Wireless sensor networks offer high-tech assurance for a world wary of earthquakes

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An earthquake strikes a large city, wrecking roads and bridges, stranding rush-hour commuters, trapping office workers inside high-rise buildings. As director of the city's transportation authority, you have minutes to make a momentous decision. What is the safest, fastest route that rescue teams can take to travel to hard-hit areas of the city? Which bridges, even if damaged, can still support traffic loads?

Questions like these are increasingly on the minds of structural engineers and emergency personnel as the world prepares to mark the 100th anniversary of the Great San Francisco Earthquake of April 18, 1906.

The answers to the questions, says Yunfeng Zhang, can be provided by sensors – networks of tiny sensors with built-in computer chips that are attached to a bridge to monitor its safety and performance.

Sensors deployed strategically on a bridge, says Zhang, an assistant professor of civil and environmental engineering at Lehigh University, can provide a high-resolution, multi-dimensional picture of the health of a structure, giving engineers vital information about a bridge's performance and, in the aftermath of a catastrophe, its ability to carry traffic.

To be useful in the event of an earthquake or other emergency, says Zhang, sensor data must be transmitted in real time, virtually without delay, to remote processing centers for interpretation and then to decision-makers.

Wired sensors can transmit data in real time but they have limitations, says Zhang. Installing and maintaining the wires is costly and labor-intensive. Wires degrade and are prone to interference from electro-magnetic signals. And wires themselves might get damaged in earthquakes.

Zhang recently received a five-year, $400,000 CAREER Award from the National Science Foundation to develop wireless sensor networks for bridges and other structures with the aim of improving the transmission of sensor data and the ease in accessing the data. The project is titled "Integrated Research and Education in Smart Sensing and Intelligent Structures Technology."

Wireless sensor networks, which are relatively new, avoid many of the problems that hamper wired sensors. But they face obstacles. The relatively narrow communication bandwidth available for civil-engineering wireless sensors can reduce download rates to one kilobyte per second, not nearly fast enough to crunch the enormous amounts of data generated by a bridge in operation.

To improve data transmission and management, Zhang is developing high-performance sensor data compression algorithms for structural health monitoring applications. (An algorithm is a set of rules or computational procedure for solving a problem.) His algorithms incorporate structural system information to remove redundancies from sensor data and thus maximize the compression rates for sensor network data. Zhang also uses data-mining techniques to extract key information more efficiently from data.

"Using the sensor data compression algorithm I'm developing," he says, "we can minimize data-downloading time and ultimately download data in real time and evaluate it in near real-time basis."

Zhang's research draws on structural engineering, systems science, information technology, as well as electrical engineering.

As part of his NSF project, Zhang plans to implement a wireless sensor network on a cable-stayed bridge in eastern China to monitor its structural health and operating condition. The bridge, built in 2000, was accidentally damaged during construction and its actual operating condition is thus different from its design condition. The bridge was repaired and is operating, says Zhang, but aggressive monitoring is needed to ensure that it can continue to be safely used by traffic.

Using wireless sensor networks that Zhang will help develop, Zhang and the Chinese engineers are planning to conduct a full-scale validation test on the Chinese bridge in 2009.

Zhang says the data he collects from testing the Chinese bridge will also be useful for bridge operators in the U.S., where cable-stayed bridges have a relatively short history of use and have not yet generated a large body of data.

As part of his NSF award, Zhang will incorporate his research into his classes. This spring, Zhang is teaching an upper-level undergraduate course in smart structures technology that he first taught as a graduate course in 2004.

In the course, students will construct a Japanese pagoda and attempt to shed light on an ancient mystery – why, in earthquake-plagued Japan, the wooden temples have for centuries withstood seismic forces much better than any other type of structure.

Zhang, who joined the faculty in 2001, believes the smart structure technology course is the first civil engineering course in the U.S. to integrate sensors, control, smart materials, information technology, structural engineering and structural health monitoring. Twelve senior civil engineering majors and five grad students are enrolled in the course this spring.

"I want to educate the next generation of engineers about an exciting technology that has broad future applications," says Zhang. "Smart structure technology is only in the developmental stages, but as educators, we need to plan ahead so that when this technology is available in 10 years, our graduates will know how to utilize it."

Source: Lehigh University