FLUORESCENCE-BASED NON-INVASIVE LIGHT FOCUSING INSIDE SCATTERING MEDIA VIA SPECKLE VARIANCE OPTIMIZATION

Antoine Boniface, Baptiste Blochet, Jonathan Dong and Sylvain Gigan
Laboratoire Kastler Brossel, Sorbonne Université, École Normale Supérieure–Paris Sciences et Lettres (PSL) Research University, CNRS, Collège de France, 24 rue Lhomond, 75005 Paris, France
E-mail: antoine.boniface@lkb.ens.fr

KEY WORDS: wavefront shaping, multiple scattering, speckle, linear fluorescence, non-invasive imaging

Propagation of coherent light through a scattering medium generates a speckle pattern, which is detrimental for imaging applications. Since 2007, various wavefront shaping techniques have emerged to control this very complex figure of interference. In particular, they can be used to focus light behind scattering media [1]. Still, all of these approaches require some feedback signal from the targeted focal point. Usually, the feedback is either measured with a detector placed behind the scattering medium, or recovered from implanted guide stars. Both approaches are invasive and thus not directly applicable when it comes to imaging at depth. To go beyond this major limitation, wavefront shaping has recently been combined with techniques such as acoustics or nonlinear optics [2]. However, focusing non-invasively on extended fluorescent objects with linear excitation remain to date unresolved.

Here we report on a new method allowing focusing inside a scattering medium using an incoherent linear optical signal as feedback, for instance fluorescence, in an epi detection geometry. Contrary to [3], our technique does not rely on speckle correlations and is also efficient in the multiple scattering regime. We use an optimization procedure to find the incident phase correction that maximizes the spatial variance of the linear fluorescence speckle, retro-reflected by the medium. The speckle pattern variance is the product of the contrast and the intensity of the speckle, meaning it is maximal when all the excitation light is focused on a single fluorescent target, since fluorescent signals emitted by multiple targets are summed incoherently. Experimentally, we demonstrate diffraction-limited focusing of light scattered after propagation through multiple layers of parafilm using the variance of the fluorescence speckle pattern as a feedback signal. This approach should be adaptable to several microscopy techniques and linear optical signals.

REFERENCES

[1] S. Rotter, S. Gigan, "Light fields in complex media: mesoscopic scattering meets wave control" *Rev. Mod. Phys.* 89, 015005 (2017)
[2] Horstmeyer, R., Ruan, H., & Yang, C. "Guidestar-assisted wavefront-shaping methods for focusing light into biological tissue". *Nature photonics*, *9*(9), 563. (2015).
[3] Galya, S., Katz, Ori. "Noninvasive focusing through scattering layers using speckle correlations." *Optics Letters* 44.1 (2019): 143-146.