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RESEARCH
Oregon Department of Transportation

OREGON DEPARTMENT OF TRANSPORTATION
Research Notes

Can bridges have nerves?

NEW TECHNOLOGY DEVELOPING FOR 'SMART' INFRASTRUCTURE

Fiber optic sensor technology offers the possibility of implementing "nervous systems" for infrastructure elements that allow high performance, cost effective health and damage assessment systems to be achieved.

In this nerve system, the optical fibers are the information carrier and along their length are the fiber sensors, or nerve endings, which are used to sense the environment. They can be readily incorporated into new construction or retrofitted into existing infrastructure.

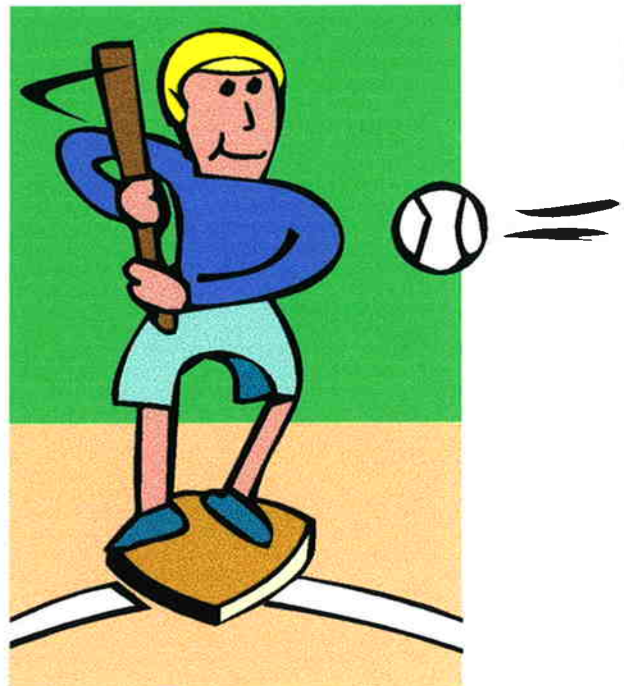
The information from these "nerves" (optical fibers) and "nerve endings" (fiber optic sensors) is carried to optical/electronic demodulators. These demodulators do a rudimentary sorting of the information, similar to that occurring in the lower part of a brain. This first-level processing is similar to the overall "awareness level" of nerves in a human body. For some fiber optic sensor systems this is all the sophistication required. Environmental effects are simply recorded when they happen.

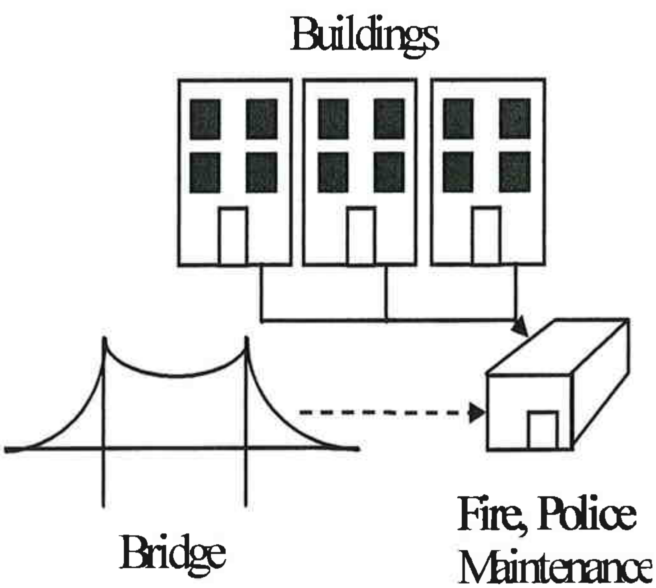
In the future, however, large systems integrated into bridges, tunnels, large sections of highways or retaining walls may have very large numbers of sensors, perhaps numbering in the thousands.

When something happens to an area of a large structure that requires additional analysis, the demodulated signals may be subject to considerable post processing, an action similar to higher order brain functioning.

HOW FIBER OPTIC SENSOR TECHNOLOGY WORKS

As an example of a similar system, consider the case of a little league baseball player who is batting. The pitch is thrown and the batter is hit on the arm. The first level of awareness is the hit on the arm. The nerves identify the location of the damage and the batter then looks it over carefully to assess the area for swelling, redness, or bleeding. When the player is batting, not all nerves are firing and demanding attention at once. If this happened the batter could not function, as the brain would be overwhelmed. Instead, the brain is provided with a low-level situational awareness. When the batter is hit, the low-level brain functions indicate an area of pain, and the higher order brain functions take over to do a detailed assessment.





Fiber Optic Sensor Networks for SMART Structures

Consider a bridge with thousands of fiber optic sensors deployed to perform detailed health and damage assessment. The signals from these many sensors would be used to provide the sensor data processor with an overall status of the health of the bridge at a low level. When damage occurs, such as a barge slamming into a piling, the low-level signals from the fiber sensor system would indicate the location of the damage. Then the level of interrogation of the sensors would be reconfigured so that a detailed assessment of the damage could be made and appropriate action taken. In extreme cases, the system could close the bridge.

As the technology progresses, there is the prospect of merging fiber optic sensor and communication systems into very large systems capable of monitoring the status of buildings, bridges, highways and factories over widely dispersed areas. Functions such as fire, police, maintenance scheduling and emergency response to earthquakes, hurricanes and tornadoes could be readily integrated into very wide area networks of sensors. It is also possible to use fiber optic sensors in combination with fiber optic communication links to monitor stress build-up in critical fault locations and volcano dome build-up. These widely dispersed fiber networks may offer the first real means of gathering information necessary to form prediction models for these natural hazards.

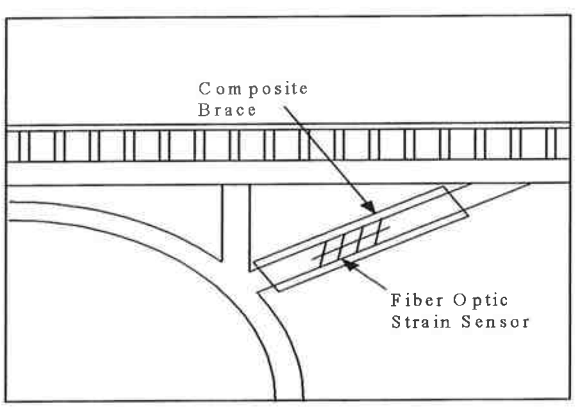
APPLICATIONS OF FIBER OPTIC TECHNOLOGY

This technology is now possible, largely due to synergistic developments in the fiber optic telecommunication and optoelectronics fields, where industries with multi-billion dollar research and development budgets exist. Essential components are becoming available with prices and performance that are improving dramatically on an annual basis.

Fiber optic sensors are based on hair thin optical fibers. A first step to understanding optical fibers is to think of them as light "pipes", in which light actually reflects from the inside surface, which could be thought of as a mirror. The fibers can be configured to measure a wide range of effects via changes in light beams that are moving through them.

There are several key features of fiber optic sensor technology that make a compelling case for infrastructure applications:

- immunity to electromagnetic interference,
- very small size,
- environmental ruggedness,
- the ability to multiplex many fiber optic sensors,
- possible low cost, high performance devices in the future,
- multifunctional capabilities, and
- a wide range of sensor gauge lengths.



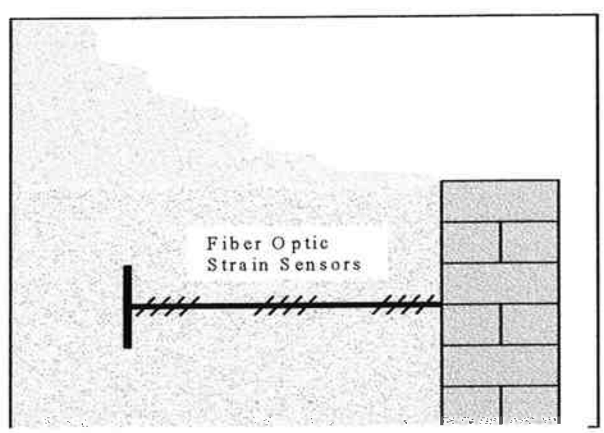
Strain Sensor Monitoring Truss Reinforced with Composite Brace

These features allow the designer to have a range of options that are unavailable using conventional sensor-based technology.

There are four main categories of fiber optic sensor use in infrastructure applications: attached or embedded sensors, nondestructive testing of parts prior to installation, health monitoring systems, and control systems.

The following are application examples:

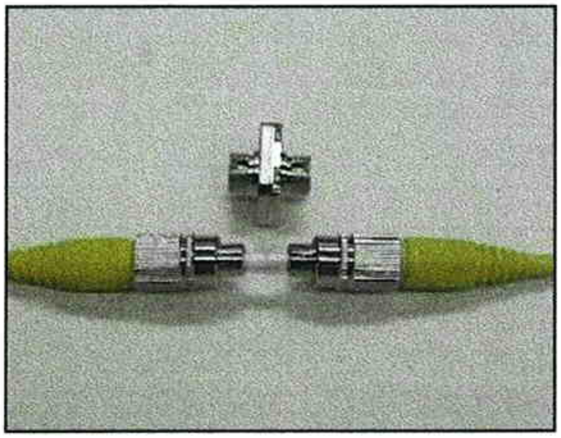
- Strain sensors on a retaining wall anchor or on a suspension bridge
- Sensors embedded in supports to measure the balance of a drawbridge
- Monitoring truss reinforced with a composite brace
- Sensors used for traffic control, speed and weight measurements
- Sensors to monitor the condition of tunnels
- Sensors embedded into composite washers
- Fiber sensors placed at important points in a structure to measure corrosion on rebar
- Embedded temperature sensor to measure the curing of a thick concrete pad
- Acoustic sensors to detect anomalies in roads, bridges, or railway tracks
- Arrays of fiber optic pressure sensors to perform such critical geotechnical measurements as water content and compaction of the soil for infrastructure construction operations



Strain Sensors on Retaining Wall Anchor

An example of a road-weather condition monitor is a Fiber Bragg Grating ice sensor, which can detect ice on the road and trigger an action, such as posting warnings on electronic signs in the area.

Currently, fiber optic sensors are being developed and used in two major ways. The first is as a direct replacement for existing sensors where the fiber sensor offers relative immunity to electromagnetic interference, significant weight savings, and significantly improved performance, reliability, safety and/or cost advantages to the end user. The second is the development and deployment of fiber optic sensors in new market areas.



Fiber Optic Connectors Touch Inside of Mating Sleeve

For the case of direct replacement, the inherent value of the fiber sensor to the customer has to be sufficiently high to displace older technology. The ability of fiber optic sensors to displace traditional sensors for rotation, acceleration, electric and magnetic field measurement, temperature, pressure, acoustics, vibration, linear and angular position, strain, humidity, viscosity, and chemical measurements has been enhanced as component prices have fallen and quality improvements have been made.

The automotive industry, construction industry and other traditional users of sensors remain relatively untouched by fiber sensors, mainly because of cost considerations. This can be expected to change as the improvements in optoelectronics and fiber optic communications continue to expand, along with the continuing emergence of new fiber optic

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