Lighting a path to smarter homes, roads and bridges

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If you're worried about carbon monoxide poisoning, you might purchase a detector for your home. But what if your house itself could sense carbon monoxide and other potentially harmful gases – nitrogen oxides, natural gas, formaldehyde – without the need for a separate device for each chemical?

And what if all these sensors spoke to each other through a single interface, a sort of super-thermostat?

This vision could be realized one day using sensor technology currently being developed at the National Institute of Standards and Technology (NIST) in Gaithersburg, Md. The techniques make use of photonics – measurements made by manipulating light.

"We want to get away from the idea of having one sensor for one thing" and another sensor for another, says Zeeshan Ahmed of NIST's Physical Measurement Laboratory (PML). Instead, he says, a network of sensors could be spread throughout a building, integrated into the walls. They could even be built into roads and bridges, to monitor the health of these structures in real time.

Furling Fibers

To create light-based chemical detectors, the NIST team of researchers has been experimenting with commercially available optical fibers, similar to the ones that are becoming ubiquitous in network communications. Thinner than a human hair, the fibers have a grating inside them, a pattern etched into their glass cores, that allows only certain wavelengths of light to pass through.

Deforming the fiber – perhaps by bending, expanding, or compressing it – changes the wavelengths that make it through the grating. That change in wavelengths is a signal that can be matched up to changes in the environment that caused the deformation.

To turn a fiber into a humidity sensor, for example, the researchers have tried coating it with materials that are sensitive to water. The one that works best so far is carboxymethyl cellulose (CMC), a compound with a honey-like viscosity. CMC absorbs water vapor like a sponge, explains NIST guest researcher Matthew Hartings, who is also an assistant professor of chemistry at American University in Washington, D.C. When saturated, it expands, and the fiber straightens. But when the coating dries, it shrinks, and that puts a strain on the glass fiber, which bends to accommodate it.

"It turns out that by putting a small amount of material on the fiber you get a huge mechanical deformation" in just seconds, Ahmed says.

Right now, the researchers are trying to maximize the bending effect by changing the thickness of the coating and how uniformly it is applied. But detecting water is just the beginning. Coating the fiber with a different material could make it sensitive to something else. The team plans to explore other kinds of coatings, in the hopes of finding ones that will swell in response to carbon monoxide, airborne formaldehyde, and other potentially harmful gases.

Crushing Concrete

Bridges and roads get a lot of abuse from the heavy loads they support. Integrating photonic sensors into these structures would allow engineers to monitor the structures to determine whether they are degrading over time. As a proof-of-concept experiment, and working with NIST's Engineering Laboratory (EL), the PML team recently showed that their sensors could be used to measure the pressure being applied to concrete.

Even on initial tests, the fiber sensors could detect changes in load in real time, says NIST's Kevin Douglass. The researchers were also pleasantly surprised to find that they didn't have to embed the sensors in concrete to see a pressure change. Simply gluing the sensor onto the concrete's surface was enough, meaning that fiber sensors like these could be added to existing infrastructure to monitor cracks and other kinds of structural degradation.

By distributing multiple sensors via optical fiber within and along the outside of structures, photonic devices could "provide rich information on the spatial variation of strain, as well as other quantities, such as temperature and humidity," says EL's Joe Main. In particular, the ability to make humidity measurements within concrete could be used to detect the infiltration of water, "which results in corrosion of reinforcing steel, accelerating the degradation of a structure."

Ahmed says the team has used the sensors to measure changes in temperature and humidity inside concrete as it sets, too, which could help materials researchers design better recipes for concrete.

"If you understood the chemistry better, you could optimize the concrete you're making to get something that would last for thousands of years," Hartings says.

Moving forward, the researchers hope to find ways to streamline the sensors so that they could be commercialized, and used by people who aren't Ph.D. physicists. "Making it cheaper and easier to use is our big focus," Ahmed says. "How do you develop techniques that someone who hasn't spent years and years learning these can use it?"

They will also experiment with photonic sensors built into chips. Instead of having several different fibers each tuned to a different property, a single chip could have all the different sensors built into it. "It's a much more holistic way to look at things, to really capture what's going on in an environment," Hartings says.

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