Preface

Light serves as a powerful tool for capturing and recording object characteristics on a rewritable mold. The quest to extract spatially resolved information from light has driven significant progress in optical imaging. Optical imaging is highly regarded for its non-invasive nature and has been extensively used in scenarios where the medium is homogeneous, allowing the wavefront of light to remain well-defined. However, the effectiveness of conventional imaging techniques diminishes significantly when the medium becomes inhomogeneous, such as in the presence of scattering walls, fog, atmospheric turbulence, or biological tissues. In such cases, coherent light propagating through these random scattering media generates random intensity patterns, known as speckle patterns.

Formation of speckles is regarded as a noise in imaging, and imaging with conventional methods is hampered by such randomness. Despite its noisy features, speckle patterns encode important signatures of objects. Reconstructing object information from these speckle patterns has been a long-standing challenge, with many approaches focusing on eliminating randomness using techniques such as adaptive optics or transmission matrix measurements. However, these methods often fall short in highly scattering and dynamic media.

On the other hand, statistical features such as different correlations of speckle patterns have enabled researchers to leverage the randomness of light for innovative optical imaging methods. While speckle correlation-based imaging originates in astronomy for measuring stellar angular diameters, modern methods such as two-point intensity correlations combined with holography have steered new interest in phase imaging from random fields. However, these techniques are underexplored for dynamically fluctuating light fields like fog or atmospheric turbulence.

In parallel, the study of polarization imaging through random light has garnered significant interest, as the polarization state of light also undergoes scrambling in scattering media. Correlation optics holds substantial potential for developing novel polarization imaging techniques from scattered random light. This thesis focuses on these issues by developing novel experimental methods using second-order intensity and polarization correlations. Objective is to combine the theoretical foundation of correlation optics with holographic technology and to develop innovative approaches for unconventional holography, i.e., holography with second-order correlations and the Hanbury Brown-Twiss (HBT) approach. This thesis also provides a fresh insight on polarization of spatially fluctuating light and leveraging polarization correlations for new statistical analysis and imaging methods.

The thesis is organized into **six** chapters.

Chapter 1 provides an overview of optical imaging in free space and scattering media. It introduces the basic concepts of optical imaging, including the roles of intensity, phase, and polarization, and highlights the limitations of conventional first-order intensity detection in information processing and imaging. The chapter also discusses advances in quantitative phase and polarization imaging, as well as the challenges posed by the scattering media. Techniques leveraging statistical correlation optics and holography to address these challenges are reviewed.

In **Chapter 2,** we present two statistical methods for characterizing laser speckles with spatial polarization fluctuations. The first technique models random polarization fluctuations using the von Mises-Fisher (vMF) distribution on the Poincaré sphere to demonstrate a statistical insight of different types of speckle fields. Parameters like spatial mean direction and spatial concentration parameter, evaluated using spatial averaging of Stokes parameters (SPs) are utilized for this purpose. Experimental measurements of SPs were performed using an interferometric approach, to extract the SPs in single-shot. This interferometric technique requires the use of a separate reference arm to measure the SPs, which increases experimental complexity and is sensitive to external disturbances. The second technique evaluates two-point correlations of SPs to analyze spatial polarization dynamics. Two-point correlations of SPs provide a 4×4 matrix with sixteen elements. Out of these sixteen elements, only four diagonal elements of the matrix are used to determine the spatial polarization dynamics of the polarization speckle. A stable experimental method, based on non-interferometry, is also used to measure the SPs, and these quantities are used for the analysis of polarization dynamics. Detailed theoretical frameworks, numerical simulations, and experimental results obtained using holographic and non-interferometric techniques are discussed for various types of speckle fields.

Chapter 3 presents new experimental techniques for imaging through dynamic scattering media, such as a dynamic diffuser and fog. The first method utilizes the HBT-based intensity correlation principle with dynamically fluctuating intensity patterns to recover amplitude and phase information of objects hidden behind dynamic scattering media. The second method extends this approach to develop a correlation holography technique for imaging through fog, using laboratory-mimicked fog conditions. Theoretical framework and experimental validations are discussed in detail for both techniques.

Chapter 4 discusses new experimental methods to quantitatively characterize the statistical properties of vector sources using Beam Coherence-Polarization (BCP) matrix. SPs of the scattered random light are used and two-point correlations between SPs fluctuations are evaluated in this approach. This provides a 4×4 correlation matrix that contains sixteen elements. Out of these sixteen elements, only four elements i.e., correlation of only two SPs S_0 and S_1, are considered to build a theoretical basis and subsequently applied for the estimation of BCP matrix of vector sources. A compact folded interferometer is designed to measure BCP matrix elements of spatially and temporally fluctuating intensity patterns. Experimental setups, theoretical models, and results are presented to validate the approach. Three different experimental techniques have been developed for the measurement of elements of BCP matrix for both spatially and temporally fluctuating intensity patterns. A detailed theoretical model, experimental setup, and results are presented to validate the approach.

Chapter 5 outlines a novel single-shot Stokes polarimetry technique for polarization imaging. This method eliminates the need for mechanical rotation of optical components by employing tuneable beam displacers and randomness-assisted measurements of SPs. Theoretical analysis, experimental results demonstrate the imaging of polarized sources and characterization of state of polarization for various vector sources.

Chapter 6 summarizes the findings and highlights the role of intensity and polarization correlations in developing advanced imaging and statistical characterization methods. Future directions, including polarization imaging through dynamic scattering media and computational imaging techniques are also discussed.