EE Times: Sensor nets bridge safety gap

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Engineers in laboratories nationwide are perfecting embedded sensor networks that could alert crews to defects in critical structures well before the problems cause catastrophic failures such as the recent collapse of Minneapolis' I-35W bridge.

Structural health monitoring (SHM) is a sensor-based preemptive approach that could supplement the current system of visual inspections and follow-on tests of bridges, buildings, aircraft and other safety-critical structures. But SHM sensor systems have not been deployed in the United States, where the approach is too new to be covered under current codes.

Today, companies like Material Technologies Inc. (Los Angeles) can conduct on-site structural tests when called upon, but the ability of such tests to prevent disasters is limited because the monitoring is not continuous. Sensor-based SHM, on the other hand, theoretically would safeguard structures 24/7, wherever it is deployed.

"Structural health monitoring's time has come," said Dennis Roach at Sandia National Laboratories, leader of a team investigating the available options for SHM. "Embedded sensors offer vigilance that periodic checkups cannot. Using them for structural health monitoring is a reliable and inexpensive way to sense the first stages of defect formation."

Besides bridges, buildings and aircraft, SHM can be used to monitor the structural well-being of spacecraft, weapons, rail cars, oil recovery equipment, pipelines, armored vehicles, ships, wind turbines, nuclear power plants and even the fuel tanks in hydrogen-powered vehicles. But today SHM is routinely used only in Asia, where governments concerned about seismic activity have sprung for the sensor networks.

"The best thing we could do is build sensor networks into our bridges, buildings and aircraft--especially while they are being constructed, so you can place sensors inside their structures," said Jerome Lynch, an EE from Stanford University who is now a professor at the University of Michigan (Ann Arbor). "The most instrumented bridge in the world is over Hong Kong Bay, and at least half a dozen bridges going up in China will have arrays of sensors embedded from the start. But in the U.S., nobody is doing that."

What will it take?
The United States today depends almost entirely on visual bridge inspections: Tests using eddy currents, ultrasound or penetrating dyes are used only if corrosion or cracks are spotted visually. In the wake of the I-35W bridge collapse, U.S. labs are recommending the use of wireless nodes that would continuously transmit structural-health information to maintenance crews. Because sensors can detect cracks that are smaller than can be seen with the naked eye, workers privy to fault data from sensors could make repairs while the defects are still microscopic.

The University of Michigan has created a "nanotube paint" that can turn any surface into a two-dimensional imager of its own underlying health. By spraying on the paint and attaching a wireless transmitter, Lynch said, workers could equip bridges for remote monitoring at a cost low enough to allow the approach to be deployed as standard equipment for all new projects and as retrofits for existing structures.

Michigan's solution is a spray-on sensing "skin." Lynch, who has designed blast-resistant structures for the Central Intelligence Agency and installed a wireless SHM system on the Geumdang Bridge in Icheon, South Korea, claims the nanotube paint can turn any surface into a two-dimensional imager of its own underlying health. By spraying on the paint and attaching a wireless transmitter, Lynch said, workers could equip bridges for remote monitoring at a cost low enough to allow the approach to be deployed as standard equipment for all new projects and as retrofits for existing structures.

The cost is kept low because the monitoring sensors only have to be placed around the perimeter of the painted area. Any location on the surface of the skin can be imaged, with corrosion and cracks shown as areas of high resistance. Lynch said the technique can be adapted to specific applications by adjusting the density and type of nanotubes used. Michigan is seeking a commercialization partner.

In the meantime, a piezoelectric sensor solution can be bolted onto structures today at a cost of about $1 per node, according to Los Alamos National Lab.
The piezoelectric patch would emit an ultrasonic ping in actuator mode. Then the system would rapidly switch to sensor mode to record and analyze the ping's reflection using the same piezoelectric element (this time to transduce an electrical signal from vibrations in the bridge caused by the ping). Using pattern recognition software, the computer analyzing the ping's reflection would sense changes in the bridge's structure.

"We are using something like active sonar," said Chuck Farrar, an engineer at Los Alamos, which conducted the work with a University of California-San Diego team. "We stimulate the structure with a high-energy elastic wave between 50 and 250 kHz. Then we compare its response to what we heard the last time it was tested."

Later this month, a bridge in southern New Mexico will be the first to have the piezoelectric sensors and actuators installed. The wireless sensor nodes were cost-reduced by dispensing with a power supply: Instead, the sensors "are powered by microwaves beamed from a small unmanned helicopter. That charges up a capacitor on the sensor's circuit board, giving it enough power to take its readings and wirelessly broadcast the results back to the helicopter, where a single board computer tallies it," said Lynch.

Sandia (Albuquerque), for its part, is championing an ultracheap but supersensitive sensor called a comparative vacuum monitor. CVM sensors use a grooved strip that is glued to the structure to be monitored. Air is pumped out of the grooves, enabling a very sensitive monitoring device whose vacuum will be broken by even molecular-sized cracks in the surface to which it is attached. The thin, self-adhesive rubber patches range from dime- to credit-card-sized and cost only about a dollar each, and any number of them can be monitored with a single vacuum line.

"If cracks form, they will be detected by breaking open the vacuum seal," said Roach. "These are the first in situ sensors that can monitor fatigue and are cheap enough to be embedded into structures and left there" for continuous monitoring.

A CVM manufactured by Structural Monitoring Systems Ltd. has been monitoring commercial airlines for several years as part of a test of the technology. Boeing recently validated the approach.

Sandia is also experimenting with a bridge repair system based on reinforced composites. It recently repaired a fatigue crack on a New Mexico bridge with new composites, then installed an eddy-current-monitoring sensor with a built-in wireless sensor that allows the health of the repair to be remotely monitored.