COMPLEX OBJECT RECONSTRUCTION FROM FAR-FIELD INTENSITY AND ITS APPLICATION

A thesis submitted

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by

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Abstract

Non-destructive testing techniques are beneficial in many applications where one needs to study delicate objects or the objects that are located far away from the physical reach. Utilizing the optical methods, one can access the information of such objects without touching them physically or non-destructively. Existing non-destructive optical methods such as 1) holography and 2) phase retrieval iterative algorithms have some limitations.

To overcome those limitations, this thesis presents several novel optical non-destructive methods for reconstructing the complex object from an intensity recorded at the far-field using a conventional camera. Most of the methods presented in this thesis require capturing of a single intensity; therefore, opening up immense opportunities in real-time complex object imaging applications which are suitable for static as well as dynamic objects. Existing technique such as holography requires a separate beam which is derived from the illumination beam. This separate beam is considered as the reference field for encoding the phase of the illumination beam modified by the object in intensity redistribution resulting from their interference. The presence of this separate reference field being independent from the object field makes the system prone to external vibrations leading to phase error while reconstructing the phase. On the contrary, the methods proposed in the thesis employ edge point of the object itself as a source of reference field; therefore, the proposed methods do not require a separate reference beam. In the first method, we utilized the fact that object autocorrelation that can be obtained from the recorded far-field intensity at the Fourier plane by performing a two-dimensional Fourier transformation operation numerically contains the object information provided the object has a direction of asymmetry. Therefore, we crop some part of the object autocorrelation, which contains the object information, and utilize it as an initial guess to solve the problems involved in the phase retrieval iterative algorithm, resulting in unique, deterministic, twin-image free reconstruction. We follow up this investigation using a second method where the beam used for the illumination is structured utilizing an additional beam. By incorporating this additional beam, we can create the asymmetry in the beam itself. Due to this modification in the

illumination beam, irrespective of whether the objects have the direction of asymmetry or not, the proposed method provides desired results along with fast convergence. In holography, the reference field is generally independent and kept separately from the object. Considering the fact that one cannot isolate the optical system completely from the external vibration, the reference field can vibrate slightly with respect to the object field due to the external vibration, this can cause repeatability problem in the reconstruction from the holography. Moreover, for some objects which are located far from physical reach, putting the reference source nearby is difficult. Whereas in the proposed method where additional beam is used to illuminate the object edge point, even if object field oscillates due to the vibration, reference field which is scattered from the object edge point also oscillates in a similar manner. In order to reduce vibrational effects further, additional beam used to illuminate the edge point of the object is derived by utilizing simple, common path and robust optical setup. As a result, the relative motion between the reference and object's field is reduced significantly and thus, our approach works better in practical situations where the effect of external vibration cannot be avoided and is also suitable for analyzing the objects located far from reach. Utilizing the edge point of the object as a reference field makes the proposed method suitable even in vibrational environment, as compared to those based on the holography. Further, another method is proposed for reconstructing the complex object information from the hologram recorded optically. This method is beneficial in volumetric holographic data storage and reconstruction application. Furthermore, a technique is developed where one needs to capture the object photograph along with the far-field intensity for the reconstruction in a single shot. In addition, a non-iterative approach is also proposed; however, this approach needs two shots of the recording. There are several applications where one can utilize the proposed methods to study the object properties non-destructively. One of the applications in measuring the real-time deformation of an object under the mechanical loading is also presented in the final part of the thesis. Throughout the thesis, in each chapter, a detailed mathematical derivation is first established for proof of concept. Secondly, simulations are performed to support the theory. In the initial part of the thesis for reconstructing the complex object, modified iterative techniques are designed and discussed, while non-iterative techniques are developed and presented in the final part of the thesis. Thirdly, novel, simple experimental setups are suggested and examined for recording the far-field intensity of a complex object, and image processing codes are also created for retrieving the complex object numerically in the MATLAB programming language.