Fiber Optic Sensing Error Analysis



Overview

In this paper, the factors influencing positioning error is analyzed, and a comprehensive assessment of the system accuracy is provided.

Key Takeaways

Error analysis in fiber optic sensing experiments involves identifying, quantifying, and mitigating measurement inaccuracies to ensure reliable strain, temperature, or current detection.

Key Sources of Error

Sensor Characteristics: Variations in fiber diameter, polarization, and cable jacket can introduce measurement errors in distributed sensing systems like BOTDR, affecting both precision and systematic accuracy.

In FBG and OFD

R sensors, the intrinsic linearity and repeatability of the grating or distributed fiber influence the strain measurement error, typically below 2–5% under controlled conditions. Environmental Factors: Temperature fluctuations, electromagnetic interference, and mechanical vibrations can alter the optical signal. For example, linear birefringence in optical fibers can cause polarization-related errors in current sensing systems, which can be mitigated by introducing circular birefringence.



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Strain Transfer and Installation: In surface-bonded or embedded fiber sensors, imperfect bonding or viscoelastic properties of the host material can lead to incomplete strain transfer, resulting in underestimation or local deviations in measured strain. Signal Processing and Resolution: The spatial resolution, noise level, and frequency step in OFDR or BOTDR systems directly affect the accuracy of strain or temperature measurements. Convolution effects between the injected pulse and the intrinsic Brillouin spectrum can amplify errors if not properly modeled.

Methods for Error Quantification

Experimental Calibration: Using standard beams or reference strain gauges allows comparison of fiber optic measurements with known values, enabling quantification of cyclic stability, linearity, and repeatability. Finite Element Analysis (FEA): Simulating the strain distribution in the host structure and comparing it with measured data helps identify systematic deviations and validate sensor performance. Optical Modeling: Constructing theoretical models of Brillouin backscattering or polarization effects allows parametric studies to predict how noise, birefringence, or misalignment affect measurement error.

Strategies to Reduce Errors

Sensor Design Optimization: Selecting fibers with low birefringence, proper coating, and optimized grating parameters improves measurement stability. Environmental Compensation: Temperature compensation techniques and shielding from electromagnetic interference reduce external error contributions. Improved Installation: Ensuring uniform bonding and minimizing gaps between the fiber and host material enhances strain transfer accuracy.

Signal Processing Enhancements: Using high-resolution detection, averaging, and filtering techniques can suppress noise and improve precision.

Practical Implications

Accurate error analysis ensures that fiber optic sensing systems provide reliable data for structural health monitoring, composite material testing, battery temperature monitoring, and current sensing in power systems. Understanding the sources and magnitudes of errors allows researchers and engineers to design experiments with high confidence in measurement fidelity, often achieving strain measurement errors below 2–5% and high repeatability.

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First, the relationship between the central wavelength shift and curvature of the multi-core fiber is analyzed which is based on the principle of multi-core fiber shape sensing, and a temperature

Uncertainty Analysis of Fiber Optic Shape Sensing Under Core

Shape sensing with optical fiber sensors is an emerging technology with broad applications across various fields. This study evaluates the metrological performance of shape

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Finally, an experimental system for the optical fibre small-current sensor is implemented. The experimental results show that the effect of linear birefringence on the fibre current sensing

Error Analysis and Experimental Research of Temperature/Strain Sensing ...

1. Since the first fabrication of fiber Bragg gratings (FBG) in 1978, they have been widely used in optical filtering, optical sensing, optical fiber communication, fiber lasers and other fields [1...

Distributed optical fiber sensing: Review and perspective

Distributed optical fiber sensors characterized by spatially resolved measurements along a single continuous strand of optical fiber have undergone

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In recent years, distributed fiber-optic sensing technology, due to distributed and long-distance advantages, was widely used in subsurface displacement monitoring of landslides.

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