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Modelling iterative optical phase conjugation through random media

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Abstract: A 2D modelling study is presented on the transmission enhancement by iterative optical phase conjugation through diffusive random media. Factors affecting coherent control for enhancing the total transmission is discussed.

1. Introduction

With the emergence of wavefront shaping in random media [1], several methods have been proposed to overcome coherent light scattering faced during diffusive transport. Iterative optical phase conjugation (IOPC), where spatial light modulators are placed on two sides of the random medium, is one of such methods that has the potential for multi-speckle transmission enhancement. In this paper, we explore the goodness or controllability of wavefront shaping by IOPC with a suitable gain profile, starting with a random wave incidence. Inspired by the observation given by Katz et al [2] that the highest transmitting eigenchannel is equivalent to the light transport profile obtained by a large number of IOPC, we aim to attain coherent light transmission enhancement, after a sufficient number of back and forth round-trips of phase conjugation. As noted by Popoff et al [3], Goetschy and Stone [4] and Hsu et al [5], the controllability of multi-speckle transmission enhancement is dependent upon the degree of transverse diffusion of light inside the medium relative to the incident shaped beam width addressing a certain number of geometrical basis modes. Hence our aim is to bring out the inter-relationship among highest transmitting eigenchannel, IOPC and controllability of wavefront shaping.

2. Methodology

Transmission matrix (S_{21}) of a disordered waveguide was estimated using the Fisher-Lee relationship acting on the perturbed Green's function[1]. The standard method was modified to include the effects of transverse diffusion, by incorporating incoming and outgoing leads with same transverse width $D < W$, as shown in Fig 1. When D of the incoming and outgoing leads approaches W, standard random matrix theory (R.M.T) applies. If c_{rand}^{inc} denotes the modal coefficients for a random incident wave (travelling left to right of the sample) chosen at the beginning of the round-trips, then a time reversal operator [2] for phase conjugation could be defined for the k^{th} round-trip such that

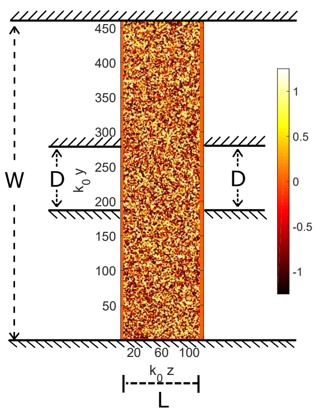

Fig. 1: A disorder realization, $\delta\varepsilon_r(r)$ where $k_0L = 110$, $k_0L_c = 1.2$, $\eta_0 = 1.5$, sampled from a uniform spatial random process with disorder correlation length L_c. Leads excite $\approx 2\eta_0 D/\lambda$ geometrical modes.

$c_k^{inc} = (g_1 g_2 S_{21}^H S_{21})^k c_{rand}^{inc}$ where c_k^{inc} is the incident wave after k^{th} round-trip and $g = g_1 g_2$, the gain associated with each round-trip. Hence, the disorder was continuously incident from the left side with $c_k^{inc} = (g_1 g_2 S_{21}^H S_{21})^k c_{rand}^{inc}$ for $k = 0, 1, 2, 3, ..$ for modelling IOPC. A varying gain profile was chosen such that in the beginning of every round-trip, the phase conjugated wave was amplified for unit flux injection through the incident lead.

3. Results and discussion

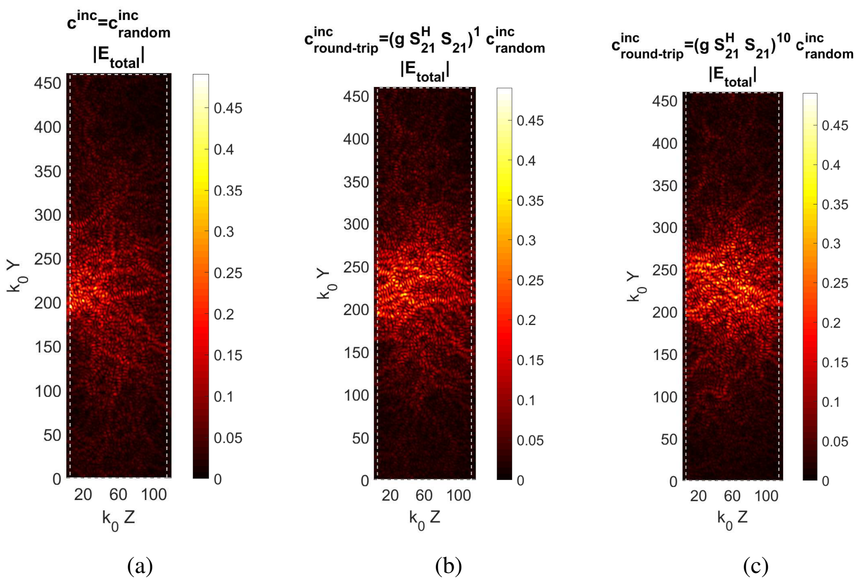

Fig. 2: (a) Magnitude of the total field inside the slab for a random wave incidence for $D/L = 0.84$ and transmission $T = 0.09$ (b) after first round-trip, $T = 0.31$ (c) after 10^{th} round-trip, $T = 0.49$.

With IOPC round-trip progression, total transmission enhances by attaining a convergent wave transport profile (as shown in Fig. 2), with transmission close to that of the highest transmitting eigenchannel in the medium. With larger D/L ratio, we also see a better control on wavefront shaping as expected, which in turn results in higher transmission enhancement for IOPC. Largest transmission enhancement was expected when $D = W$ where standard R.M.T applies and it predicts high variance for the singular value transmission coefficient (τ) of S_{21}. When D/L becomes smaller than that of the R.M.T scenario, it results in reduced variance of singular value transmission coefficients (τ) of S_{21}. Since the convergent total field with several rounds of IOPC was equivalent to the highest transmitting eigenchannel, the total transmission also reduces due to a reduction in the τ_{max}. The particular gain profile adopted for phase conjugation was chosen to attain convergence in a fast manner.

4. Acknowledgement

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