Simultaneous Multidimensional deformation measurements in holographic interferometry using phase shifting

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Abstract. The information about object displacements is encoded in the phase of a fringe pattern. The potential of holographic interferometry has however failed to fully express itself due to the challenges, not easily fulfilled, involved in determining simultaneously the three-dimensional components of displacements. Specifically, the applicability of the state-of-the-art optical methods for multi-dimensional deformation measurements is strongly limited by their reliance on sequential operations and complex experimental configurations. Hence, it is essential to develop vastly more targeted ways to address this issue. This has primarily lead to research focused on understanding and implementing processes needed for supporting information embedded in multi-wave interferometers. This talk presents an overview of estimation techniques based on spectral decomposition developed to address the problem, and summarizes various aspects based on accuracy and data frames.

Introduction

Phase Shifting has been widely adopted in optical interferometry for retrieving phase information encoded in the interference fringes. The technique functions primarily by acquiring a number of intensity images with phase increments between successive frames. These phase increments are generally applied using a piezoelectric device (PZT). Although three frames are normally sufficient to compute the phase distribution, the measurement process is sensitive to various systematic and random errors. Several phase shifting algorithms have been designed which minimize the systematic and random errors. However, these algorithms cannot be applied to holographic moiré configurations involving two PZTs. Even in the case of a single PZT, these algorithms impose the selection of a particular value of the phase step in order to minimize some of the systematic errors such as the presence of harmonics, PZT miscalibration, or the detector non-linearity. Hence, there is a need to design a generalized phase shifting technique which at a time caters to the presence of multiple PZTs in an optical configuration (for instance, in holographic moiré the use of two PZTs has been suggested); is insensitive to errors due to nonsinusoidal waveforms, to PZT miscalibration and additive white Gaussian intensity noise; has the ability to work with diverging as well as converging beams; and provides a means of determining simultaneously the three-dimensional components of displacements.

High-Resolution Methods

The introduction of high-resolution methods such as annihilation filter, State-space, Multiple Signal Classification (MUSIC), Minimum-Norm (min-norm), Estimation of Signal Parameter via Rotational Invariance (ESPRIT), and Maximum-likelihood estimator in phase shifting interferometry [1-4] have enabled the determination of phase distributions in the presence of harmonics and noise. These methods draw upon the complementary strengths of the conventional and generalized phase shifting algorithms. Moreover, the algorithms developed prior to the advent of high-resolution phase shifting methods have also tended to be prohibitively restrictive as far as accommodating multiple PZTs in an optical setup is concerned.

Discussion and Results

These high-resolution methods are well known for estimating the frequencies present in the spectrum embedded in the noise. These methods assume the noise to have normal distribution with zero mean and variance σ^2 in accordance to the central limit theorem. The performance of these methods is studied based on the mean-square-error (MSE) in the estimation of phase steps in the presence of noise, and the most robust of these methods is identified. Comparison between the best high resolution methods and the other bench marking algorithms is performed for various levels of signal-to-noise ratio. The values of optimum phase steps are determined while using the most robust of the established methods in the presence of noise. The presentation also focuses on determining the performance of high resolution methods in the estimation of multiple phases. In the case of the estimation of dual phase steps, a proper choice of the estimation method and the pair of phase steps is of utmost importance. A similar study as carried out in the case of a single PZT is performed by identifying the best method from the MSE plot for various magnitudes of noise and percentage separation between the phase steps α and β. Once the best method for dual PZT is identified, the important issue of selecting an allowable pair of phase steps is addressed in the presence of noise using the Cramer-Rao bound. Cramer-Rao bound gives an insight into the potential performance of the estimator. Experimental results are shown to provide an insight into the feasibility of these methods for the estimation of single phase in holographic interferometry and multiple phases in holographic moiré.

Conclusions

This talk reviews high resolution phase shifting methods which have the capability of accommodating the requirements inherent in multiple beam holographic interferometry, such as, holographic moiré. These methods facilitate the use of multiple PZTs in an optical setup, offer the flexibility of using arbitrary phase steps and spherical beams, and provide the ability of making simultaneous multidimensional deformation measurements. The main sources of errors in implementing phase stepping are caused by the miscalibration of the piezo electric device (PZT) and by the presence of nonsinusoidal waveforms (consequence of CCD nonlinearity or multiple reflections inside the laser cavity). The proposed phase stepping methods render the holography related interferometry techniques insensitive to the error sources mentioned above, and also show reduced sensitivity to random sources of errors. The talk also reports on the statistical behavior of these methods using Cramér-Rao bound. Experimental results show the feasibility of the proposed methods.

References

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