Focusing Through a Scattering Medium

International College on Modern Applications of Optics and Photonics (MAOP)

Duration: 90 minutes | Level: Master's students

Conference Website: https://photonicsai.com/home_maop2026/

1. Introduction and Learning Objectives

This laboratory task demonstrates how Spatial Light Modulator (SLM) allows beam focusing through Scattering Medium (SM). This task will help students understand basics of SLM operation, light propagation through SM and principles of computational optics.

During the laboratory session, students will:

1. Set parameters for SLM phase mask;
2. Chose and adjust the Region of Interest (ROI) on the camera image;
3. Perform focusing via Python code;
4. Find optimal set of parameters for phase mask and ROI and analyze the results.

2. Scientific Background

2.1. Focusing through a scattering medium

In free space, focusing a coherent laser beam is straightforward: a lens introduces a spatially varying phase that causes the optical field to interfere constructively at the focal point.

A scattering medium—such as a layer of ground glass, biological tissue, or a strongly scattering material—randomizes the propagation of light. The incident optical field is broken into many partial waves that travel along different paths. At the output, these waves have different amplitudes and phases, producing a **speckle pattern** rather than a well-defined focus.

Importantly, scattering does **not** destroy the optical information. For a static medium, the relationship between the input field and output field is deterministic. This relationship can be represented by a **transmission matrix**:

$$E_{out} = TE_{in}$$

where E_{in} is the complex optical field incident on the scattering medium, E_{out} is the resulting output field, and T describes the optical transmission through the medium.

If we could determine the appropriate complex field E_i, we could make the waves arriving at one selected point interfere constructively, thereby creating a focus.

This is the basic idea behind **wavefront shaping**.

2.2. Role of a Spatial Light Modulator

A **Spatial Light Modulator (SLM)** is an electronically controlled optical device that allows the properties of light to be modified independently at different spatial locations.

For this experiment, a **phase-only SLM** is particularly relevant. It consists of a large array of pixels whose optical phase can be controlled electronically.

The SLM does not necessarily change the intensity of the incident beam directly. Instead, it changes its **phase**, and consequently changes how different parts of the beam interfere after propagation through the optical system. This makes the SLM a programmable optical wavefront.

Controlling the phase at each point of the light beam, we can control the interference profile on the camera plane. Therefore, if the phase of many independent contributions can be controlled so that they arrive **in phase at one point**, a bright focus can be produced even though the medium itself strongly scatters the light.

2.3 Why does the SLM allow focusing after scattering?

Imagine dividing the SLM into many independent regions, or segments. Each segment produces a different contribution to the electric field at the target point after passing through the scattering medium. For a particular target point,

$$E_{target} = \sum_{n=1}^{N} A_n e^{i\varphi_n}$$

Initially, the phases φ_n are essentially random because of the scattering medium. The contributions therefore interfere partly constructively and partly destructively, producing a random speckle intensity.

If we adjust the phase of each SLM segment so that

$$\varphi_1 = \varphi_2 = \cdots = \varphi_N$$

The contributions add constructively:

$$|E_{target}| = \sum_{n=1}^{N} A_n$$

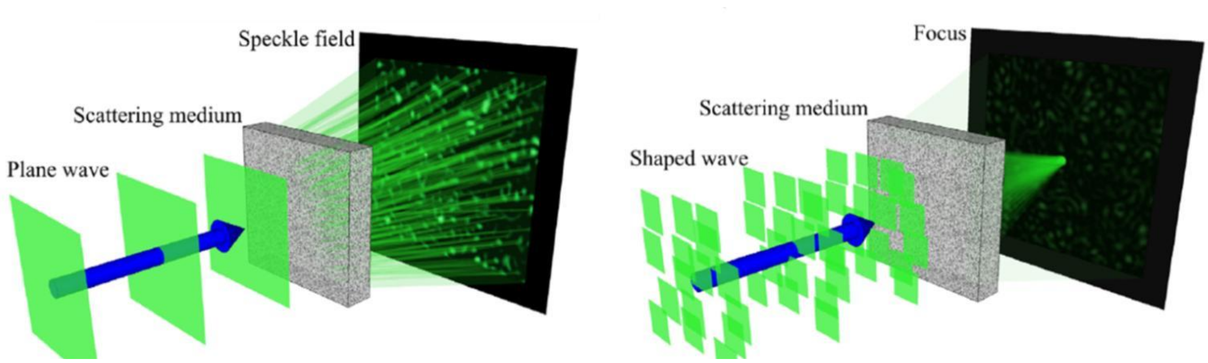

Figure 1Focusing with SLM

The intensity at the target can then become much larger than the average speckle intensity. This is called focusing through a scattering medium or scattering-assisted wavefront shaping.

3. Experiment

Task 1. Define the Region of Interest (ROI): Display a uniform or random mask on the modulator and capture the background speckle pattern. Select a specific area on the camera sensor (e.g., a single speckle grain) to serve as the optimization target. Calculate the initial average background intensity ⟨Ibg⟩ across the field of view.

Task 2. Define the Phase Grid: Choose the SLM Macropixel size. Generate the grid and check the image in ROI.

Task 3. Run the optimization: Execute the algorithm for a sufficient number of iterations to ensure convergence. Record the ROI intensity at each iteration step. Change the grid and repeat the optimization.

Task 4. Analysis: Fill the data in the table below and plot the saturation curve for EC over Total Iterations for different grids.

Run	**Macropixel Grid (e.g., 32x32)**	**Total Iterations**	**Initial** ⟨Ibg⟩	**Final** IROIoptimized	**Enhancement coefficient (EC)**
1					
2					
3					

4. References

[1] Vellekoop, Ivo M., and Allard P. Mosk. "Focusing coherent light through opaque strongly scattering media." *Optics letters* 32.16 (2007): 2309-2311.

[2] Vellekoop, Ivo Micha, and A. P. Mosk. "Phase control algorithms for focusing light through turbid media." *Optics communications* 281.11 (2008): 3071-3080.

[3] Vellekoop, Ivo M., Aart Lagendijk, and A. P. Mosk. "Exploiting disorder for perfect focusing." *Nature photonics* 4.5 (2010): 320-322.