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Resolution methods for multimode optical fibers



Overview

Resolution limits for imaging through multi-mode fiberAbstract: We experimentally demonstrate endoscopic imaging through a multi-mode fiber (MMF) in which.

Key Takeaways

Resolution in multimode optical fibers can be enhanced using computational imaging, wavefront shaping, compressive sensing, modal decomposition, and deep learning-based super-resolution techniques.Computational Imaging Approaches

Wavefront shaping (WFS) and raster-scan imaging are widely used to control the input light field in MMFs, compensating for mode mixing and speckle formation. By precisely modulating the phase and amplitude of the input beam, WFS enables the reconstruction of high-resolution images at the fiber output, effectively overcoming the limitations imposed by inter-modal interference and the small core size of MMFs . Compressive imaging (CI) leverages sparse sampling and computational reconstruction to achieve super-resolution. By using fewer measurements than traditional raster scanning, CI can reconstruct high-resolution 3D images efficiently, making it suitable for flexible, thin probes in biomedical applications .

Modal Decomposition Techniques

Modal decomposition involves characterizing the individual modes propagating in an MMF. Two main methods are used:

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• Spectrally and spatially resolved imaging, which maps the intensity distribution of modes at the fiber output, suitable for large-mode-area fibers.

• Simplified intensity-based decomposition, which is faster and applicable to various fiber types, including standard index-stepped and photonic-crystal fibers . These methods allow precise control and reconstruction of the optical field, improving resolution by mitigating mode-dependent distortions.

Super-Resolution and Deep Learning

Super-resolution imaging through MMFs can be achieved by combining physical speckle properties with deep learning (DL). DL models trained on speckle patterns can reconstruct high-resolution images from low-resolution measurements, effectively upsampling the image while preserving spatial information. Physics-informed DL approaches integrate speckle correlation theory to enhance reconstruction fidelity and resolution beyond conventional limits . Endoscopic imaging using MMFs benefits from these methods, enabling minimally invasive, high-resolution visualization of internal tissues while maintaining a compact fiber footprint .

Advanced Linear Optimization Methods

Recent studies demonstrate that nonlocal reconstruction using linear optimization can increase the number of resolvable features up to four times the number of spatial modes per polarization. This is achieved by inputting sequences of random field patterns and reconstructing the image from the resulting intensity patterns, exploiting the squaring effect in field-to-intensity conversion .

Summary

To enhance resolution in multimode optical fibers, researchers employ a combination of:

• Wavefront shaping and raster scanning for precise input control

• Compressive imaging for efficient high-resolution reconstruction

• Modal decomposition to characterize and correct mode propagation

• Deep learning-based super-resolution for data-driven reconstruction

• Linear optimization techniques to maximize the number of resolvable features

These methods collectively address the challenges of mode mixing, speckle formation, and limited core size, enabling high-resolution imaging and sensing through MMFs.

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Article Content

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Fast mode decomposition in few-mode fibers

Characterizing the modes at the output of a multimode fiber is time consuming due to computational cost. Here the

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However, high-dimensional optical fiber systems, usually necessity bulk-optics approaches for launching different

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Conventional optical fiber temperature/strain sensors often have to make compromises between the resolution and

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For in vivo observation of the internal tissues or organs, endoscopy has become an emerging method to directly

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They began exploring how to achieve multiple optical transmission channels in a single fiber. However, the

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Subcellular spatial resolution achieved for deep-brain imaging in vivo ...

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Speckle Analysis in Multimode Optical Fibers for Chemical and

We examine how these algorithms perform when analyzing speckle patterns from a polymer optical fiber exposed to

Optical resolution photoacoustic microscopy based on multimode

The efficacy of multimode fibers for achieving tight focus is beneficial for developing high-resolution photoacoustic endoscopy

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Here, we propose, to our knowledge, a novel method for achieving fast and high-resolution speckle imaging via

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Dual holographic and polarization encoding for high fidelity image ...

Our method leverages angular correlations in the far-field regime of MMFs, providing a mechanism to exploit the fiber''s

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