Non-invasive imaging through a scattering wall

Antonio M. Caravaca-Aguirre¹, Donald B. Conkey¹, Jacob D. Dove,² Hengyi Ju,² Todd W. Murray² and Rafael Piestun¹

¹Department of Electrical, Computer, and Energy Engineering, University of Colorado, Boulder, Colorado, 80309, USA
²Department of Mechanical Engineering, University of Colorado, Boulder, Colorado, 80309, USA

We investigate the problem of optical non-invasively imaging through scattering media without the use of the so-called memory effect, namely allowing for thick and highly scattering obstacles. A photoacoustic (PA) signal, consisting of the integration of PA emissions from multiple speckle grains, is used as optimization feedback for focusing through such a scattering material. We use a liquid-crystal spatial light modulator (LC-SLM) to modulate the input wavefront and optimize the PA response using a genetic algorithm [1]. The spatially non-uniform sensitivity of an ultrasound transducer to the PA emission from multiple speckles results in the enhancement of a single speckle creating a sub-acoustic optical focus [2].

The optical focus is used to reconstruct sub-acoustic resolution images of a bee wing scanned behind a diffusing wall. Figure 1 compares the PA image under three different illuminations: uniform illumination (Fig. 1a) where the diffuser is removed, random speckle illumination where a random phase is projected onto the SLM (Fig. 1b), and optimized illumination (Fig. 1c). After optimization, the signal strength improved by a factor of 10 versus the random speckle field revealing interesting complex structure and significant resolution and signal improvement. Figure 1c shows that even the bee wing hairs are individually resolved.

Figure 1. Sweat bee wing PA image reconstruction through a glass diffuser using a, uniform illumination, b, Random phase mask c, Optimized phase mask. d, PA image superimposed with the optical image. Scale bars are 100µm.

In a different imaging modality, the transducer is scanned and the wavefront optimized at each transducer position; thereby building an image point-by-point without moving the scattering wall or the sample. Figure 2 shows a theoretical (a) and experimental (b) results for a 1D scanning of the transducer, imaging 55µm wide chromium bars separated by 55µm. Similar to the prior example of the sweat bee wing, we compare the PA signal under three different illuminations. The results indicate that the optimized focus and subsequent scanning imaging improves the ability to resolve the individual bars and is limited by the optical speckle size.
