

The principles of statistical optics and image formation

A Statistical Description of Optical Science

Course Objective: This course aims to introduce the intrinsic nature of optical fields, their propagation, statistical properties (i.e., coherence), and imaging methods based on statistical properties of light, such as coherence imaging and scattered light imaging. This course will also explain how the characteristics of a light source can be determined by measurements of the light fields that the source generates (i.e., to determine how much information about the source can be transmitted through an imaging system).

Course Outlines (lecture notes will be posted on

<http://www.jyhuang.idv.tw/StatisticalOptics.aspx> when they are available.):

1. Introduction to Statistical Optics and Image Formation (**1 week**)
2. Introduction to Probability Theory and Random Variables (**2 weeks**)
3. Stochastic Processes in Optics (**2 weeks**)
4. Statistical Properties of Light (**1 week**)
5. Modern Theory of Optical Coherence (**2 weeks**)
6. Effects of Partial Coherence on Imaging Process (**2 weeks**)
7. Image Retrieval Problem in Optics (**1 week**)
8. Lightfield Imaging with Wigner Distribution Function (**3 weeks**)
9. Imaging Formation through Light Scattering (**1 week**)

Textbooks:

- J. W. Goodman, *Statistical Optics*, Wiley.
- B. R. Frieden, *Probability, Statistical Optics and Data Testing*, Springer Series in Information Sciences, Springer-Verlag, Berlin 1991.
- M. Bertero and P. Boccacci, *Introduction to Inverse Problems in Imaging*, IoP publishing.

1. Introduction to Statistical Optics

1.1 Statistical Approach of Optics

The historical perspective

Light has an intrinsically statistical nature. At the beginning of quantum mechanics, light was viewed as a duality of photon and wave. The statistical interpretation of quantum mechanics for electrons and photons had been served as the foundation of quantum mechanics (the Copenhagen school of QM).

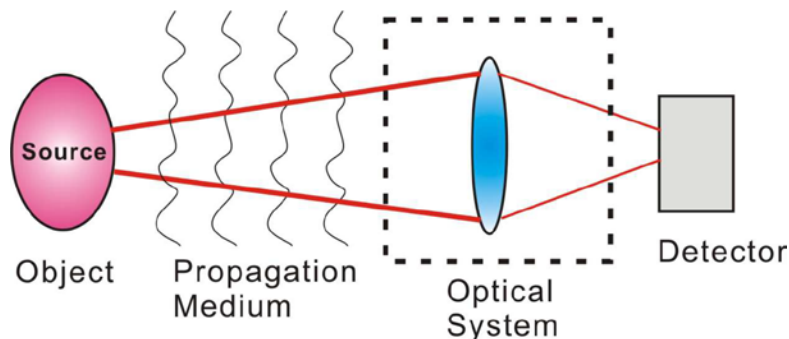
Coherence properties of light waves

In 1954, E. Wolf (Univ. of Rochester) pioneered in developing a unified approach in order to solve many important statistical problems in optics.

Light detection theory

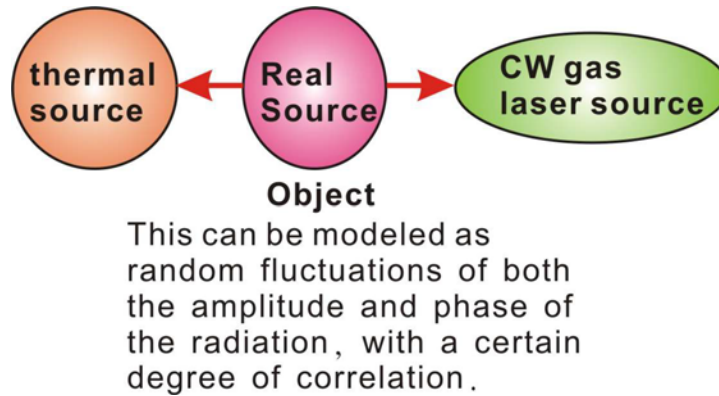
Later on, L. Mandel, *et al.* (Univ. of Rochester) was the first to investigate the important issue of the statistical fluctuation of light wave and the fluctuations associated with the interaction of light and matter.

1.2 Statistical Phenomena in Optics



Here we use an optical imaging problem as an example to introduce the important concept of statistical optics. Referring to the above figure, we shall immediately discover the following issues:

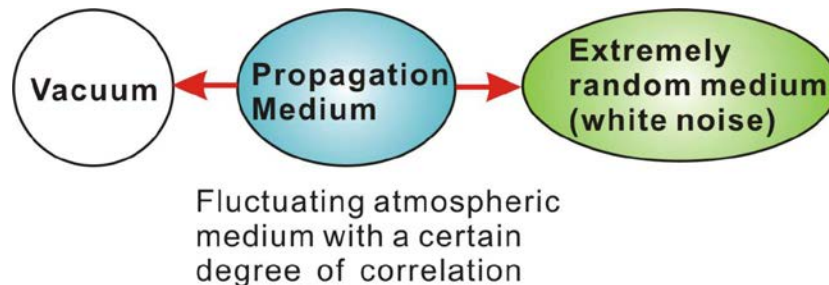
I. We need a statistical model to properly assess the properties of the emittance from an object



Statistical fluctuations of light are of great importance in many optical experiments and play a central role in determining the character of the image produced by an optical system.

II. We have to model the propagation of light wave properly since the radiation travels through an intervening medium

We need a statistical method to quantify the degradation of the image by a fluctuating medium.



To depict the distorted light wave accurately, we have to invoke a variety of instrumentations properly. The following techniques are typical methods to offer useful information about the light wave if they are used properly.

- (i) an interferometer;
- (ii) Fourier spectroscopy; or
- (iii) Lenses.

How well we know about the distortion of the **wavefront** by using these processing instruments?

III. Detection of radiation by optical detector

A statistical model is required for the description of the discrete nature of the interaction between light and matter and the presence of internal electronic detector noise.

In summary, statistical processes are observed in (i) illumination (emittance), (ii) transmission, (iii) image formation, (iv) detection in an optical system. Thus, this course aims to introduce the knowledge and mathematical techniques to students and enable them to possess the ability to pursue an accurate description and modeling of the fluctuating processes in an optical system.