Experimental analysis of laser beams with variable spatial coherence propagating underwater

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Abstract: Multi Gaussian Schell Model beams with variable spatial coherence and fully coherent Gaussian beams were propagated underwater in two complex media scenarios. Experiments demonstrated that less coherent beams have less scintillation.

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1. Introduction

The motivation for our work is in the investigation and basic research on the performance of spatially partially coherent laser beam (PCB) propagation underwater as compared with fully coherent Gaussian beam propagation. More specifically we intend to explore the effects of spatially pseudo partially coherent beams (PPCB). PPCBs are of interest due to their potential for reduced scintillation on propagation as it has been suggested in literature on propagation of PPCB in turbulent atmosphere [1]. We seek to extend the literature to include additional testing and analysis of experimentally generated and propagated beams in the underwater environments.

Multi Gaussian Schell Model beams (MGSM) are spatially PPCBs with a flat intensity cross section and a diameter dependent on the prescribed degree of coherence. The PPCB is an experimental realization of a partially coherent beam where the beam is physically limited by how fast individual source realizations are produced as compared with the detection rate and atmospheric turnover time. Here we will only give an overview of the theory behind the generation of the MGSM beams since number of references [2] address the details of MGSM beam construction.

A recently developed model for the MGSM (flattop) beams, gives the following spectral (scalar) degree of coherence at the:

$$\mu^{(0)}(\rho_1, \rho_2) = \frac{1}{C_0} \sum_{m=1}^{M} \binom{M}{m} \frac{(-1)^{m-1}}{m} exp\left[-\frac{|\rho_2-\rho_1|^2}{2m\delta^2}\right], \quad (1)$$

where ρ_1 and ρ_2 are position distances and superscript (0) refers to the source plane,

$$C_0 = \sum_{m=1}^{M} \binom{M}{m} \frac{(-1)^{m-1}}{m}, \quad (2)$$

is the normalization factor used for obtaining the same maximum intensity level for any number of terms M in the summation, where $\binom{M}{m}$ is the binomial coefficient. In Eq. (1), δ is the r.m.s. width of the degree of coherence which describes the degree of coherence of the beam; and a value of $\delta = 0$ gives a spatially incoherent beam and a value of $\delta \to \infty$ gives a spatially coherent beam. Additionally, the upper index M relates to the flatness of the intensity profile formed in the far field: $M = 1$ corresponds to the classical Gaussian Schell-Model source and $M \to \infty$ corresponds to sources producing far fields with flat centres and abrupt decays at the edges.

2. Experimental set up

The research objective was to experimentally explore propagation of spatially PPCBs in underwater homogeneous regimes (calm water) and with moving scatterers. The experimental set up is given in Fig. 1. A stabilized HeNe laser source at 632.8 nm and a power of 2 mW was used to generate a Gaussian laser beam. Eight thousand screens with prescribed statistics and cycling rate of 333 Hz were generated using spatial light modulator (SLM) to simulate the spatially PPCB. The SLM had spatial resolution of 256x256 pixels and sensor area of 6.14 mm x 6.14 mm. A one-meter long water tank with a 10 x10 cm of cross section was filled with distilled water. Additionally, the laser beam was propagated through air for about 5 m before passing through the water tank. Sea salt was added to the water in order to provide entrained scatterers where water salinity was 41g/L with water temperature of 20.8 C. A camera with neutral density and red notch filters was placed one meter away from the water tank and directly in the path of the laser beam propagation. The camera had a spatial resolution of 480x640 pixels and an intensity resolution of 14 bits. Additionally, for each data run, approximately 500 images were collected at a rate of 3 Hz which was well under the 333 Hz cycling rate of the SLM and allowed for a beam that more closely represented a theoretical partially coherent beam vs. pseudo partially coherent beam.

The experiments were conducted in two medium regimes: a) still water with no (or minimal) motion of scattering particles and b) water mechanically perturbed by moving blades providing a low level motion of the scattering particles in the water. The still water regime with minimal particle motion was achieved by letting the water sit for approximately 24 hours before conducting the experiments. The steady state regime with low level of particle motion was achieved by exercising mechanical blades for 15 minutes, then collecting data measurements. A Gaussian beam (with no modulation by an SLM) and a MGSM beam with various degrees of coherence were propagated and measured in each of the medium regimes. Similar set is used in reference where the scattering of the PPCB was explored.[3].

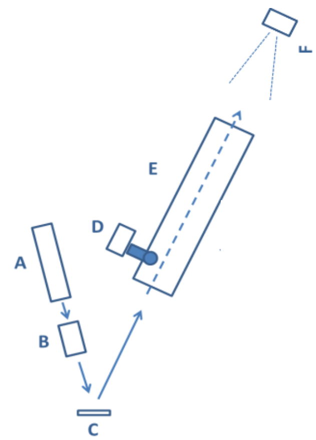


Figure 1. Experimental setup - A – HeNe laser, B – beam expander, C – spatial light modulator, D – mechanical agitator, E – 1 m propagation tank, F – camera.

3. Results

Data processing focus in this paper is on characterizing the mean light intensity and its fluctuations as expressed through the normalized variance or scintillation index. The images of laser light fluctuations as the beam propagated through the water were converted into the time series and the mean and variance were calculated for each pixel on the light sensor. In this paper we used the normalized variance to calculate the scintillation index. All of the results are given as the averaged values across the light sensor in order to demonstrate significant tends of our research.

Fig. 2 presents the increasing trend of the measured light intensity as the speckle size increase and the beam becomes more coherent. In addition Fig 2. shows that the light intensity on target is higher in calm environment compared to the moving scatterers environment, as expected. The valuable information is how much the intensity changes as the environment becomes more complex. For the most coherent PPCB we measured with speckle size of 1.07mm the decrease in the intensity was 20%.The comparison of the absolute value of the light intensity on the target between the Gaussian beam and PPCB is not effective due to the method of PPCBs generation, but based on our measurements the intensity change from the calm environment to the moving scatterers environment was significantly higher for the Gaussian beam vs PPCB. We measured the decrease in the intensity of the Gaussian beam propagation to be 74%.

Fig. 3a. summarizes the scintillation index changes in different environments when Gaussian beam and PPCB are propagating. It is clear that the scintillation index increases with laser beam becoming more coherent. In addition the scintillation index also increases when the environment changes to more complex scenario. The noteworthy trend to observe the difference between the scintillation indices in calm and moving scatterer environments as shown in Fig. 3b. The most significant increase in scintillation index is when the Gaussian beam propagates in more complex environment. These observations lead to the conclusion that PPCBs have beneficial performance when compared with Gaussian beams.

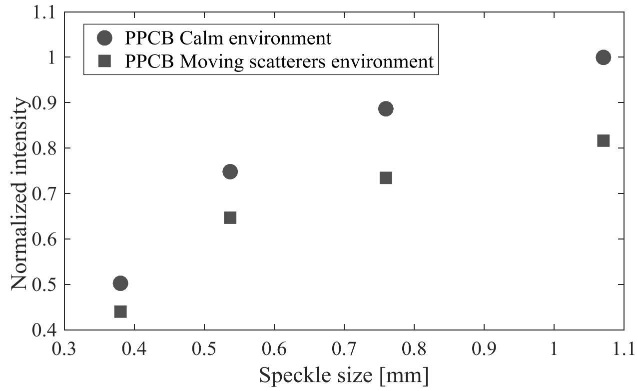
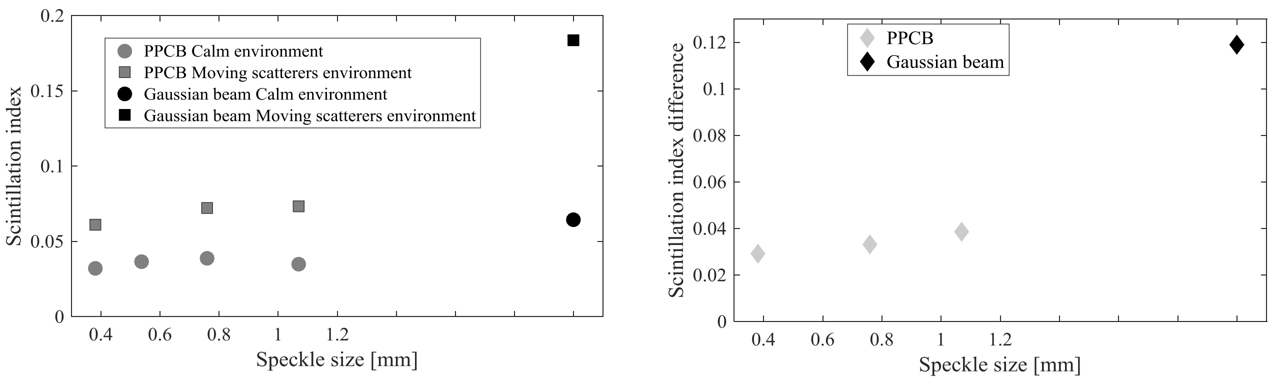


Figure 2. Normalized light intensity as a function of speckle size measured as partially coherent laser light propagated through the calm environment and the environment with the scatterers moving.



a) b)

Figure 3. a) Scintillation index measured in calm and moving scatterers environments when PPCBs and Gaussian beams were propagated. b) Scintillation indices difference trend between the moving scatterers and calm environments for PPCB and Gaussian beams.

4. References

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