

might be too large. The actual experiment is not optimized regarding time since only mechanical shutters and liquid crystals SLM are used. For two bending joint with a ΔR from infinity to 10mm for example, we would need to calibrate the fiber for 20 positions for each joint to keep the same ratio as in Fig. 6(b). This will result in a number of calibration positions of 20^2 . We need then to learn the patterns needed for phase conjugation for 400 conformations of the fiber.

3. Discussion

We showed that by recording the phase and the speckle pattern for 9 bending configurations of the fiber, it is possible to maintain focusing over a 5 mm change of radius of curvature of the fiber. To implement such a system in real-time only a limited number of prerecorded patterns can be used due to limitations in computation speed. It is therefore essential to know how fast the enhancement drops when the fiber is bent in order to determine the optimal number of bending radii for which the pre-calibration has to be done. We showed that the enhancement as a function of radius of curvature is strongly related to the core diameter of the fiber. The larger the core, the faster the enhancement decreases. For a fixed number of prerecorded patterns (limited by the computation speed of the system), one can choose between high enhancement and a smaller bending range obtained with a large core fiber, or a smaller enhancement and a larger bending range for a fiber with a smaller core diameter.

The use of a virtual beacon to recover the spatial configuration of the fiber provides the basis for the implementation of a semi-flexible endoscope using a multimode fiber. However, the allowed bending configurations have to be fixed in advance in order to calibrate the fiber.

We showed an implementation using a single mode fiber alongside the MMF. We hence demonstrated that focusing through a bent multimode fiber could be done without having access to the distal tip of the fiber. An implementation with a double clad fiber would simplify the geometry and provide a compact system by avoiding a separate single mode fiber to bring the calibration beam to the fiber tip.

4. Conclusion

We have shown in this work that we can dynamically compensate for bending while focusing through a multimode fiber. The method consists of creating a virtual holographic beacon by using a single mode fiber illuminating a hologram of a point source at the distal tip of the multimode fiber. We demonstrated that the bending configuration of a multimode fiber can be found by comparing the speckle pattern originating from the virtual beacon source with previously recorded speckle patterns corresponding to various bending configurations of the fiber. Up to now, all methods to image through multimode fibers were restricted to rigid fibers, which was a major limitation. The proposed method lifts this limitation, which may pave the way to many new applications of high-resolution lens-less endoscopes based on digital scanning through optical multimode fibers.

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