

Speckle in multimode fiber



Overview

Anti-perturbation multimode fiber speckle imaging and recognition. Specifically, we propose a speckle imaging model that consists of a lightweight encode.

Key Takeaways

Speckle patterns in multimode fibers arise from interference among guided modes and serve as unique fingerprints for wavelength, input light, or transmitted images. Formation of Speckle Patterns

In a multimode fiber, light propagates through multiple guided modes, each with a slightly different propagation constant. The interference of these modes at the fiber output produces a speckle pattern, which is a granular intensity distribution of bright and dark spots. The pattern is highly sensitive to the input wavelength, fiber length, core diameter, numerical aperture (NA), and polarization of the light, making it a unique signature for each input condition .

Influence of Fiber Parameters

- Core Diameter and NA: Larger core diameters and higher NA allow more modes to propagate, which tends to reduce centroid offset and make the speckle energy distribution more uniform. Smaller cores, however, are better for high-resolution spectral measurements because they produce more distinct speckle features .
- Fiber Length: Longer fibers produce speckle patterns that decorrelate more rapidly with small wavelength changes, enhancing spectral resolution in fiber-based spectrometers .



- **Light Source Bandwidth:** Narrowband sources generate high-contrast speckles, while broadband sources produce more uniform patterns due to superposition of multiple wavelength components .

Applications

- **Fiber-Based Spectroscopy:** By calibrating the wavelength-dependent speckle patterns, a multimode fiber can act as a compact, high-resolution spectrometer. Each wavelength produces a distinct speckle “fingerprint,” which can be reconstructed using a transmission matrix and computational algorithms .
- **Image Transmission and Recognition:** Speckle patterns can encode images transmitted through multimode fibers. Machine learning models, including convolutional neural networks like Inception V3, can classify and reconstruct these patterns with high accuracy, enabling applications in endoscopic imaging and biomedical diagnostics .
- **Mode Scrambling and Noise Reduction:** Mechanical scramblers or controlled perturbations can reduce modal noise and stabilize speckle patterns, improving measurement accuracy in spectrographs or imaging systems .

Key Considerations

- Speckle patterns are extremely sensitive to environmental perturbations such as bending, temperature changes, or mechanical stress.
- The number of modes and fiber geometry directly affect the speckle contrast and spatial distribution, which must be considered when designing fiber-based sensors or spectrometers.
- Advanced computational techniques, including machine learning, can enhance the interpretation of speckle patterns for both spectral and imaging applications . In summary, the speckle pattern of a multimode fiber is a complex interference phenomenon that encodes information about the input light and fiber properties. Its sensitivity and uniqueness make it a powerful tool for spectroscopy, imaging, and optical sensing.

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