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Demodulation of single interferograms using a sliding 2-D continuous wavelet transform method

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In this paper, we present an alternative technique for the demodulation of single interferograms using a sliding 2-D continuous wavelet transform (2-D CWT) method. The sliding strategy proposed in this work is used with two purposes: to reduce the processing time when the 2-D CWT is applied, and to solve the problem of the phase ambiguity when closed fringes are present. Experimental results with real and simulated interferograms show that the proposed multiresolution method is a proper alternative for many applications of interferogram demodulation with closed fringes.

Keywords: fringe patterns; phase recovery; wavelets

1. Introduction

Demodulation of interferograms is an important task in optical metrology and interferometry that is applied to obtain measurements of the physical quantities under study. The most common demodulation techniques are the Fourier based methods [1], used when a fringe carrier is present, and the phase-shifting methods [2] that require several interferograms. Demodulation of interferograms, however, becomes complicated when a carrier fringe frequency is missing or when only a single interferogram with closed fringes can be acquired, hindering the use of the mentioned methods. The demodulation of single interferograms without carrier has been a widely studied problem and several proposals have been reported [3–12]. The demodulation of single interferograms with closed fringes is usually a complex procedure owing that this kind of images contain elements with high anisotropy and many times with a large wide band. Compounding the problem, the presence of high noise levels and large wide-band fringes makes the procedure even more difficult because noise and the fringes are mixed in some areas of the Fourier space.

In the last two decades, there have been a big increase in the application of wavelets in signal and image processing. Wavelet transforms are tools that provide local, sparse, and decorrelated multiresolution analysis of signals, which are properties well exploited for denoising and demodulation. In recent years, 2-D wavelets [13] have increased its attractiveness in image processing because 1-D wavelets present some strong limitations that reduce their effectiveness in two dimensions. Unfortunately, 1-D wavelets do not efficiently represent elements with high anisotropy because they are nongeometrical and do not properly model structures as is the case of fringe images. Unlike 1-D wavelets, 2-D wavelets are a proper alternative to sparsely represent elements with high anisotropy. In particular, the 2-D continuous wavelet transform have recently been proposed for the processing of interferometric images. All the advantages for denoising and demodulation of interferogram using the 2-D CWT have been widely discussed and demonstrated in [14–19].

We now present in this work a sliding 2-D CWT technique for the phase extraction of single interferograms that uses a simple heuristic methodology to substantially reduce the processing time at the same time that the phase ambiguity problem is solved. Owing to the multiresolution analysis of the 2-D CWT technique presented here, one of its main advantages compared with standard techniques is its high capability to deal with noise, as will be shown in the experiments.

2. The 2-D continuous wavelet transform for interferogram demodulation

2.1. The 2-D continuous wavelet transform of a fringe pattern

We start by defining the mathematical representation of a fringe pattern with closed fringes as

$$I(x) = a(x) + b(x)\cos\phi(x), \tag{1}$$

where $x = (x_1, x_2)$ is a 2-D variable, $a(x)$ represents the background illumination, $b(x)$ represents the amplitude modulation, and $\phi(x)$ represents the phase to be recovered.

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