Spatial light modulator control algorithm to focus moderately scattered laser beam

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Abstract

The algorithm to increase the efficiency of focusing of partially coherent laser radiation propagated through the 5 mm layer of the scattering suspension of 1 µm polystyrene microspheres in distilled water with the concentration values ranging from 10^5 to 10^6 mm^{-3} was developed, implemented and tested using spatial light modulator with 1920x1080 pixels resolution. Experimental investigations of the focusing improvement have demonstrated that it is possible to increase the integral intensity of the focal spot by 8% and decrease the diameter of the focal spot by 16%.

Keywords

laser beam focusing, scattering medium, spatial light modulator, control algorithm

1. Introduction

The wavefront of the radiation can be correctly defined and optimized using the principles of classical adaptive optics if the refractive index of the inhomogeneous medium changes smoothly and continuously in space. On the other hand, the image of the target object could be completely lost if the medium has random inhomogeneities of high concentration (biological tissues). In that case the wavefront shaping technique can be applied [1]. Our paper is devoted to the cross-over regime — when the light passed through the scattering medium is partially coherent, the wavefront (so-called averaged wavefront) is not completely scrambled, and methods of classical adaptive optics still could be applied. In this paper we demonstrated the improvement of focusing of a laser beam passed through the scattering medium using phase-only spatial light modulator.

2. Laser beam focusing using spatial light modulator

In order to improve the focusing efficiency of scattered laser beam we assembled the experimental setup with the spatial light modulator (Figure 1).

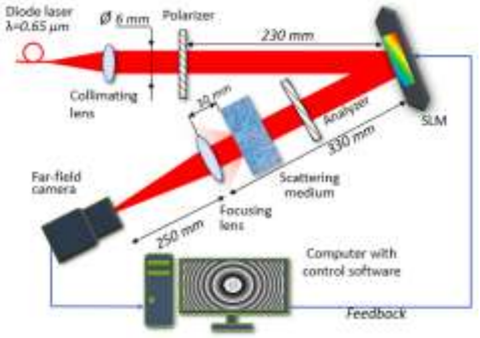

Figure 1: Experimental setup for scattered laser beam focusing using spatial light modulator. Beam diameter – 6 mm, SLM resolution – 1920x1080 pixels, SLM active area – 12.5 x 7.1 mm

The idea of the algorithm of scattered laser beam focusing was as follows — we grabbed the image from the camera, calculated merit function, set the probing control signals (phase screen) to the SLM, grabbed the image and analyzed the merit function again. As it was shown in earlier papers [2], low- and high-order axial-symmetric distortions predominated in the averaged wavefront of scattered light. Thus, we decided to operate SLM using phase screen approach but not the conventional single pixel approach. Basically, we calculated the phase surface φ corresponded to the specified value of the particular Zernike polynomial, then calculated the phase pattern using the formula $fp = 255 \cdot remainder(\varphi / \lambda)$, sent it to the SLM, and then calculated the merit function. If merit function became better, we increased the previous value of Zernike polynomial by the fixed step (0.015 μm) and ran the cycle again. If not, we rolled back Zernike polynomial value and tried to decrease it. After that we remembered the resultant (the best) value of the current Zernike polynomial and moved to the next Zernike polynomial and repeated the procedure [3, 4]. In such a way we improved the merit function step by step. As a merit function M we used the combination of the diameters (D_x, D_y) and maximal intensity (I_{max}) of the focal spot in the far-field $M = max(D_x, D_y) \cdot (D_x + D_y) / I_{max}$.

We calculated the encircled energy and integral intensity of the far-field focal spot before and after optimization with the SLM (**Figure *2***).

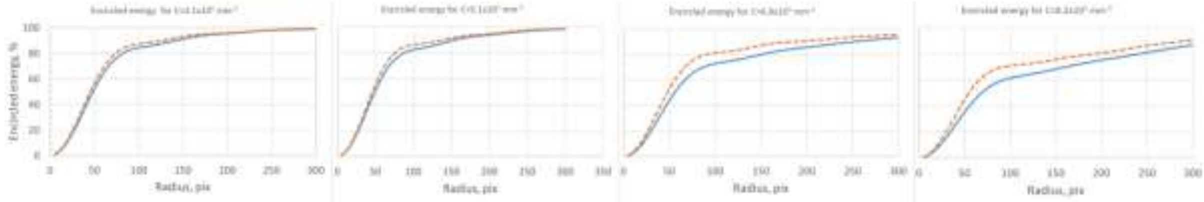

Figure 2: Encircled energy charts of the far-field focal spots without the scattering medium (dotted gray curve) and with the scattering medium before running optimization procedure (solid blue line) and after (dashed orange line) for the scatterers concentration values 3.1×10^{5}mm^{-3}, 5.1×10^{5}mm^{-3}, 6.8×10^{5}mm^{-3}, and 8.2×10^{5}mm^{-3}

3. Conclusion

The integral intensity of the focal spot obtained when no scattering medium was introduced in the setup was considered as 100 %. Then the integral intensities of the focal spots before and after optimization procedure were as follows: 95.7% (before) and 97.7% (after) for the concentration value 3.1×10^{5}mm^{-3}, 93.8% and 96.6% for the concentration value 5.1×10^{5}mm^{-3}, 85.1% and 91.9% for the concentration value 6.8×10^{5}mm^{-3}, 74.3% and 82.2% for the concentration value 8.2×10^{5}mm^{-3}. The diameters of the focal spots were reduced by 5.2%, 9.7%, 16.4%, and 13.2% during the optimization process.

4. References

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