from Rensselaer, along with 10 researchers from Boston University and the University of New Mexico, serve as the research core of the Smart Lighting ERC.

The ERC has enlisted nearly 30 industry partners so far, including major lighting companies GE Lighting, Philips, Osmo, Sylvania, and Aucotec Brands. Other industry collaborators include ABB, which specializes in automation technologies, and Aimis, a global provider of high-performance sensors and analog integrated circuits.

Lighting systems will one day communicate with building control systems to improve heating, ventilation, and air conditioning operation, as well as security.

Putting the “Smart” in Lighting

The research, development, and commercialization of smart lighting systems build on the advancements of solid-state lighting, particularly LEDs, over the last decade.

LEDs, which don’t have a filament that burns out easily, illuminate by the movement of electrons in the semiconductor material from which they are made. LEDs have been developed to emit virtually any color of light without the use of filters, and in many cases, they offer better quality light and deliver it more efficiently.

Perhaps the most notable aspect of LEDs that opens the door to smart-lighting innovation is that they enable color tunable lighting designs in which the quality, color, and quantity of the light can be precisely controlled and modulated at high speeds, making them attractive for exploring new ways to transmit data and building systems that can use digitized lighting to sense their surroundings.

Rensselaer researchers are combining these and other smart lighting elements in numerous R&D projects in the ERC’s Smart Conference Room, an advanced test bed designed for experiments in areas that range from energy efficiency and color controls to occupant task estimation and human factors studies.

The room, with a large conference table that seats 16, is equipped with 10 five-channel LED light fixtures. Each channel is a different color—red, green, blue, amber, or white. They can be combined to form almost any color imaginable and can be tuned independently of one another.

Twelve color sensors distributed around the room are used to measure the red, green, blue, and white LED intensities reflected from the objects in the room. The fixtures are controlled through an Ethernet connection that allows fast data transfer to and from the lights and sensors.

The color sensors also allow the lamps to respond to incoming daylight, a technique known as daylight harvesting, to automatically adjust the electric lighting. The sensors can tell the difference between sunlight coming in from the windows and light coming from the fixtures to achieve the ideal intensity and color balance along with maximum energy savings.

“Daylight harvesting is an important feature of future lighting systems. Currently, lighting...”

company that specializes in LED lighting systems for plant research and greenhouse cultivation. There, she ran a program to develop specific LED light regimes to optimize plant growth while manipulating plant morphology and biochemistry naturally.

“One thing I’m really interested in is increasing nutrient value in crops, and you can do that just by using dynamic LED lighting systems,” Pocock says.

In her lab, Pocock has several growth chambers, where she keeps rows of kale, basil, and a variety of lettuce. The plants are exposed to various combinations of red, blue, and green LEDs.

All parts of the visible spectrum are used in photosynthesis, but light also affects plant development. Adding more blue or red light affects different plants in different ways. Red tends to affect germination, plant height, flowering, and leaf area. Blue light affects a plant’s biochemistry, and therefore the nutrient level.

“Light and plants have a complex and important association. By changing the spectrum, you can shake up the plant’s biochemistry and you can push the light regulated genes to their maximum capacity,” Pocock says. “You can control and regulate the pigmentation, and therefore the nutrient value. The more red the lettuce, for example, the more nutritious it is.”

Plants also emit their own light that is just beyond our visual range, which can be detected with today’s advanced optical instruments. When a plant is under stress, for instance, it will emit deeper red light.

With this knowledge, Pocock is developing a biofeedback system that will allow plants to communicate their lighting needs. The concept is that a plant, through its own light, will signal to the biofeedback device what type of lighting it needs at a given moment. An LED lamp will then automatically adjust to the right setting.

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"Imagine your whole ceiling is a camera now, but you only have one pixel in every light fixture. That’s your new camera, a five-pixel camera. What can you do with that?"  

ROBERT KARLICEK

contributes to about 15 percent of the total electrical energy consumption in the U.S.,” says Sina Allahbakhsh ’15, a Smart Lighting ERC postdoctoral associate who was involved in the design of the conference room’s lighting system. “We have shown in our research that this number can be decreased by half without loss of illumination quality.”

The color spectrum control capabilities of the lighting in the Smart Conference Room have generated interest from two faculty members who collaborated on a study called Lighting and Mindful Practice (LAMP). The study assessed a meditation practice for stress reduction in the context of different lighting conditions.

Tomie Hahn, associate professor in the Department of the Arts and director of the new Center for Deep Listening, taught a course called Deep Listening and Creativity. Deep Listening is a meditation practice developed by Rensselaer Distinguished Research Professor of Music Pauline Oliveros that is based on music, visual art, science, and technology. Alicia Wolf, a neuroscientist who specializes in hormones and stress, is a lecturer in the Cognitive Science Department. She taught a course called Stress and the Brain.

The two classes composed of 35 students met in the conference room for three sessions. The students were exposed to various levels of white light of fixed color temperature and brightness, but with variable color rendering. Students took their heart rates and blood pressure and filled out questionnaires about stress before and after five minutes of meditation.

The lower the light’s color saturation (in which the colors looked more washed out), the higher the perceived stress levels were among the study’s preliminary findings. Heart rates were also the highest under low-saturation conditions. The study was presented at the Psychology Convention at Hunter College in New York City in April.

“It’s valuable to note how different lighting conditions in random with Deep Listening meditation practices affect stress levels,” Hahn says.

Karlicek adds, “This new ability to dynamically control the color properties of lighting is being studied in health care, education, and workplace settings to improve well-being and productivity, but there is still a lot to learn.”
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JOHN WEN

electrical engineering and is now a camera application engineer at Apple. She worked on the ToF occupancy tracking system from its inception under Radke’s direction.

“Although it’s more challenging to work with this much lower pixel count, it turns out you can do perfectly good tracking and get a rough estimation of if a person is standing up or falling down,” Radke notes. “You don’t need a high-resolution camera to answer these kinds of questions. You can use these simple types of sensors that are less expensive and just as efficient.”

COLOR FOR HEALTH, PRODUCTIVITY, AND WELL-BEING

It is well known that daily cycles of light exposure influence circadian rhythms, which regulate themselves about every 24 hours, including the human circadian clock.

The circadian rhythm can vary slightly from person to person, and even in the same individual over time, in part because the sleep-wake cycle is slightly longer than the 24-hour day. This makes it difficult to create a one-size-fits-all therapeutic light solution.

“So far, there hasn’t been a way to accurately and automatically measure a person’s circadian rhythm from everyday activities,” Wen says. “Our technology provides a way to accomplish this and will therefore help doctors and others build a customized approach for light therapy.”

The app, which is being developed for smartphones as well as for the fitness tracking wristband called Microsoft Band and for other wearable devices, can be connected to lighting systems or even for smartphones and tablets, the process of linking photodiodes to digital systems, ranging from our phones and tablets to self-driving cars. The idea is that this autonomous vehicle will be able to control lighting in a space, whether indoor light to the circadian rhythm can help people sleep better and improve health overall.

COMMUNICATING WITH LIGHT

Researchers are exploring a type of visible light communications (VLC) technology sometimes referred to as “Li-Fi.” This technology uses LED light to enhance productivity. The term Li-Fi, short for “light fidelity,” was coined by Harald Haas, chair of mobile communications at the University of Edinburgh, to describe the emerging use of VLC for wireless data access. In 2011 during a TEDGlobal conference, he presented a prototype of a device that transmitted a video of Hispanic dancers onto a screen behind him using a standard LED lamp. Li-Fi shares the same delivery concept as Wi-Fi except that data is wirelessly transmitted via electromagnetic waves in the visible instead of the invisible RF electromagnetic range.

The modulator is so fast and subtle that it is imperceptible to the human eye and does not interfere with the quality of illumination. With the explosion in the use of smartphones and tablets, there is growing interest in providing new ways to create more data access capacity. VLC brings new opportunities for this capacity,” says Thomas Little, Smart Lighting ERC associate director.

Little also leads the Multi-media Communications Lab at Boston University, where the Communication Test Bed has been set up to develop and evaluate VLC and motion-tracking technologies.

“Lights in the test-bed ceiling are conveniently dispensed to provide both high-quality lighting and delivering data access where users are located in the space,” he notes.

Still, there are many hurdles to overcome before Li-Fi becomes ubiquitous. One challenge is the ability to sustain continuous connectivity as a smartphone, laptop, or other electronic device is moved about in a space.

In the cellular communications world, this technique is called handshaking, the process of linking phone calls or data wirelessly from one point to another. This allows us to maintain a phone call as we are traveling between cell towers.

“Li-Fi is a different world,” says Joseph (Gaoyang) Li, associate professor at Rensselaer, who leads the Li-Fi research team in evaluating Li-Fi technology for wireless systems. “Li-Fi is a different world,” says Joseph (Gaoyang) Li, associate professor at Rensselaer, who leads the Li-Fi research team in evaluating Li-Fi technology for wireless systems.

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