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The diffraction limit restricts the resolution of far-field microscopies to half of the free-space wavelength (λ/2). A wide range of optical techniques have been developed to improve the resolution of microscopes beyond the diffraction limit, including fluorescence-based methods (STED, STORM), near-field imaging, and scanning approaches[1]. Here we introduce a novel artificial intelligence (AI)-enabled scanning microscopy approach and demonstrate numerically an improvement of x1.4 over standard techniques (scanning confocal microscopy).

In our approach, the imaging target (e.g. a Siemens star in an otherwise opaque screen, see Fig. 1a,b) is scanned with a 640 nm tightly focused laser beam with spot size of 600 nm ($1/e^2$) and the resulting diffraction patterns are recorded at a distance of 2λ. The recorded patterns corresponding to different relative positions of the sample and laser beam are then reconstructed by a convolutional neural network (Fig. 1c). During the reconstruction, the imaging target is considered to consist of sets (superpixels) of 3x3 (fully opaque/transparent) pixels, resulting in 512 distinct superpixels. The superpixel is fully encompassed by the incident beam, having size of 360 nm. To consider the effect of the surroundings of superpixels on the corresponding diffraction patterns, the training set comprised diffraction patterns from different superpixels with randomly selected neighbouring pixels, resulting in training set size of 12,288.

The resolution of the method was evaluated using fringe visibility analysis at different radii of the Siemens star target[2]. The threshold for the resolution of 0.07 was selected, so that the fringes become invisible by eye [3] (see red dashed line in Fig. 1c). This corresponds to 170 nm or ~x2 beyond the conventional diffraction limit (Fig. 1e). For comparison, we considered confocal imaging of the same target (see Fig. 1d). In this case, resolution drops to 235 nm, x1.4 lower than our approach.

In summary, we demonstrated an AI-enabled scanning microscopy approach outperforming the conventional diffraction limit twice. We expect our approach finds applications in nanotechnology and biomedical sciences.

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3. E. Rogers, et.al., APL Photonics **5**(6), 066107 (2020).