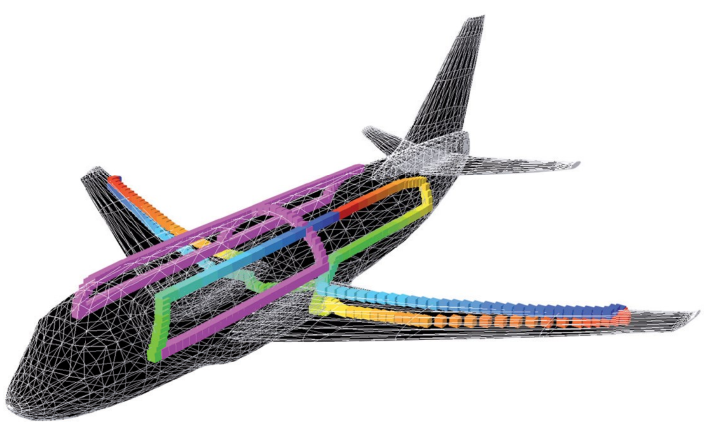
Deflection Sensing for Structural Health Monitoring

Structural Health Monitoring (SHM) is an essential branch of engineering science focused on the surveillance of structural behavior. SHM is implemented to detect, locate, qualify, quantify, and prevent various types of material damage. As the nation's infrastructure ages and air & space vehicles grow ever more complex, SHM systems and algorithms must be increasingly comprehensive, robust, and reliable. Fiber optic sensing (FOS) systems based on coherent Optical Frequency Domain Reflectometry (OFDR) are poised to dramatically improve upon current SHM technologies through unparalleled measurement capabilities and exclusive two-dimensional (2D) deflection sensing algorithms.

The Sensuron OFDR methodology involves the use of a continuous distribution of Fiber Bragg Gratings (FBGs) embedded within 70 micron diameter glass optical fibers coupled with very high performance digital signal processing. The fibers can be integrated within or adhered to the surface of the monitored structure in a manner analogous the human nervous system. Due to the light weight and flexibility of optical fiber and the high density of FBGs, a boundless number of sensor configurations can be employed and a multitude of key engineering parameters, including strain, can be monitored in real-time. Strain, the measure of the intensity of deformation of a material, is typically sensed using a foil strain gage applied at a discrete point on the monitored object. The foil strain gage offers a one-dimensional, singular picture of deformation. Even using several foil gages along the length of a structural component yields an incomplete picture of the response to forces. In contrast, the high density of FBG sensors along an optical fiber opens the door to a whole new realm of strain sensing by obtaining the response of a material in a continuum. Coupled with Sensuron's unique algorithms and high-speed data acquisition and signal processing hardware, the in-plane strains (strains down the length of the material) can be used to accurately calculate out-of-plane parameters critical in SHM applications. 2D deflection profiles, internal bending moments and shear forces, as well as out-of-plane distributed loads can all be monitored in real time.



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SHM applications that are ideally suited for FOS technology contain critical components for which knowledge of the in- and out-of-plane deflections and loads is imperative to the structure's efficient operation and safety. The unique capabilities of FOS enable it to detect shape deformations in beams and shells, buckling in columns, and excessive loads on plates, shelves, bridge girders, and airfoils. Fiber optic sensing systems can also be used to monitor vibrational loads on the bulkhead or hulls of vessels. A common type of deformation that FOS can detect and monitor is "oil-canning." Oil-canning occurs in light-gauge, metal products with broad flat areas where uneven stresses at the fastening points result in deformation. Normally, oil-canning does not affect structural integrity; however, it can be a symptom of malfunctioning material or fastenings. Real-time SHM would ensure that the structure could be monitored and remedied prior to catastrophic failure.

Space launch vehicles are another targeted application for FOS 2D deflection sensing. Long and thin for its height and built from lightweight composite materials, a launch vehicle's high aspect ratio makes it ideal for shape sensing. Not only would the FOS system provide real-time SHM of the integrity of the structure, 2D deflection sensing would also be valuable for flight guidance and could be used to control the trajectory of the vehicle even while the body is deforming.

Limitations that plague traditional strain gage measurements, like oddly-shaped and complex structures, do not affect the shape and out-of-plane load sensing capabilities of FOS. The algorithms analyze each FBG optical fiber as if it were an individual beam using modifications to classical beam theory. Also known as Euler -Bernoulli beam theory, classical beam theory is a simplification of the theory of linear elasticity which provides a means of calculating load-carrying and deflection characteristics. The elegance and power of these algorithms is in the simplicity and quality of the results delivered to the user, while the complex calculations are performed by the system. Items with a high aspect ratio and high levels of displacement, such as long thin flexible planes and long small- diameter flexible rods, are optimum components for monitoring. The accuracy of the measurements during experimental testing was typically within one to two percent. Objects with small displacement, such as stout, strong, stiff composites, can also be measured, but with slightly less accuracy due to shear effects. The accuracy of FOS shape measurements can vary with the application. For instance, despite having a low level of displacement, an experiment conducted by the National Aeronautics and Space Administration (NASA) on heat shields – stiff, nearly circular components – yielded measurable results.

The objective of a fiber optic sensing system in Structural Health Monitoring is to continually observe and reliably assess the integrity of a structure or its components with a high level of confidence. FOS provides a dynamic, embedded replacement to traditional strain gage monitoring. FBG fiber optic sensors are more durable and sensitive than conventional foil strain gauges and can be multiplexed to sense more than a single engineering property continuously across a structure. FOS can be programmed to monitor strain, loads, 2D deflection, temperature, and various other engineering parameters, allowing for real-time monitoring of structural health and ease of maintenance inspection. It can also be used as a safety sensor to identify and avoid system failure.