Fluorescence imaging through a multimode fiber

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Summary: Glass fibers can be utilized for imaging in hard-to-reach places by taking advantage of their flexibility and light guiding properties. Here, we present and compare two different imaging methods: conventional raster scanning and speckle-based compressive imaging. While the raster scanning approach is diffraction limited, compressive imaging has the potential for super-resolution endo-microscopy beyond the Nyquist-Shannon limit.

A multimode fiber can be used as an ultra-thin and flexible endoscope [1] [2], offering a potentially minimal invasive way of imaging. Here, we present two endoscopic imaging methods using either diffraction limited raster scanning (RS) or speckle-based compressive imaging (CI) [3].The setup (Fig. 1 (a)) consists of a DMD, which was used to facilitate the two different imaging methods. In RS mode, the wavefront shaped beam creates a diffraction limited spot at the output of the fiber, which was subsequently scanned across the sample. In CI mode, a spot was generated on the input facet of the fiber and scanned across the fiber core to create random speckle patterns at the output facet of the fiber, which illuminated the sample. In both modes the emitted fluorescence of the sample was measured in epi-direction with a photodiode or photo multiplier tube. A camera placed behind the sample allows for the acquisition of the speckle patterns, which is necessary for pre-calibration.
In Fig. 1(c) we show the obtained RS image of fluorescence beads (size: 1μm, Fig 1(b)). The cluster of beads (dark blue spots) can not be distinguished, since the size of the beads is below the diffraction limit. In contrast to RS, CI has the potential to obtain images of higher resolution and at the same time reduce acquisition time [4]. In Fig. 1(d) we show a zoom in of the speckle-based CI image of the same sample, obtained with the illumination of 1223 speckle patterns and recovery via a (ℓ_1-norm minimization) Basis Pursuit algorithm, far below the Nyquist-Shannon limit. In summary, we have demonstrated two different ways of imaging through a multimode fiber. The conventional raster scanning approach is diffraction limited while the compressive imaging approach has the potential go beyond the Nyquist-Shannon and Abbe limit.

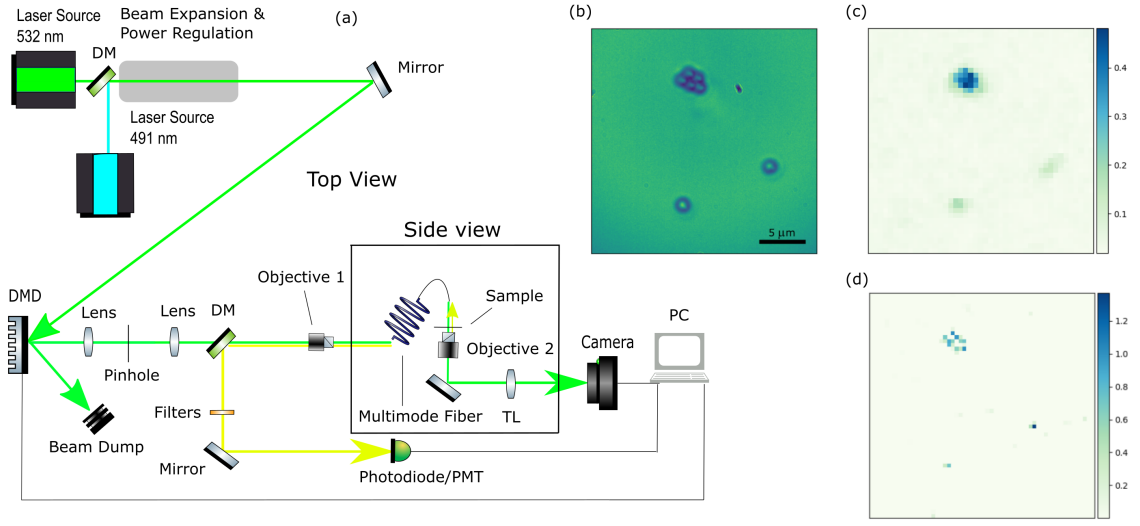

Figure 1: **(a)** Schematic representation of the optical setup. DM = Dichroic mirror, TL = Tube Lens, PMT= Photo Multiplier Tube, DMD = Digital Micromirror Device. **(b)** Bright light image of 1μm diameter fluorescent beads, ex/em wavelength: 535/575 nm. **(c)** Diffraction limited raster scan of fluorescent beads, excited with 532 nm; Emission detected in epi-direction via a photodiode. Image size: 45 x 45 pixels with a pixel size of 540 nm. **(d)** Zoom-in on compressive imaging reconstruction, pixel size = 420nm

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