Enhanced Depth of Focus Optical Coherence Tomography with Higher Order Mode Fiber Laser

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Optical coherence tomography (OCT) allows non-invasive measurement of the 3-dimensional structure of tissues. OCT is most proliferated in ophthalmology but has applications in many other medical, biological and technological studies. While the resolution in the propagation direction of the light is uniform across the tissue and can be very fine depending on the bandwidth of the light source used, the transverse resolution depends on the focusing conditions and deteriorates with increasing distance from the geometrical focus. Thus, it is challenging to obtain a high resolution in all three dimensions for a large volume. Several approaches have been demonstrated to tackle this issue, most prominently of which the use of Bessel beams. An ideal Bessel beam is not diffracting, and practical implementations of Bessel beams allow for a considerable length of constant small beam size, at the cost of a significant portion of the energy contained in concentric rings around the sharp central peak. In practical terms, OCT systems with Bessel beam illumination achieve this using axicon lenses, which make the system extremely alignment sensitive and cumbersome. Our approach replaces the axicon lens generating the Bessel beam by a higher-order-mode fiber. The LP_{02} mode in the fiber is excited exclusively through transmission through a UV-written long-period grating in the fiber, which allows splicing the higher-order-mode fiber directly to a standard single mode fiber to achieve the LP_{02} mode at the output.

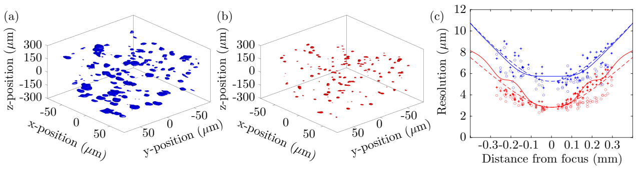

Figure 1: (a),(b) Rendered volumes showing the beads detected in the volumes measured with the LP_{01} (Gaussian-like) illumination and the LP_{02} (Bessel-like) illumination, respectively, with the red isosurfaces at approximately the $1/e$ signal value of the beads. (c) extracted – apparent – widths ($1/e$ radius) of the detected beads for the measurements with the LP_{01} beam (blue) and with the LP_{02} beam (red). Horizontal and vertical sizes are shown with + symbols and open circles, respectively. Detected bead sizes are consistently smaller with the LP_{02} illumination, as the (central) spot size of the LP_{02} illumination is significantly smaller than the spot size of the LP_{01} illumination

We experimentally and numerically compare the imaging performance of our higher-order-mode driven OCT setup with the performance of the same system driven with the output from a single mode fiber. The LP_{02} output from our higher-order-mode fiber allows us to achieve a sharper focus, that is maintained over a longer range than the fundamental (LP_{01}) output from the standard single-mode fiber. Figure 1 shows the results of our measurements of a test target with polystyrene beads suspended in agarose and simulations.

Finally, we apply our novel system for the phenotypical characterization of seeds. These measurements allow to non-invasively measure the thickness of the pericarp layers of sorghum seeds for the first time.