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# Science & Technology REVIEW

Lawrence
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Light Lock Optical Security System

OptiPro AED Proximity Sensor

## R&D 100 AWARDS

HERMES Bridge Inspection System

Optical Dental Imaging System

Laser Peening for Metal Protection

Two-Color Fiber-Optic Infrared Sensor

INDUCT95 Software Simulation Code

# Bridge Diagnosis at 55 mph

SAY the words "closed" or "construction ahead," and see despair cloud a driver's face. It's hard enough to drive on roadways these days without added disruptions. But happen they will because some $20-billion worth of highway infrastructure maintenance must be done each year in the U.S. to keep motorists on the move safely. State departments of transportation—owners of most of the nation's highways—face this large workload with scarce maintenance resources; they could use new technologies to help perform tasks faster, cheaper, and more effectively.

The Federal Highway Administration (FHWA) has helped sponsor a research project at Lawrence Livermore that produced a beneficial new tool as well as an R&D 100 Award. The HERMES Bridge Inspector will provide an invaluable capability to diagnose the problems of deteriorating bridge decks and do it accurately, efficiently, nondestructively, and, perhaps most important to motorists, without closing bridges. Almost 30% of 600,000 large highway bridges in the U.S. are classified "deficient" by the FHWA, and HERMES can make a significant contribution toward solving the problem of infrastructure assessment and repair. With further development, HERMES holds promise for other concrete inspection problems, such as railroads, tunnels, and runways.


**Figure 1.** Trailer containing the HERMES Bridge Inspector system. Livermore team members include (left to right front row) Scott Nelson, Ming Liu, Jeff Mast, Stephen Azevedo, Jose E. Hernandez, Bob Stever, and Richard Gilliam; (back row) Tom Story, Mark Vigars, Tom Rosenbury, Greg Dallum, Holger Jones, Pat Welsh, George Governo, and John Warhus.

HERMES, or High-performance Electromagnetic Roadway Mapping and Evaluation System, is a radar-based sensing system mounted in a trailer. It can be pulled by a vehicle at traffic speeds over a bridge deck to collect information about the roadway subsurface—its sensors gathering data 30 centimeters or more into concrete. An onboard computer system processes the data into three-dimensional images that pinpoint problems in the roadway concrete and give engineers quantitative information about deterioration in the bridge deck. Engineers can then better assess what repairs or reconstruction is necessary and avoid the cost overruns and delays that result from inexact problem diagnoses.

HERMES technology is a radical change from conventional bridge inspection methods in use today. Most inspections are still done visually—with inspectors looking for external manifestations of internal flaws—a tedious and not completely reliable method. Another conventional inspection method uses sound: after the top layer of asphalt is stripped off, an inspector with a trained ear "listens" for faulty concrete as chains are dragged over the underlying concrete. The latter technique is costly, requiring time-consuming bridge closure, asphalt removal, and resurfacing.

In contrast, when put to the test last summer in Weaverville, California, HERMES quickly and accurately found significant problems on the Grass Valley Creek Bridge, where retrofit work had been scheduled. The internal flaws revealed the need for a complete deck replacement instead of the planned rehabilitation. What HERMES "saw" was verified once work began and the roadway's top asphalt layer was removed. Consequently, the bridge repair project had to be revised, causing a delay of a year and a million dollars in costs that could have been avoided had HERMES been available before the bidding process began.

### Applying MIR Technology Again

The idea for using radar to inspect bridges was born out of the Laboratory's expertise in pulsed power and computational imaging and a collaboration with the FHWA. Engineering's Karl Freytag and the FHWA's Structures Division Manager Steve Chase foresaw the need for a visualization tool for infrastructure assessments. Under Engineering's initial funding and the FHWA's sponsorship and guidance, HERMES researchers experimented with a number of approaches to system development and settled on a small impulse radar sensor developed at Livermore as the visualization technology.

Micropower impulse radar (MIR) is a spinoff invention from Livermore's laser fusion diagnostics work in transient digitizers, itself an R&D 100 winner in 1993 (see articles in *E&TR*, April 1994, and *S&TR*, January/February 1996). Since the first award,

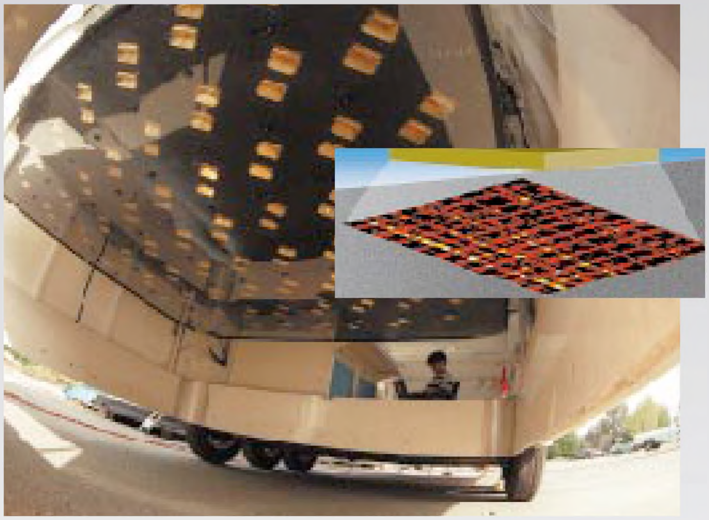

**Figure 2.** A fisheye-lens view of HERMES modules from under the rear door. The array of 64 radar modules can be raised and lowered in the bottom of the trailer. Inset image shows the condition of rebar in a bridge deck.

MIR has been applied to numerous uses, ranging from an electronic dipstick to measure fluid levels in automobiles (winning another R&D 100 Award in 1996; see *S&TR*, October 1996) to a land-mine detection system (*S&TR*, November 1997). Much of the MIR development and the current MIR projects have been headed by Stephen Azevedo.

Experiments using MIR to image concrete slabs showed vast improvements over the higher-powered, lower-frequency systems tested earlier. At the same time, Laboratory engineers were developing unique three-dimensional reconstructive imaging software, using diffraction tomography that was refined to “see” through layers of material.

In contrast to conventional radar, which uses continuous microwave energy to detect objects over many miles, impulse radar transmits ultrashort electromagnetic pulses that allow the detection of objects at very short ranges. MIR’s pulses, producing a wide band of frequencies, generate a great deal of information about detected objects at high resolution and accuracy. The echoes of these pulses are measured by an extremely sensitive receiver that is set for a detection range of a few centimeters to many tens of meters. MIR system components also include timing circuitry, a signal processor, and antennas. Together, they determine system range, directionality, and how well materials such as concrete, wood, and other nonmetallic materials can be penetrated.

An MIR system is compact and lightweight and has low power requirements; it is cheaper to produce than a conventional radar system and is amenable to many more applications. Furthermore, MIR modules can be grouped into arrays to increase system speed and area of coverage.

For HERMES, 64 high-speed impulse radar modules were mounted underneath the HERMES trailer to send out very fast, short pulses—1 to 5 gigahertz—into the ground, penetrating roadway concrete to a depth of up to 30 centimeters. As the pulses propagate through the bridge deck, concrete defects alter the return signals because of the change in dielectric constant. These alterations are recorded by the computer system located inside the trailer. As the array of radars is driven over the bridge, a three-dimensional map of the deck is constructed using sophisticated imaging software. The map shows in remarkable detail the reinforcement bars and anomalies that may indicate delamination, faulty concrete, or other problems that occur in the inspection area.

One engineering challenge was to configure all 64 radar modules to fit underneath a normal-width trailer yet be sufficiently separated to avoid causing interference. The HERMES team, now headed by Jose E. Hernandez, experimented with several arrangements before settling on the final configuration of eight rows of eight MIR modules. Insulating foam between modules minimizes crosstalk.

## Down the Road

The project team continues to gain understanding of the images the system generates and of how to better design the next generation of bridge inspectors for improved detection capability, higher speed, ruggedness, and eventual transfer to the private sector. On the road again in July 1998, HERMES could be seen testing its system upgrades on bridges along highway I-80 near Truckee, California. Also, the HERMES team is using electromagnetic models for analyzing the radar data to understand how concrete inhomogeneities, temperature differences, chemical processes, and normal concrete structures contribute to the imaging results. This modeling will enable them to predict inspection results under varying conditions and suggest changes to the radar parameters and detection algorithms.

The HERMES Bridge Inspector will save the public money—up to $100 million per year, according to FHWA estimates—and inconvenience. Even more important, it will result in higher confidence and safety in our public roadways.

*—Gloria Wilt*

**Key Words:** HERMES Bridge Inspector, infrastructure maintenance, micropower impulse radar (MIR), nondestructive evaluation, roadway inspection, ultrawideband sensors.

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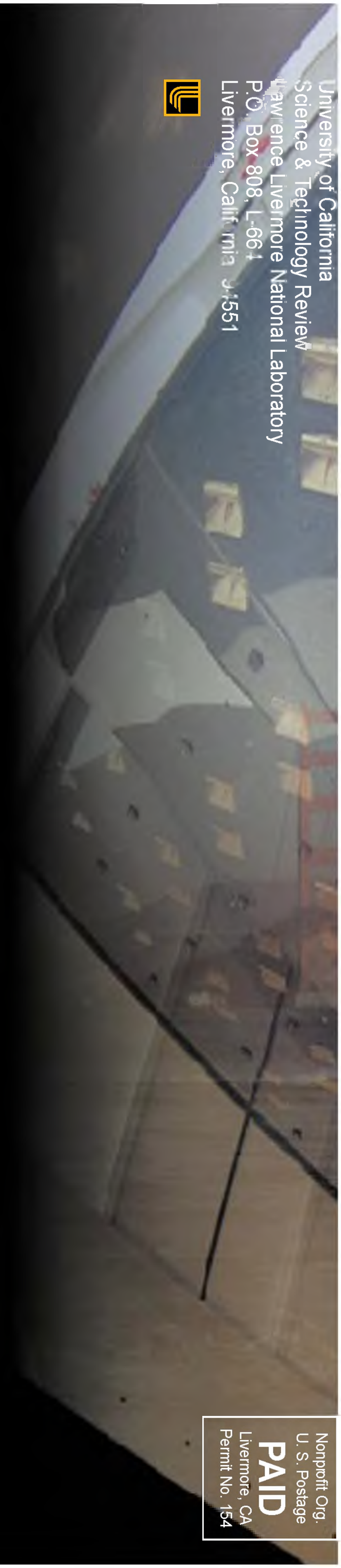

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