SHAPING AND ANALYSIS OF LASER SPECKLE FOR IMAGING APPLICATIONS

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by

VINU R.V

Department of Physics

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Thiruvananthapuram-695547

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ABSTRACT

The potential of laser speckle pattern as a versatile tool in numerous application regimes in science and engineering secure interest of researchers to explore different application based scenarios where speckle effects can be implemented. Advancements towards this direction of using the speckle pattern leads to new application areas such as surface roughness estimation, speckle interferometry, speckle photography, astronomy, laser speckle contrast imaging, optical manipulation, correlation imaging etc. The randomness associated with speckle pattern provides the potential to treat speckle pattern as a part of statistical optics, and the theoretical and experimental progresses in the field of statistical optics give new opportunities in the study of random fluctuations in the speckle pattern. The main objectives of this thesis are shaping and analysis of laser speckle pattern and the effective utilization of their randomness for optical manipulation and imaging through scattering layers.

Active shaping approach for shaping the laser speckle size based on correlation of the amplitude and intensity of the speckle pattern has been developed and successfully demonstrated. The use of diffractive optical elements such as holograms, phase gratings, Dammann gratings, apertures etc in active shaping of the speckle pattern is discussed and demonstrated by developing field and intensity based interferometers. A single-shot correlation analysis is performed by relying on the spatial averaging (rather than temporal averaging) and demonstrated applications of spatial stationarity feature of random fields in different applications ranging from characterization to imaging. Initial part of the thesis focus on the shaping of the speckle pattern with various diffractive optical elements and its analysis using field and intensity based interferometers. Final part of the thesis focuses on the applications of the active shaping approach in imaging through the complex scattering layers.

A polarization sensitive interferometer capable of single-shot detection of orthogonal polarization components is developed and experimentally demonstrated. The efficient execution of diffractive optical element such as Dammann phase type grating by exploiting the characteristic feature of phase only SLM and polarization sensitive interferometer provides the potential to control the orthogonal polarization components of the fluctuating field. This potential is effectively implemented to generate uniform array of spatial coherence points both in 1D and 2D with desired spacing. The technique offers a new method for synthesis and analysis of laser speckle pattern and consequently controls the coherence and polarization properties of the random field. The speckle holographic approach combined with two point intensity correlation is implemented to retrieve the complex information of the random field in scalar and vectorial cases. A singular point array generation with desired densities is

efficiently demonstrated in spatially fluctuating random field by utilizing the concepts of two point intensity correlation and spatial average approach. An experimental technique for the determination of generalized Stokes parameters or coherence-polarization matrix elements is experimentally demonstrated by making use of the speckle holographic approach in combination with the intensity correlation. Applicability of this technique is demonstrated in the controlled synthesis of coherence and polarization properties of random light field.

The active shaping approach used for speckle (or correlation function) is efficiently applied in the optical imaging through random scattering layers. The complex valued object lying behind the scattering layer is recovered by making use of speckle holographic approach in combination with two point intensity correlation. By efficiently implementing this approach, a single-shot imaging technique is demonstrated for the recovery of an off-axis hologram hidden by a scattering layer. The technique has unique ability to retrieve the 3D complex field behind a scattering medium resulting into the reconstruction of actual position of the object. The potential of the technique is validated to more real time situation where the holographic diffraction is dominant by the recovery of in-line hologram through scattering layer. The depth resolved imaging of reflecting type and transmitting type object hidden by the scattering layer are efficiently demonstrated and analyzed quantitatively by presenting the reconstruction parameters. These imaging technique has a remarkable achievement in true non-invasive single-shot and depth resolved 3D imaging through complex scattering layers, and have robust practical applications in biomedical imaging, imaging through turbid media, astronomy etc