A Particle Swarm Optimization Approach to Log-Gabor Filtering in Fourier Transform Profilometry

Jesús Pineda,[1] Jhacson Meza,[1] Andrés G. Marrugo,[1] Raúl Vargas,[1] Lenny A. Romero[2]

[1]*Facultad de Ingeniería, Universidad Tecnológica de Bolívar, Cartagena, Colombia.*
[2]*Facultad de Ciencias Básicas, Universidad Tecnológica de Bolívar, Cartagena, Colombia.*
agmarrugo@utb.edu.co

Abstract: In this work, we propose a particle Swarm Optimization approach to Log-Gabor filtering in Fourier transform profilometry. Encouraging experimental results show the advantage of the proposed method.

OCIS codes: 070.0070, 100.0100, 120.0120.

1.   Introduction

Fourier transform profilometry (FTP) is still a widely used technique for fringe analysis. The FTP method relies on the Fourier Transform (FT) to extract the phase information of the fringe pattern by filtering the signal in the frequency domain [1]. The filter design plays an important role in the measurement accuracy. If the zero frequency component and the high order spectra component interfere with the useful fundamental spectra, the reconstruction precision of FTP decreases. Recently, some authors have successfully applied optimization techniques for filtering in fringe analysis algorithms [2, 3]. In view of the developing trend, we propose a particle swarm optimization (PSO) [4] approach to Log-Gabor filtering to achieve a more accurate extraction of the first-order spectrum in FTP.

2.   Proposed method

2D Log-Gabor filters are constructed in terms of two components: radial and angular filters, $H(r,\theta) = H_r(r) \cdot H_\theta(\theta)$, given by,

$$H(r,\theta) = \exp\left(-\frac{[\log(r/f_0)]^2}{2 \cdot \sigma_r^2}\right) \cdot \exp\left(-\frac{(\theta - \theta_0)^2}{2 \cdot \sigma_\theta^2}\right) \ , \tag{1}$$

where (r,θ) represents the polar coordinates, f_0 is the central frequency, θ_0 is the orientation angle, σ_r is the standard deviation of the radial filter and σ_θ is the standard deviation of the angular filter. σ_r and σ_θ determinate the scale and angular bandwidth, respectively. In the PSO algorithm, at the n-th iteration, the i-th particle can be described as $\hat{x}_i(n) = [x_{i,f_0}(n), x_{i,\theta_0}(n), x_{i,\sigma_r}(n), x_{i,\sigma_\theta}(n)]$. This particle moves around the multi-dimensional search space comparing its current objective function with its individual best function result so far, $pb_i(n)$. The global best $gb(n)$ is determined such that $f_{obj}(gb(n)) \le f_{obj}(pb_i(n))$. Our approach is based on a phase residue analysis [5]. The algorithm focuses on finding the optimal filter in such a way that the presence of phase residues is minimized.

3.   Experiments and results

The test object is the palm of a subject, its fringe image and FT spectrum are shown in Fig. 1(a) and Fig. 1(b), respectively. In this application, errors in phase retrieval can be attributed to the skin structural changes. Notice slight specular reflections on the bottom right corner of the image and a partial obscuration along palm lines. Also, the fringe width changes throughout the image due to the object topography and the system configuration. The order $+1$ of the spectrum is relatively close to the $0th$-order, and spreads. These circumstances may lead to failures if the filter is not designed properly. The results are shown in Fig. 1(b)-(f). The optimized filter is compared against the conventional Hanning filter, which despite being heavily used in FTP is known to miss or add spectrum data during filtering. Notice that the filter covers a range of frequencies larger than the Hanning filter, even approaching slightly the $0th$-order.
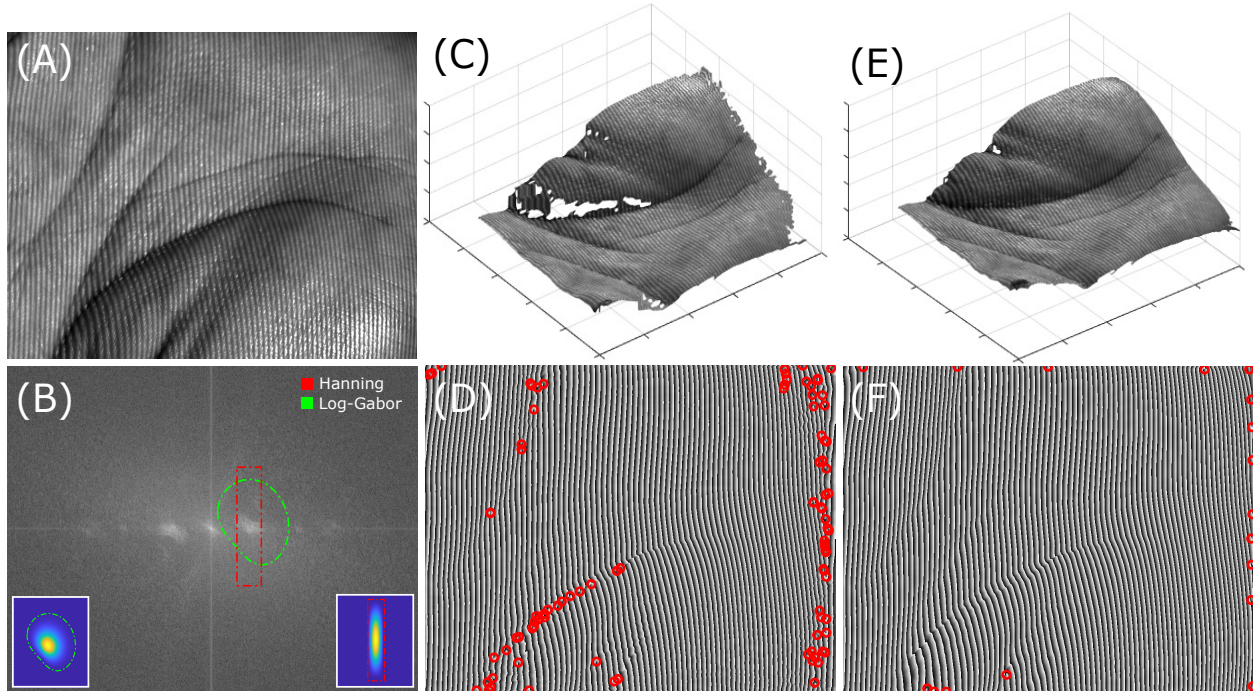
Fig. 1. (a) Acquired fringe image. (b) Fourier transform spectrum. (c) 3D reconstruction and (d) wrapped phase map by applying the Hanning filter. (e) 3D reconstruction and (f) wrapped phase map obtained using the proposed method.

This may be due to low frequencies which are part of the topography missed by the Hanning filter. Phase residues are plotted as red dots on top of the wrapped phase images. The optimized filter significantly reduces the number of residues as compared to the Hanning filter result. The 3D reconstruction using the optimized filter shows a much more accurate reconstruction including regions where phase retrieval errors were found using the Hanning filter.

4. Conclusions

In this work we have proposed a particle swarm optimization approach to Log-Gabor filtering to achieve a more accurate extraction of the first-order spectrum in Fourier Transform Profilometry. Results shows the effectiveness of the proposed method for removing phase residues introduced during the filtering stage.

5. Acknowledgment

References

1. M. Takeda and K. Mutoh, Applied Optics **22**, 3977–3982 (1983).
2. T. Zhang, F. Gao, H. Muhamedsalih, S. Lou, H. Martin, and X. Jiang, "Improvement of the fringe analysis algorithm for wavelength scanning interferometry based on filter parameter optimization," Applied Optics **57**, 2227–2234 (2018).
3. K. Yatabe and Y. Oikawa, "Convex optimization-based windowed fourier filtering with multiple windows for wrapped-phase denoising," Applied Optics **55**, 4632–4641 (2016).
4. J. Kennedy, "Particle swarm optimization," in "Encyclopedia of machine learning," (Springer, 2011), pp. 760–766.
5. D. C. Ghiglia and M. D. Pritt, *Two-dimensional phase unwrapping: theory, algorithms, and software*, vol. 4 (Wiley New York, 1998).