HELICAL MODES AND POLARIZATION GUIDING TO DELIVER OPTICAL INFORMATION THROUGH RANDOM SCATTERER: LOOKING THROUGH RANDOMNESS

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Chapter 6

Conclusion

In this chapter, the overall conclusion of the research work done as a part of this thesis is summarized. The future scope and future work to be carried out are also discussed in this chapter.

6.1 Summary

The faithful delivery and recovery of optical information through the random scattering media is a long-lasting issue and a very arduous task. The presence of random scattering media in the propagation channel of the optical signal distorts the signal's wavefront and direct access to the wavefront is a tremendously challenging task. Inhomogeneities in the refractive indices of the random scattering media randomly distribute an input optical signal into arbitrary variations of bright and dark spots called speckles. For instance, when the composition of helical beams in the optical information using mode division multiplexing (MDM) coaxially transmits through the random scattering media, then the inhomogeneities of the scattering media disturbs the interchannel orthogonality of the helical modes and generate crosstalk between these modes. On the other hand, random scattering limits the detection and imaging of objects hidden behind an obstacle or barrier. Due to this reason, the information available at the observation plane is low contrast, random, or completely obscured. Nevertheless, the random light at the observation plane encodes enough information about the incident optical signal, but the unique problem lies in the characterization of random light and retrieving the useful optical signal from the random light. The advent of phase conjugation, transmission matrix, and adaptive optics techniques make this characterization and retrieving feasible to some extent. Apart from these methods, correlation optics-based methods utilize the randomness of the light (rather than canceling it) to develop and design high-resolution detection techniques for optical signals. This thesis exploits the randomness of light to develop and design highly stable new experimental geometries to faithfully deliver and recover optical information from the randomly scrambled light. This thesis encapsulates highly stable and robust new experimental schemes with helical modes of the light and polarization guiding to faithfully deliver and recover the information through a random scattering media.

Pilot-assisted strategy i.e polarization guiding and encoding optical information into one of the orthogonal polarization modes is utilized to deliver coherent light through a random scattering medium and consequently see through the scatterer by the polarization correlation. The higher-order polarization correlation is implemented to recover the desired optical signal from the randomness. Coherence and polarization features of the random light from Stokes correlation are employed to develop new non-interferometric experimental setups to recover helical modes of the incident optical signals from random light, and also in designing highly stable in-line unconventional holography techniques. The two-point correlation between Stokes parameters (SPs) fluctuations provides a 4-by-4 matrix known as a complex polarization correlation (CPC) matrix with a total of sixteen elements. The different combinations of the elements of the matrix have been examined to develop new methods to retrieve optical information from random light. To exploit the benefit of single-shot correlation analysis of the random light, we rely on spatial averaging (rather than temporal averaging) and demonstrated the application of spatial stationarity feature of random fields in different applications i.e helical modes detection and unconventional holography techniques. This implementation of spatial averaging in experimental techniques gives the potential of single-shot optical signal recovery and thereby reduces the experimental complexity.

In Chapter 2 two different new techniques have been developed to recover the single helical mode propagating through the random scattering media using higher-order SPs correlations. In these techniques, the polarization fluctuation in the random field is used to obtain SPs correlations by introducing different helical modes into orthogonal polarization components of the light prior to random scattering from a diffuser. Spatially varying polarization states are generated by introducing the helical modes in one of the orthogonal polarization components of the incident light. This makes coupling between the spatial and polarization modes of the light. The two-point correlation between orthogonal polarization components encodes the signature of the incident beam. The first technique uses only four elements of the 4-by-4 matrix to develop a theoretical basis to recover the complex polarization correlation function (CPCF) and subsequently helical mode from the random light and this offers to design a highly stable lensless non-interferometric setup. However, this technique requires a quarter wave plate (QWP) to measure all the SPs of the random light. The presence of QWP in the experiment requires proper calibration in power to avoid unnecessary influence on the state of polarization (SOP) mapping due to the absorption of light. Therefore, the second technique has been built to avoid the issues arising owing to QWP by measuring the first three SPs of the random light using only a polarizer. These SPs were implemented to evaluate the 3-by-3 CPC matrix and only two elements of the matrix are used to recover the real part of the CPCF. The combination of the phase-shifting along with the real part of the CPCF helps to unscramble the helical mode. The limited SPs of the random light help to design lensless non-interferometric phase-shifting techniques for the coherence wave. These techniques are validated by numerical simulations and followed by experimental tests.

Two new techniques are developed and demonstrated to recover compositions of helical modes from the random light by employing higher-order SPs correlations and discussed in Chapter 3. These techniques are based on the principle of pilot-assisted strategy i.epolarization guiding and encoding compositions of helical modes into one of the orthogonal polarization components and another polarization component is reserved as a reference beam. This couples spatial and polarization modes of the light before entering into the scattering media. The two-point polarization correlation is evaluated from the measured SPs of the random field and provides a 4-by-4 CPC matrix. Now, the first technique demands only four elements of the matrix to develop a new theoretical framework to recover compositions of helical modes transmitting through the random scattering media. This supports to design of a highly stable non-interferometric setup. The second technique demonstrates the recovery of compositions of helical modes by employing three-step phase-shifting with SPs correlation in a lensless condition. This is realized by using only two elements of the matrix calculated from the first three SPs of the random light which is measured by a polarizer. The three-step phase-shifting in the SPs correlation aids to design highly stable lensless non-interferometric geometry to recover compositions of helical modes. The orthogonal projection method is applied to sort the different integer OAM modes in terms of the OAM power spectrum from the recovered complex field. The feasibility of these techniques is evaluated by numerical simulation and followed by the experimental demonstration for the recovery of the compositions of helical modes.

A new method to estimate the helical mode of the light from the random scattering media is explained in chapter 4. In this method, only two SPs of the random light are implemented to evaluate the SPs correlation helps to develop a new theoretical model for the estimation of the helical mode. To validate the proposed approach, we designed a highly stable experimental geometry in a coaxial propagation of two orthogonal polarization states of the light and use this configuration to estimate the TC of the incident helical beam from the random light. A detailed theoretical model, numerical simulation, and experimental results are also presented.

Another major highlight of the thesis is the demonstration of correlation holography methods for the delivery and recovery of 3D optical information through a random scattering medium. Two different in-line correlation holography methods using randomly polarized light for 3D optical information processing are described in chapter 5. These techniques utilize depolarization of the orthogonal polarization components along with correlation of the Stokes parameter for the reconstruction of the hologram from the randomly scattered light. The proposed experimental techniques are compact and highly stable which offers flexibility and robustness owing to in-line geometry in the correlation measurement. We have further verified the applicability of the proposed technique by recovering the complex field of the different objects from the random light.

6.2 Future Work

Ongoing interests in spatial statistical optics are effectively exploited in the present thesis using randomness of the light for the faithful delivery and recovery of the optical signals through the random scattering media. Experimental demonstrations presented in the thesis based on spatial statistics provide the potential to explore new possibilities in the emerging field of spatial statistical optics. Some of the future scopes of the present work are as follows

- The characterization of the random electromagnetic field can be implemented by utilizing the non-interferometric setup for the detection of helical modes. Using this technique non-interferometric geometry for imaging applications with random light can be developed. The developed experimental technique may also find applications in the imaging of polarization-sensitive objects, especially in biomedical fields.
- Non-invasive single-shot imaging technique through scattering layer can be implemented for more biomedical samples and its possibility of real-time implementation can be explored further to develop this technique as a potential tool in biomedical imaging.
- Non-line of sight imaging (NLOS) and underwater imaging can be implemented as potential tools using the developed methods.

- The developed techniques will be useful in optical communication through scattering media.
- The imaging systems in the depolarization condition can be demonstrated using developed correlation holography techniques.