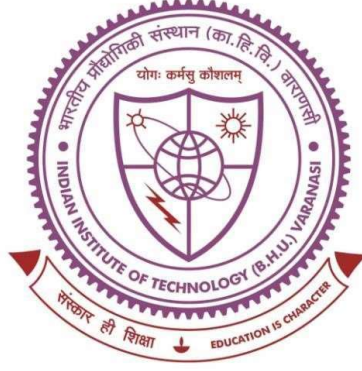


# Randomness assisted holography and ghost diffraction



A thesis submitted in partial fulfilment for the  
Award of Degree of

**Doctor of Philosophy**

By

*Manisha*

**DEPARTMENT OF PHYSICS  
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## **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. In spite 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 components 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 occurring 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.



# Table of contents

<b>List of figures</b>	<b>xxv</b>
<b>List of tables</b>	<b>xxxiii</b>
<b>Nomenclature</b>	<b>xxxiii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Light and Optical field . . . . .	1
1.2 Diffraction . . . . .	4
1.3 Fresnel and Fraunhofer integrals . . . . .	5
1.3.1 Discrete Fourier transform . . . . .	8
1.3.2 Angular spectrum method . . . . .	9
1.4 Coherence . . . . .	13
1.5 Holography . . . . .	16
1.5.1 Off-axis holography . . . . .	18
1.5.2 Phase shifting Digital Holography . . . . .	19
1.6 Polarization digital holography . . . . .	20
1.7 Optics with randomness . . . . .	23
1.7.1 Propagation of coherent light through randomness: Laser Speckle	23
1.7.2 Adaptive optics . . . . .	25
1.7.3 Optical phase conjugation . . . . .	27

---

1.7.4	Schemes based on Transmission matrix(TM) . . . . .	27
1.7.5	Correlation optics . . . . .	29
1.7.6	Polarization Speckle . . . . .	35
<b>2</b>	<b>A compact and lens less digital holography setup for polarimetric analysis of spatial light modulator</b>	<b>43</b>
2.1	Introduction . . . . .	43
2.2	Methodology . . . . .	48
2.3	Results and Discussion . . . . .	52
2.4	Conclusion . . . . .	58
<b>3</b>	<b>Single shot and speckle free reconstruction of orthogonal polarization modes with a tuneable beam displacer</b>	<b>61</b>
3.1	Introduction . . . . .	61
3.2	Theory . . . . .	65
3.3	Experiment . . . . .	71
3.4	Results and Discussion . . . . .	73
3.5	Conclusion . . . . .	82
<b>4</b>	<b>Randomness assisted in-line holography with deep learning</b>	<b>83</b>
4.1	Introduction . . . . .	83
4.2	Theory and Methodology . . . . .	86
4.3	Experimental recording . . . . .	90
4.3.1	Description of Auto Encoder model . . . . .	94
4.4	Conclusion . . . . .	104
<b>5</b>	<b>Ghost diffraction</b>	<b>105</b>
5.1	Introduction . . . . .	105

---

5.2	Methodology . . . . .	107
5.3	Experiment . . . . .	113
5.4	Results and Discussion . . . . .	114
5.5	Ghost Polarimetry . . . . .	120
5.6	Conclusion . . . . .	123
<b>6</b>	<b>Conclusion and future plan</b>	<b>125</b>
6.1	Conclusion . . . . .	125
6.2	Future plan . . . . .	127
	<b>References</b>	<b>129</b>



# List of figures

1.1	Representation of a plane wave . . . . .	2
1.2	Wavefront of plane wave . . . . .	3
1.3	Wavefront of spherical wave . . . . .	3
1.4	Vortex beams representing spatial and wavefront profile with different topological charges, $l=0,1,2$ . . . . .	4
1.5	Diffraction through far field . . . . .	5
1.6	Huygens principle . . . . .	6
1.7	Diffraction from aperture plane . . . . .	7
1.8	Fourier transform with a lens . . . . .	9
1.9	Angular spectrum method: Effect of different propagation distances .	12
1.10	Young's Interference Experiment . . . . .	14
1.11	The distribution of average intensity for different degrees of coherence cases . . . . .	16
1.12	Schematic of an inline holography geometry . . . . .	17
1.13	Conceptual design for holographic recording in an Off-axis holography scheme . . . . .	18
1.14	Phase Shifting Digital Holography . . . . .	19
1.15	Polarization Imaging Interferometer . . . . .	20
1.16	On-axis Polarization Imaging Scheme . . . . .	21

1.17 Single shot polarization Imaging Interferometer . . . . .	22
1.18 Experimental design for interferometric polarimeter with an integrated calibration scheme . . . . .	23
1.19 Laser Speckle . . . . .	24
1.20 A speckle formed by the interaction of coherent light with rough surface	25
1.21 A schematic of adaptive optics approach . . . . .	26
1.22 Optical phase conjugation scheme . . . . .	27
1.23 Optical schematic for a ring-interferometer digital optical phase con- jugation . . . . .	28
1.24 A schematic to record transmission matrix . . . . .	29
1.25 A schematic of programmable spectrum shaping . . . . .	30
1.26 A conceptual design for angular memory effect principle . . . . .	31
1.27 A conceptual design for intensity correlation measurement . . . . .	32
1.28 A schematic for the interference of coherence waves . . . . .	34
1.29 A conceptual design for the generation of polarization speckle . . . . .	35
1.30 Poincare sphere representing Stokes vectors . . . . .	36
1.31 Experimental setup for phase imaging of target behind scattering medium with phase shifting . . . . .	38
1.32 A conceptual design for intensity correlation measurement of vector field . . . . .	39
1.33 A conceptual design for the measurement of Stokes parameters corre- lation . . . . .	40
1.34 Application of randomness in different research areas . . . . .	42
2.1 Experimental setup of the common-path digital holography based on a slightly trapezoid Sagnac interferometer . . . . .	45

2.2	Experimental setup of the $\tau$ interferometer fitted into the output of an inverted microscope . . . . .	46
2.3	(a) Schematic of the experimental technique. (b) Flowchart for the processing of Interferograms [P: polarizer, HWP: Half wave plate, SF: Spatial filter, L: lens, SLM: Spatial light modulator, BS <sub>n</sub> (n=1, 2): beam splitters, M <sub>n</sub> (n=1, 2): mirrors, CCD: Charge coupled device, BD: Beam dump]. (c) Laboratory picture of experimental design. . .	50
2.4	Schematic of the proposed cyclic interferometer and corresponding interferogram (b) Fringe formation from reference and modulating part of SLM screen. . . . .	51
2.5	Recorded interference patterns for $E_x$ component (a-c) and for $E_y$ component (d-f) at gray values 5, 180 and 255 for SLM with 45 degree linearly polarized incident light . . . . .	52
2.6	Fourier spectrum for $E_x$ component (a-c) and for $E_y$ component (d-f) at gray values 5, 180, and 255 of SLM with 45 degree linearly polarized incident light. Fig. in the inset represents the highlighted Fourier spectrum). . . . .	53
2.7	Amplitude distribution for $E_x$ component (a-c); for $E_y$ component(d-f). Phase distribution ( $\phi_x$ ) for $E_x$ component (g-i), at gray values 5, 180 and 255 of SLM with 45 degree linearly polarized incident light. .	54
2.8	Amplitude and phase modulation curve for incident 45 degree linearly polarized light. Amplitude and phase curve corresponding to field component $E_x$ : (a) & (b) ; amplitude and phase curve corresponding to field component $E_y$ : ( c) & (d). . . . .	55

2.9	Amplitude and phase modulation curve for incident 45 degree linearly polarized light in the presence of additional external vibrations, by placing a vibrating cell phone near to the setup. Amplitude and phase curve corresponding to field component $E_x$ : (a) & (b); amplitude and phase curve corresponding to field component $E_y$ : (c) & (d) . . . . .	57
2.10	Polarimetric phase of the electric field components using cyclic interferometric setup . . . . .	58
3.1	Conceptual representation of speckle at arbitrary distance $z$ . . . . .	67
3.2	(a) The experimental scheme of the proposed work, Ln( $n = 1,2$ ): lens, HWP: half wave plate, T: object with edge reference (shown by red dotted arrow), GG: ground glass, PBS: polarizer beam splitter, Mn( $n = 1,2$ ): mirrors, CMOS Camera: complementary metal-oxide semiconductor camera. The green arrow represents the observation plane which is imaged by imaging lens L2. (b) The tuneable beam displacer used to split the polarization speckles corresponding to x and y polarized light, the speckle field at distance $z = 100$ mm as shown by a green arrow location, is imaged by the tuneable beam displacer assembly at the detector . . . . .	73
3.3	(a) Speckle pattern for diagonally polarized light; both orthogonal polarization in one frame (b) speckle pattern for $60^\circ$ polarized incident light (c) speckle pattern for x polarized light (d) speckle pattern for y polarized light . . . . .	74

---

3.4 Correlation fringes for number ‘2’: (a), (b) for diagonally polarized incident light, (a) x polarized component, (b) y polarized component; (c), (d) for 60° polarized incident light, (c) x polarized component, (d) y polarized component; (e) for horizontally polarized incident light, x polarized component and inset in the right corner represents very weak y component ;(f) for vertically polarized incident light, y polarized component and inset in the right corner represents very weak x component. . . . . 77

3.5 Reconstruction of number ‘2’: (a), (b) for diagonally polarized incident light, (a) x polarized component, (b) y polarized component; (c), (d) for 60° polarized incident light, (c) x polarized component, (d) y polarized component; (e) for horizontally polarized incident light, x polarized component; (f) for vertically polarized incident light, y polarized component. . . . . 78

3.6 Reconstruction of number ‘2’ for incoherent addition of 45 random patterns: (a), (b) for diagonally polarized incident light, (a) x polarized component, (b) y polarized component; (c), (d) for 60° polarized incident light, (c) x polarized component, (d) y polarized component; (e) for horizontally polarized incident light, x polarized component ;(f) for vertically polarized incident light, y polarized component. . . . 79

3.7	Reconstruction of Hindi letter ‘ $\text{ठ}$ ’ for incoherent addition of 45 random patterns: (a), (b) for diagonally polarized incident light, (a) $x$ polarized component, (b) $y$ polarized component; (c), (d) for $60^\circ$ polarized incident light, (c) $x$ polarized component, (d) $y$ polarized component; (e) for horizontally polarized incident light, $x$ polarized component; (f) for vertically polarized incident light, $y$ polarized component . . . . .	80
3.8	Flow chart for the process of reconstruction of object from the recorded speckle . . . . .	81
4.1	A comparison of (a) conventional and (b) our technique . . . . .	88
4.2	Experimental Setup; SF: Spatial filter, L1 and L2: Lens with focal lengths 200 and 100mm respectively, BS: Beam splitter, SLM: Spatial light modulator, RGG: Rotating ground glass, A1 and A2: Apertures, CMOS Camera: Complementary metal oxide semiconductor camera . . . . .	91
4.3	(a) Conventional inline hologram for $\beta$ ; (b) Inline hologram in terms of second order correlation . . . . .	92
4.4	An auto-encoder network utilizing deep convolutional layers in an hourglass architecture . . . . .	95
4.5	A flow chart of our scheme . . . . .	97
4.6	(a),(b) Fourier spectrum for $\beta$ in conventional case and proposed scheme respectively; (c),(d) Fourier spectrum for $V$ in conventional case and proposed scheme respectively . . . . .	98
4.7	(a-b) Conventional case results for letter $\beta$ ; (a) Amplitude (b) Phase, (c-d) Proposed scheme based results for letter $\beta$ ; (a) Amplitude (b) Phase . . . . .	98
4.8	(a-b) Conventional case results for letter $V$ ; (a) Amplitude (b) Phase, (c-d) Proposed scheme-based results for letter $V$ ; (a) Amplitude (b) Phase . . . . .	101

4.9 Effect of propagation:(a)Amplitude distribution at different propaga-  
tion distances ;(b)Phase distribution at different propagation distances 102

4.10 Conventional scheme: Reconstruction under different noise levels:(a),(b)  
and (c) represent reconstructed amplitude under noise level 3,4 and  
5 respectively; (d),(e) and (f) represent reconstructed phase under  
noise level 3,4 and 5 respectively . . . . . 102

4.11 Proposed scheme: Reconstruction under different noise levels:(a),(b)  
and (c) represent reconstructed amplitude under noise level 3,4 and  
5 respectively; (d),(e) and (f) represent reconstructed phase under  
noise level 3,4 and 5 respectively . . . . . 103

5.1 Conceptual representations of a GD scheme with RGG and our pro-  
posed GD scheme (a) ghost diffraction scheme with RGG: rotating  
ground glass, SPD: Single Pixel Detector, transparency-  $\tau$ , reflective  
type. (b) Proposed ghost diffraction scheme with SGG: Static Ground  
Glass, BS: Beam Splitter . . . . . 111

5.2 Block diagram for the phase retrieval algorithm . . . . . 112

5.3 Schematic of the experimental setup of the proposed technique, L:  
lens,  $P_n(n = 1, 2)$  : Polarizers, GG: Ground glass, SLM: Spatial Light  
Modulator, BS: Beam splitter, CCD: Charge-Coupled device. BD-  
Beam Dumped. . . . . 113

5.4	Simulation Study (a-c): (a) only a single pixel of random field with transparency and scanning of single pixel in the space (b) window of the reference speckle and its scanning (c) Far-field pattern for annular aperture by simulation; Experimental Study (d-f): (d) only a single pixel of random field with transparency and scanning of single pixel in the space (e) window of the reference speckle and its scanning (f) Far-field pattern for annular aperture by experiment . . . . .	115
5.5	(a) 1-D line profile for single-pixel used from object (Ring) experimental speckle (b) Experimentally recorded speckle without object information; (c) Original object; (d) and (e) indicate experimental and simulation reconstructed object transparency $\tau(\rho)$ . . . . .	117
5.6	(a) 1-D line profile for single-pixel used from object (Ring) experimental speckle (b) Experimentally recorded speckle without object information; (c) Original object; (d) and (e) indicate experimental and simulation reconstructed object transparency $\tau(\rho)$ . . . . .	118
5.7	Results for different sizes of Tuckey window used in the algorithm . . . . .	119
5.8	Conceptual representation of measuring Stokes parameters in Ghost diffraction; GG: Ground glass, BS: Beam Splitter, SPD: Single Pixel Detector, QWP: Quarter wave plate, P: Polarizer . . . . .	121
5.9	Stokes fluctuations; (a-d) $C_{00}$ , $C_{11}$ , $C_{22}$ , and $C_{33}$ . . . . .	122
5.10	Generalized Stokes parameters $GS_0$ (a), and $GS_2$ (b). Retrieved object results;(c) and (d) for two parallel strips corresponding to (a) and (b)	123

## List of tables

4.1	Visibility and Reconstruction efficiency values at different z planes . .	101
4.2	Visibility and Reconstruction efficiency values for the proposed scheme at different noise levels . . . . .	104

