# High Signal-to-Noise Ratio Confocal Microscopy through Multimode Fibers

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Optical sectioning is desirable to obtain high contrast images of 2-D cross sections from within a thick tissue volume. Confocal microscopy provides this capability by employing a pinhole in the detection path to eliminate the out-of-focus light. The pinhole size dictates the tradeoff between optical sectioning and the signal-to-noise ratio (SNR). Unfortunately, even for confocal microscopy, scattering in tissue limits its feasibility to only shallow depths. Furthermore, multiphoton microscopy or optical coherence microscopy still can only reach limited depths inside tissue. Employing minimally invasive endoscopes represents the only option for deep tissue optical imaging. Therefore, the combination of confocal microscopy with minimally invasive endoscopy provides a unique opportunity to push the penetration limits of optical imaging.

Multimode fibers (MMF), with their high spatial and temporal bandwidth, small footprint and flexibility, make excellent candidates for endoscopy. However, they do not preserve spatial information so imaging through them requires calibration of their input-output relation, represented by the transmission matrix (TM) [1]. With the help of the TM, one can generate controlled illuminations on the far (distal) end of the MMF and collect the reflected signal from the object on the MMF's near end.

Confocal microscopy through an MMF can be performed by virtually backpropagating the reflected speckle patterns to the distal end using the TM [2]. The backpropagation provides access to the scanning illuminations which can then be virtually filtered through a digital pinhole to achieve optical sectioning. However, this method allows little flexibility in choosing the size of the pinhole and suffers from low signal levels.

Here, we present a digital-optical signal processing technique that minimizes the signal loss inherent in confocal microscopy while retaining its resolution gain and optical sectioning properties. Remarkably, this method is not subject to the system's shift invariance condition, unlike conventional confocal microscopy. We use the back-reflected speckle patterns to extract multi-view perspectives [3-4] of the distal fields and combine them together to obtain a single high-SNR confocal image. In this presentation, we will introduce the imaging principle and present experimental demonstration of high-SNR and optical sectioning imaging through a single MMF.

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