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Do Macroscopic Changes Affect Mesoscopic Light Transport?

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Abstract: In most previous studies about light scattering, no geometry is used besides a slab. In this work, we study how macroscopic changes in the geometry affects light scattering using the Wavefront Shaping technique.

1. Introduction

When studying light transport in scattering media, both in theory and in experiments, the geometry is commonly unaltered: a slab shape. Slabs are cuboid objects with a finite small size in one dimension and infinite on the others two. This geometry is especially comfortable for simulations, but at the same time very distant from real-life applications.

Due to fabrication and material limitations, the geometry of scattering media used in industrial applications is mostly free-form. This is also the case for bio-imaging applications. Because of the lack of research on free-form scattering optics, there is still the enigma of how this change of geometry at the macroscopic scale affects light transport.

In this paper, we use the Wavefront Shaping (WFS) technique to optimize light intensity through a flexible scattering sample [1, 2], and we change its geometry to compare the outcome.

2. Free-form sample

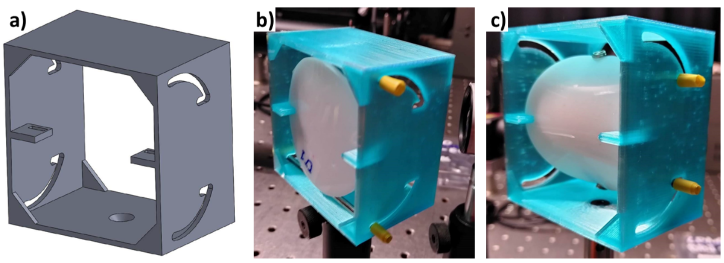

Fig. 1. Free form sample used for the experiments. a) 2D design of the tailored made holder, b) picture of silicone sample with flat surface, and c) picture of silicon sample with curved surface.

For the experiments, we implemented the WFS technique using a Digital Micromirror Device (DMD, DLP7000 Texas Instruments). To control the phase of the incoming wavefront, we used the Lee Holography technique to convert the binary modulation of the DMD to phase modulation [3]. The experimental details of this experiment were presented elsewhere [4].

The sample we used for this experiment is shown in Fig. 1. The sample is made out of TiO2 particles suspended in silicone. We exploit the flexibility of silicone to compare WFS performance with two sample geometries, namely a flat surface - which approximates to a slab - and a curved surface. To realize these two sample geometries, we used a tailored-made sample holder fabricated with a 3D printer. This holder is also visible in Fig. 1.

3. Intensity enhancement

The figure of merit of WFS is the intensity enhancement η. If we define a limited area on the CCD where we want to optimize intensity, the enhancement is defined as

$$\eta \equiv \frac{I_{\rm opt}}{< I_0 >}, \tag{1}$$

Where $I_{\rm opt}$ is the intensity at the target area after optimization and $< I_0 >$ is the average intensity with random incident wavefronts. η depends on the number of segments N ($\eta \equiv \eta(N)$). These are the individual areas on the DMD which we control their phases. The larger the number of segments, the larger is the enhancement.

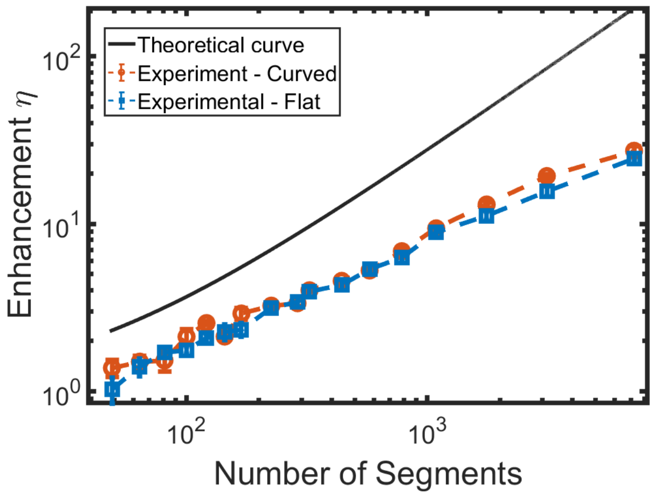

Fig. 2. Enhancement versus number of segments. The black curve is the theoretical limit, the orange circles are the enhancement for a curved sample, and the blue squares are the enhancement for a flat sample. The error bars are of the size of the markers.

To study the performance of WFS when comparing different geometries, we are interested in $\eta(N)$ for both cases. We present the results of this experiment in Fig. 2. The theoretical limit is the maximum enhancement possible, corrected by the speckle size [5]. We see that the trend for both geometries - flat and curved surface - is the same. Importantly, for each repetition, the optimization started from a plane wave. Thus, the resulting phase pattern for each case is not necessarily the same.

4. Discussion

The results we present in this study show that the performance of the WFS technique does not depend on the geometry of the object under study. This means that for real-life applications, no special treatment is needed to apply the WFS technique.

To expand these results, we are currently working on studying how the optimization and speckle correlation evolves when continuously changing the curvature, which we expect to help us to understand its effect at the mesoscopic scale.

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