



2-D Continuous Wavelet Transform for ESPI phase-maps denoising

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ABSTRACT

In this work we introduce a 2-D Continuous Wavelet Transform (2-D CWT) method for denoising ESPI phase-maps. Multiresolution analysis with 2-D wavelets can provide high directional sensitivity and high anisotropy which are proper characteristics for this task. In particular, the 2-D CWT method using Gabor atoms (Gabor mother wavelets) which can naturally model phase fringes, has a good performance against noise and can preserve phase fringes. We describe the theoretical basis of the proposed technique and show some experimental results with real and simulated ESPI phase-maps. As can be verified the proposal is robust and effective.

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1. Introduction

Optical methods are widely used for nondestructive testing and metrology. In particular, Electronic Speckle Pattern Interferometry (ESPI) is used to measure stress, deformation, vibration, etc. Important steps in ESPI techniques are the demodulation of fringe patterns and phase unwrapping. Phase unwrapping is a technique used to remove the 2π phase that jumps in the wrapped phase-map. Recovering the continuous phase-map is usually a big challenge [1], however, ESPI phase-maps are often very noisy. This characteristic hinders an easy and reliable phase unwrapping, therefore a proper filtering is often required.

Recently, several phase-map denoising techniques have been proposed. In most of these works it is remarked that the importance of filtering along the fringe orientation in order to preserve the fringes. Tang et al. [2–4] have reported some interesting techniques based on variational methods solving oriented partial differential equations (OPDE). In our previous works we also proposed a filtering technique using the regularization theory: the Regularized Quadratic Cost Function (RQCF) [5,6]. However, a drawback of all mentioned techniques is that they require the previous estimation of the so-called fringe orientation which, as it uses the computation of the image gradient, could be an inaccurate procedure in the presence of noise and low-modulation of fringes. A typical characteristic of the resulting filtered phase image is the presence of structures due to the changes in the orientation angles, which is also a drawback. Others

techniques such as the Localized Fourier Transform (LFT) filter for noise removal in ESPI phase-maps [7] and the Windowed Fourier Transform (WFT) [8] are techniques that work effectively without a previous estimation of the fringe orientation. However, in the case of the WFT technique eight parameters have to be adjusted depending on the phase image and it requires a long processing time.

The 1-D Discrete Wavelet Transform (1-D DWT) is a tool that provides local, sparse and decorrelated multiresolution analysis of images, these properties being very much exploited for denoising. However, the 1-D wavelet methods present some strong limitations that reduce their effectiveness in two dimensions. Although 1-D wavelets have impacted in image processing they do not efficiently represent elements with high anisotropy, as in the case of wrapped phase-maps. The reason is that 1-D wavelets are non-geometrical and do not properly model the regularity of such structures. Therefore, the most serious disadvantage of the 1-D DWT in phase-map denoising is its poor directionality. For instance, in the work presented by Kauffmann et al. [9], the authors present a method to reduce the speckles in TV holographic fringes using Daubechies wavelets with thresholding. Such wavelets, however, are not very effective at image edges. Also, Shakhher et al. [10] proposed a method using Symmetric Daubechies wavelets, however, authors do not present explicit formulas.

In the last decade, 2-D wavelets [11] [12] have been used as a proper alternative to the weakness of the 1-D DWT to sparsely representing elements with high anisotropy. The 2-D CWT has already been used for interferogram demodulation [12]. In particular, the 2-D CWT using Gabor atoms (Gabor atoms are composed of complex periodic functions modulated by Gaussian functions) can naturally model phase fringes. For this reason we propose a

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