Abstract

Optics has greatly contributed and influenced many research areas such as life sciences, medicine, health care, defence, and astronomy to name a few. Increasing interests to see and extract spatially resolved information from the light signal have inspired researchers to explore optics and optical imaging. Optical imaging has emerged as a mainstream inspection tool due to its nearly non-invasive characteristics. However, optical imaging through scattering media has long been a challenging issue due to the scrambling of the optical wave. Propagation of coherent light through a random scattering medium, such as living tissue, atmospheric turbulence, fog, scattering wall, etc, scrambles the wavefront of the light and generates a speckle pattern. The laser speckle is considered as a source of noise in the conventional optics and conventional imaging methods are not suitable to extract the useful information. Inspite of apparent randomness in the laser speckle, the granular intensity pattern of the speckle carry an important signature of the source and randomness in terms of fine scale fluctuations in space. Therefore, the issue of information recovery from a random field, such as speckle, is being attempted using different methods such as image processing, wavefront corrections, transmission matrix measurement etc. Major focus and emphasis of these techniques are on the removal compensation of the randomness using methods such as adaptive optics, digital holography, etc. However, these methods are having limited success for a highly scattering and dynamic media. On the other hand, recent development and introduction of new illumination sources have inspired researchers to utilize the randomness of the light and correlation principle for advanced optical imaging. The concept of exploiting correlations between the speckle patterns to obtain images of objects has started a new class of optical imaging. However, these techniques are mainly confined to the amplitude and scalar objects. Although, use of randomness and speckle in the imaging has long been proposed in astronomy with focus

on imaging of the real valued object, but techniques such as correlation holography and ghost imaging have streered new interests on randomness assisted imaging. In spite of significant developments, correlation imaging techniques require large number of random patterns for faithful recovery of the desired signals from the two-point correlations. Our goal in this thesis is to examine these issues and develop new experimental techniques using the correlations of random light. In this quest, we made attempts to extract spatial information of an object from the second-order intensity correlations of the random fields which can be traced back to the famous Hanbury Brown-Twiss (HBT) method. Objectives are to combine strong theoretical resources of the coherence theory with the technological progress of holography. This unification has helped us to bring new results and methods on the correlation holography and Ghost diffraction. In particular, we developed different experimental designs and methods to image different objects from the intensity correlations of the scalar and vector random fields. This thesis also provides a fresh insight on use of temporally and spatially fluctuating fields for new optical imaging methods. Contributions of this thesis is categorized into two major parts. First part covers our three new contributions, namely complex field imaging using digital holography, high quality holographic imaging with intensity correlation, and a tunabable beam displacer to image orthogonal modes of the light from the randomness. Second part of thesis covers scheme on the Ghost diffraction where we give major emphasis on replacing the temporal averaging by the spatial averaging. This is inspired by our interest to speed up the process of signal reconstruction in ghost imaging and also compare performance with the conventional Ghost diffraction. The research work presented in this thesis has been divided into six chapters. Chapter 1 presents a brief introduction to optics through homogenous and scattering media. Propagation of waves through free space and random scattering medium is discussed in the context of paraxial optics and imaging. In order to cover basics of the the optical imaging, we discuss diffraction limited imaging system and digital holography

(DH). This chapter also covers a brief discussion on the classical coherence theory and polarization. Chapter 2 discusses role of coherent imaging in the characterization of light and source. Role of the DH, particularly off-axis DH, is discussed in the single shot coherent field imaging and polarimetry. In order to describe the challenges of the off-axis DH, different experimental designs on the DH are covered with some possible applications. Finally, we use one of the experimental designs of the DH, based on the triangular Sagnac interferometer, for polarimetric characterization of the spatial light modulator (SLM). Our experimental design based on the Sagnac interferometer uses a residual de-collimated beam and makes a radial shearing for the quantitative complex field reconstruction and polarimetry. This strategy helps to design a highly stable experimental design which is tested by characterizing the SLM in a controlled vibration-free and in vibrating conditions. Detailed theoretical frameworks, numerical simulations, and experimental results of these techniques are discussed. Chapter 3 presents a new technique on the correlation holography for simultaneous recovery of the incident orthogonal polarization modes from the random light. In order to implement a parallel recovery of the orthogonal polarization modes of the light from the randomness, we present a triangular polarization Sagnac interferometer assembly with fine tuning of the mirror for lateral separation of the orthogonal polarization components of the light. Due to the propagation of light through the scatterer and high-angle scattering, it is hard to isolate the random patterns of the orthogonal polarization componentents at the recording plane by a fixed angle commercial Wollaston prism or beam displacer. On the other hand, our tunable beam displacer overcomes this challenge and permits independent detection and processing of the two-point intensity correlations of the orthogonal polarization components from a single measurement. A new scheme for the edge referencing is also presented to recover the phase loss problem in the HBT approach and subsequently use of this scheme for the correlation holography. Our experimental approach is free from iterations and capable of providing a speckle-free image from a single intensity measurement. Moreover, this chapter also discusses role of the incoherent addition of the random patterns to reduce the speckle noise in the recovery of the object from the intensity correlations. A detailed theoretical model, numerical simulation, and experimental results are presented.

Chapter 4 describes a new approach to image complex-valued objects using holography with the intensity correlation. Here, we report the recording of the hologram in terms of intensity correlations rather than intensity. We demonstrate that the use of intensity correlations in the recording of the hologram enhances the quality of reconstruction. Our scheme provides the amplitude and phase information of the desired object using an inline holography scheme and the usual twin image issue occuring in inline holography is removed using a deep learning-based method. This chapter in detail; discusses the role of intensity correlation for a number of incoherent random patterns that leads to the enhanced quality of image reconstruction. A quantitative analysis of experimental results is provided to prove our technique's validity. Detailed theoretical model and experimental results for two different objects are presented. Chapter 5 covers Ghost imaging and Ghost diffraction with the classical light source. Our new experimental scheme to implement Ghost diffraction with spatial statistical optics is discussed. The use of spatial averaging for the correlations instead of temporal averaging leads to reducing the number of random patterns required in ghost diffraction. The performance of this alternative approach for Ghost diffraction is evaluated for scalar and vector light fields. The performance of this alternative approach for Ghost diffraction is evaluated for scalar and vector light fields. For the polarimetric reconstruction of the ghost scheme, four stokes parameters are evaluated and experimentally measured for different objects to verify the technique. A phase iterative algorithm is applied to fully recover the spatial features of the object. Theoretical model and experimental results are presented and discussed in detail. Finally, the conclusions of the overall study have been summarized in the last chapter 6. We discuss the role of correlation optics and intensity correlations in the recovery of information and in unconventional optical imaging techniques with random light. This chapter also comprises further future research plans on this topic.