National Aeronautics and Space Administration

Sensors

Shape Sensing Innovations Dramatically Improve Structural Design Tools

Useful for transportation, infrastructure, and aerospace

Advances in fiber optic shape sensing developed at NASA's Armstrong Flight Research Center are enabling the development of next-generation flexible aircraft wings that maximize structural efficiency and reduce weight, improving fuel efficiency. These same advances will help engineers design stronger bridges, buildings, ocean vessels, and more. Fast algorithms use distributed fiber optic wavelength data to determine shape deformation of large curved and flexible structures. Dramatically improving upon earlier two- and three-dimensional (2D and 3D) shape-sensing tools by tracking multiple orientation angles—displacement, twist, and rotation—at the same time, Armstrong's technology converts distributed surface strain data into deformed shapes that can be displayed and analyzed in real time. Developed to help NASA researchers characterize complex test articles and design new aerospace structures, the innovations also will be useful for multiple applications in the transportation, infrastructure, and medical industries.

BENEFITS

- **Improved safety:** Monitors structural deformations of large structures
- **Increased accuracy:** Improves 3D shape-sensing accuracy for highly flexible structures by recording distributed twist
- **Real time:** Enables quaternion-based mathematical operations, which are computationally faster than more commonly used rotation matrices
- **Compatible:** Works with a range of fiber optic sensing systems, including NASA's award-winning Fiber Optic Sensing System (FOSS) portfolio

technology solution

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THE TECHNOLOGY

Armstrong's technologies provide a convenient way to calculate distributed deformed orientation angles—that is, roll, pitch, and yaw—as well as determine the deformed shape of an object in 3D space. Developed to facilitate monitoring and control of flexible aircraft designs when used in conjunction with Armstrong's multi-patented FOSS technology, these new tools improve shape-sensing accuracy for highly deformable structures such as bridges, wind turbines, robotic instruments, and much more. These tools also can be integrated into commercial fiber optic sensing systems.

How It Works

Researchers developed a technology that uses curved displacement transfer functions to determine 3D shape and calculate the operational load of a structure. It works by dividing the structure into multiple small domains, whose junctures match sensing stations, so that data is collected in a piecewise, nonlinear fashion. The innovation calculates structural stiffness (bending and torsion) and operational loads (bending moments, shear loads, and torques) in near real time.

The method tracks rotations and orientation by employing quaternion mathematical operations, a faster process than rotation matrices used in previous shape-sensing algorithms. The result is an algorithm that can track multiple angles—displacement, twist, and rotation—at the same time to enable curvilinear shaping sensing. Armstrong researchers have validated the method on the large-scale passive aeroelastic tailored (PAT) wing.

Why It Is Better

These new technologies advance the ability of fiber optic sensing systems to determine the shape and operational loads of nonlinear flexible surfaces. They can improve the structural integrity of a range of large structures—from buildings and bridges to ocean vessels and aircraft. These innovations reliably provide highly accurate critical information in real time, enabling corrective action to avert disasters.

For more information about the full portfolio of FOSS technologies, see DRC-TOPS-37 or visit https://technology-afrc.ndc.nasa.gov/featurestory/fiber-optic-sensing

APPLICATIONS

The technology has several potential applications:

Transportation and Infrastructure

- Structural health monitoring of buildings, bridges, oil platforms, ocean vessels, wind turbines, and other large structures
- Load balancing on cargo ships
- Designing truck and automobile frames and suspension for dynamic control and handling

Aerospace

- Real-time structural health monitoring
- Controlling flexible aircraft wings and morphing structures
- Refueling unmanned aerial vehicles (UAVs) in flight
- Designing aircraft structures

Medical

- Performing robotic surgery
- Evaluating anthropomorphic test figures

PUBLICATIONS

Patent Pending

Presentation of wing load test results, January 2019
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190000062.pdf

Paper presented at AIAA SciTech Forum 2019
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190000082.pdf