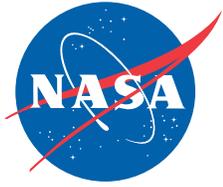




National Aeronautics and
Space Administration



Fiber Optic Sensing System (FOSS) monitors multiple critical parameters in real time

Revolutionary technology offers wealth of flexible options for a wide variety of applications

The FOSS technology developed at NASA's Armstrong Flight Research Center represents a major breakthrough in high-speed operational monitoring and sensing technology. Driven by ultra-efficient algorithms, FOSS can be used to determine in real time a variety of critical parameters, including strain, shape deformation, temperature, liquid level, strength, and operational loads. The system processes information at rates up to 5,000 times per second, representing a 1,000-fold improvement over conventional fiber optic technologies. In addition, it offers unprecedented levels of data density, as each 40-foot hair-like optical fiber provides up to 2,000 data points with adjustable spatial resolution. To achieve these revolutionary capabilities, FOSS employs fiber Bragg grating (FBG) sensors and a combination of optical frequency domain reflectometry (OFDR) for high spatial resolution and wavelength division multiplexing (WDM) for high acquisition speed, together with an interferometer technique that can simultaneously interrogate thousands of FBG sensors in a single fiber. This state-of-the-art sensor system delivers reliable measurements in the most demanding environments confronted by the aerospace, engineering, automotive, and energy sectors.

Benefits

- ▶ **Highly accurate:** Scans 8 channels simultaneously; with up to 2,000 sensors per fiber, the multiplexing system can calculate 16,000 measurements at once
- ▶ **Powerful:** Ultra-efficient algorithms and high-speed processing platform allow for rapid processing of data, enabling real-time analysis
- ▶ **Ultra-fast:** Processes information up to 100 samples per second (OFDR) and 5,000 samples/sec (WDM)
- ▶ **Lightweight:** Weighs just 10 pounds and operates on 16 to 30 volts of DC power or 120 volts of 60 Hz AC power
- ▶ **Flexible:** Outputs data in a widely recognized standard, enabling users to port data into any third-party software
- ▶ **Non-intrusive:** With thousands of sensors on a single fiber, sensors can be placed at 1/4-inch intervals (e.g. within bolted joints and in composite structures), enabling precise, high-resolution measurements in locations where conventional strain gauges will not fit

technology solution



Applications

The FOSS technology is ideal for monitoring the structural health of aircraft, buildings, and dams; improving the efficiency of turbines and industrial equipment; detecting instabilities within tunnels and power plants, and much more.

AEROSPACE

- ▶ Real-time structural monitoring for complex bending modes of in-flight aircraft
- ▶ Monitoring temperature, strain, load, and cryogenic liquid levels in aerospace launch vehicles
- ▶ Monitoring thermal/structural health of satellites
- ▶ UAV flight refueling
- ▶ Flight testing
- ▶ Aeroelastic feedback control
- ▶ End-of-life-cycle decision making
- ▶ Structural design
- ▶ Embedded-fiber design and monitoring
- ▶ Maintenance scheduling

ENERGY

- ▶ Strain and temperature monitoring for industrial borescope usage in drilling and exploration
- ▶ Strain, shape, and temperature monitoring of next-generation seismic processing instruments used for the exploration of future drill sites
- ▶ Temperature and liquid level monitoring of fluid storage tanks
- ▶ Nuclear power plant vibration and temperature monitoring
- ▶ Higher oil and gas-reserve extraction

TRANSPORTATION AND INFRASTRUCTURE

- ▶ Structural health monitoring of buildings, bridges, off-shore oil rigs, and dams
- ▶ Monitoring the structural health of moving vehicles
- ▶ Load balancing on cargo ships and oil tankers
- ▶ Monitoring hulls of tankers and naval vessels
- ▶ Studying truck and automobile frames

MEDICAL AND SURGICAL MANEUVERS

- ▶ Procedures involving endoscopes
- ▶ Placement and monitoring movement of tiny catheters
- ▶ Robotic surgery
- ▶ Vascular procedures and detection
- ▶ Biosensing
- ▶ Precision biopsy

“Designers can appreciate this technology because of the multitude of available data it can produce, which they can sift through in real time or post test and compare with their models. With conventional strain gauges, they have to pick and choose the most strategic points to apply a limited set of strain gauges. We have given designers and aerodynamicists a powerful new tool for validating their models.”

—Allen Parker, NASA Engineer

Technology Details

The advantages of fiber optic sensors over their conventional counterparts are well established; they are lighter, smaller, and can provide enormous numbers of measurements at a fraction of the total sensor weight. NASA Armstrong's FOSS technology combines ultra-efficient algorithms with a high-speed processing platform to enable multiple critical parameter measurements to be determined with a single instrumentation system. FOSS has been recognized with an R&D 100 Award and a National Federal Laboratory Consortium Excellence in Technology Transfer award, and is a runnerup to NASA's Commercial Invention of the Year.

How It Works

NASA Armstrong's novel approach to fiber optic sensing utilizes FBG sensors. The real strength of lightweight FBGs resides in its capability to be multiplexed serially. This means that a single optical fiber can contain thousands of discrete FBG sensors along its length using the OFDR or WDM multiplexing scheme. A narrowband wavelength swept laser interrogates the FBG sensors as they respond to strain resulting from stress or pressure on the structure.

The real-time algorithms and processing system measure strain at multiple locations along the length of the fiber while attached to the surface of a structure. The strain data can be correlated into displacement data, thereby displaying the shape and movement of the optical fiber (and therefore the shape and movement of the attached structure). The system calculates deformation at each measurement location in real time while the vehicle, device, or structure is in service. FOSS detects changes during operation without affecting the intrinsic properties of the structure to which it is attached.

The end result is that strain can be displayed in real-time as the optical fiber is being moved. From these strain measurements, the system calculates 2D and 3D shape, stress, temperature, pressure, strength, stiffness

(bending and torsion), liquid level, and operational load. Weighing just 10 pounds, the system is ideal for use in numerous aerospace applications, such as aboard small UAVs, aircraft, and space vehicles, in addition to a wide variety of uses in medical, transportation, energy, and engineering fields.

The vision of FOSS is that sensors can be distributed in vast networks analogous to the nervous system in the human body. In the case of an aircraft, information from these sensory networks could be fed to on-board or central processing computers, which in turn could provide instructive information to pilots, maintenance crews, or other key decision-makers responsible for ensuring vehicle performance over the vehicle's life cycle.

Why It Is Better

Traditional sensing systems are heavily based upon the production and use of copper wire, significant amounts of coating materials, and metal sensing parts. To achieve the same number of sensing points as the FOSS system, conventional systems would comprise hundreds of pounds of metals and plastics. In contrast, FOSS can acquire a large number of key engineering measurements in real time for large structures that are undergoing a wide range of displacements during operation. Fiber optic sensors also have a safety advantage because they are chemically inert and, unlike conventional sensors, are immune to electromagnetic interference and are not susceptible to sparking or Joule heating. Because of their small size, these sensors can also be embedded within composite materials. FOSS accomplishes all this with a few ounces of flexible glass inside a 10-pound robust platform.

Stresses, structural instabilities, temperature distributions, and a plethora of other engineering measurements can be monitored in real time with a single instrumentation system.



"Fiber optics is a game-changer because we can lay a line of fiber in most any orientation on a structure and get a continuous measurement of strain, temperature, or shape, not just point locations as is the case with conventional strain gauges. In a lot of our test cases, while using this technology, we've found information within the multitude of information that we've never seen or anticipated before. This technology opens up an entirely new realm of understanding when it comes to testing and validating innovations."

—Allen Parker, NASA Engineer

"I think what excites me most about FOSS is the potential that the technology has to solve some of the most challenging engineering problems. FOSS can provide an unprecedented quantity of engineering data through the use of small, almost massless, optical fibers. This opens up all kinds of opportunities for engineers to better monitor and control complex systems and make their designs more efficient and safer."

—Lance Richards, NASA Engineer

“It’s been the dream of aeronautical engineers to change the shape of an aircraft wing in flight, to be able to improve its performance and optimize its flight. The fiber optic technology we’ve been working on at NASA Armstrong is making that dream become a reality.”

—Lance Richards, NASA Engineer



Patents

Development is moving forward at a rapid pace. In addition to these patented technologies (U.S. Patents 7,520,176; 7,715,994; 8,700,358; and 8,909,040), several others are patent-pending.

Licensing and Partnering Opportunities

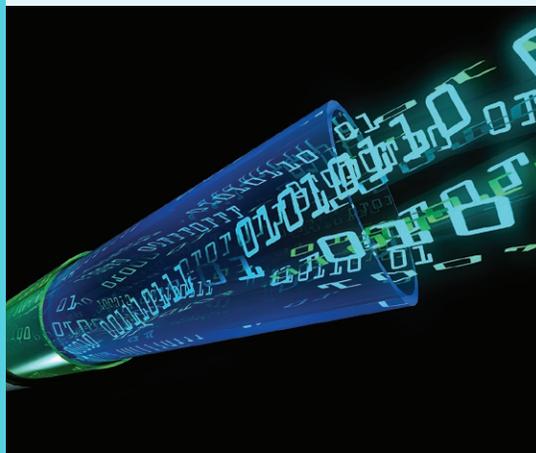
NASA invites companies to consider opportunities to license technologies in the FOSS portfolio. In addition, Armstrong’s FOSS team continues to explore novel applications and welcomes potential collaborators to discuss opportunities for research partnerships.

Expanding Applications

Innovators have developed a highly accurate method for measuring liquid levels using optical fibers. Unlike liquid level gauges that rely on discrete measurements to give broad approximations of liquid levels, Armstrong’s novel method provides measurements at 1/4-inch intervals within a tank. The system uses FBG sensors located along a single fiber optic cable. These sensors actively discern between the liquid and gas states along a continuous fiber to pinpoint the liquid level. This significant leap forward in precision and accuracy in liquid level sensing offers significant benefits to many industries. Designed to monitor a rocket’s cryogenic fuel levels, the technology can be used in many medical and industrial applications.

Taking FOSS to the Next Level

NASA Armstrong researchers are continuing to advance the FOSS portfolio. A hybrid FOSS technique (HyFOSS) employs conventional continuous grating fibers and then overlays sections every 3-4 feet with gratings that can be sampled at higher rates. The new and stronger gratings can be sampled at rates up to 5,000 Hertz (Hz) while the continuous grating sections continue to be sampled at the lower 100 Hz rate. This technique enables higher spatial resolution at specific targets without sacrificing resolution in other areas. The ultimate goal is to achieve sampling rates up to 100 kHz.



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