Depth-of-focus extension in optical coherence tomography via multiple aperture synthesis

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Abstract

In this paper, we report a novel technique for overcoming the depth of focus (DOF) limitation in optical coherence tomography (OCT). Using confocal optics on a sample arm, we scanned the illumination beam across the under-filled objective lens pupil plane by steering the beam at the pinhole using a micro-cylindrical lens. The detected interferometric signals from multiple distinctive apertures were digitally refocused, which is analogous to synthetic aperture radar (SAR). Using numerical simulations and imaging experiments, we verified that this technique can maintain a diffraction-limited transverse resolution along a DOF that is ~10 times larger than the confocal parameter. The ability to extend the DOF without signal loss and sidelobe artifacts may ultimately overcome the DOF limitation in high-resolution OCT.

Methodology

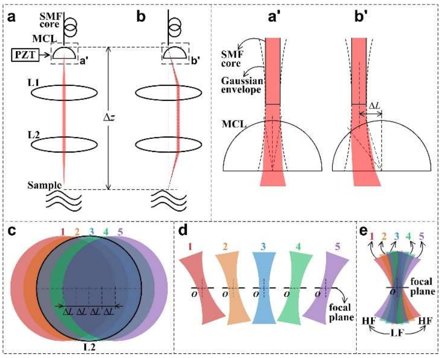

Fig. 1. Working principles of multiple aperture synthesis. (a) Schematic with a micro-cylindrical lens centered at the fiber pinhole. (b) Schematic with a micro-cylindrical lens transversely shifted by a step size of ΔL. (c) Five apertures generated by the transversely shifted micro-cylindrical lens and the aperture of the objective lens. (d) Focusing beams of the five apertures in (c). (e) Optical axes of the focusing beams of the five apertures in (c).

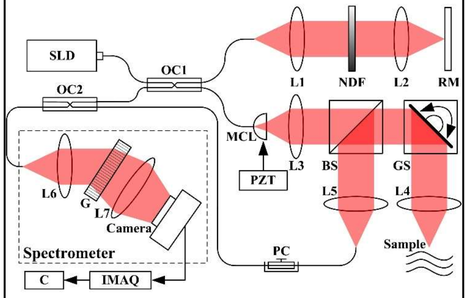

Fig. 2. Schematic of the MAS SD-OCT system. SLD, super luminescent diode; OC1-2, 90:10 fiber-optic coupler; L1, L3, L5 and L6, collimating lens; L2 and L4, focusing lens; L7, camera lens; NDF, neutral density filter; RM, reference mirror; MCL, micro-cylindrical lens; PZT, piezoelectric transducer; BS, beam splitter; GS, galvo scanner; G, transmission diffraction grating; IMAQ, image acquisition; C, computer; and PC, polarization controller.

Numerical analysis

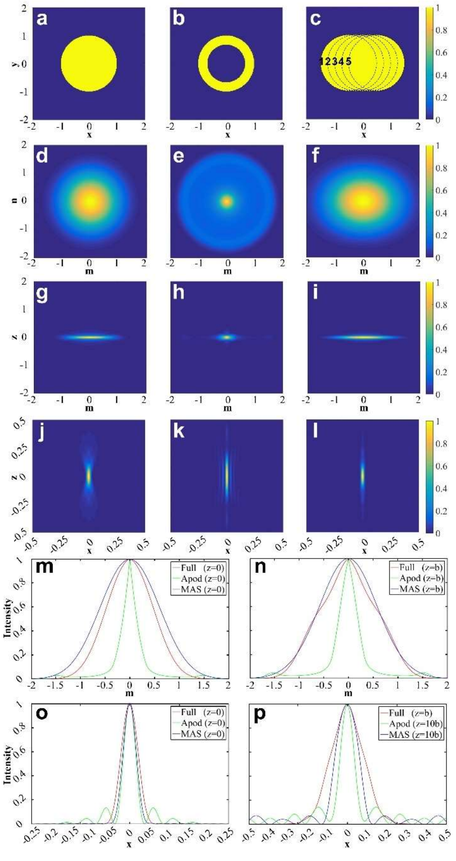

Fig. 3. Numerical simulation results. (a-c) PFs of a full aperture, an annular apodized aperture and an MAS. (d-f) Two-dimensional coherent transfer functions (CTFs) of a full aperture, an annular apodized aperture and an MAS in the focal plane as a function over the transverse spatial frequencies. (g-i) Two-dimensional CTFs of a full aperture, an annular apodized aperture and an MAS. (j-l) Two-dimensional PSFs of a full aperture, an apodization and an MAS. (m-n) Transverse CTFs. (o-p) Transverse PSFs.

Results

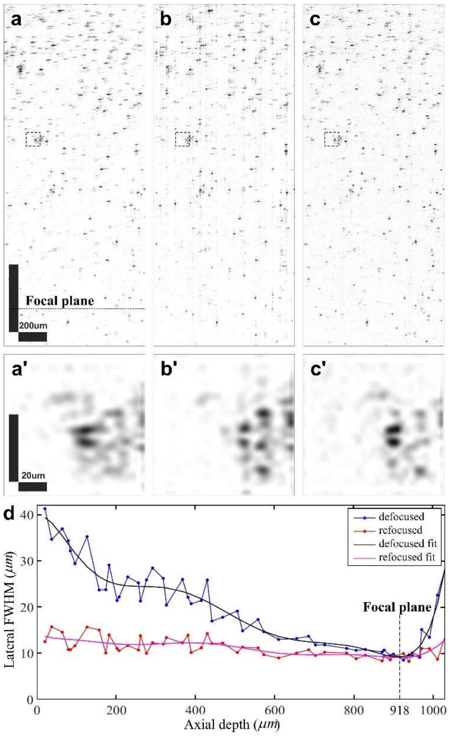

Fig. 4. Stepwise image sequence in linear scale: (a) Dispersion-compensated B-scan from one of five apertures; (b) Resulting B-scan of the axial-shift operation, which is the first step of the MAS; (c) resulting B-scan of the defocusing correction operation, which is the second step of the MAS. (a'-c') Magnified view of two calibration beads indicated by the dashed black boxes in (a-c). (d) Transverse FWHMs of 50 calibration beads at variable depths.

Conclusions

1. MAS obtains ~10 tomes DOF extension.
2. MAS is free from signal loss and sidelobe artifacts.
3. MAS can eliminate various types of optical aberrations, including the beyond the defocus.

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