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Fringe pattern denoising using spatial oriented gaussian filters

Jesús Villa [a,*], Efrén González [a], Gamaliel Moreno [a], Ismael de la Rosa [a], Jorge Luis Flores [b], Daniel Alaniz [a]

[a] Unidad Académica de Ingeniería Eléctrica, Universidad Autónoma de Zacatecas, Av. Ramón López Velarde 801, Zacatecas, C.P. 98000, Mexico
[b] Departamento de Electrónica, Universidad de Guadalajara, Av. Revolución 1500, C.P. 44840, Guadalajara, Jalisco, Mexico

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ABSTRACT

In this paper, it is proposed a gaussian convolution-based fringe pattern denoising method. As will be shown, this method is robust enough compared with some of the most outstanding methods in the literature. Additionally, the proposed method overcomes the problem of underperformance in low-frequency fringes that is common in most oriented filtering methods, while keeping the great advantages of convolution-based filters. The advantages of the proposed denoising method will be demonstrated with experiments realized over synthetic and real fringe patterns, and comparing the performance with four representative methods, already reported.

1. Introduction

Digital fringe patterns are commonly the result of optical methods of measurement such as holographic interferometry, moiré interferometry or electronic speckle pattern interferometry (ESPI) [1–3]. To extract the physical information from fringe patterns the well-known phase demodulation is required [4,5]. Due to experimental conditions in this kind of optical methods the quality of the fringe images are usually affected by noise. For this reason, for a proper phase demodulation process, fringe pattern denoising has become a relevant topic widely investigated in the last years. Owing to its particular characteristics, it is well-known that denoising fringe patterns requires the use of special kind of filters, especially if the fringe image contains high-frequency regions. The strategy of using oriented filters has been widely adopted obtaining good results. For example, in [6–8] the use of the regularization theory was adopted to propose new kind of oriented filters. The partial differential equations have also been used to design several types of oriented filters [9–16]. The oriented spatial filter masks [17,18], that resulted in a practical and effective method, is a good alternative. Methods that deal with the decomposition of the image in high-frequency fringes, low-frequency fringes, and noise, have also been proposed [19,20]. The use of the Fourier transform by means of windows has also been proposed in [21] and [22]. Although these two Fourier based methods do not require the fringe orientation, they have resulted in good alternatives for this purpose. Recently, new kind of methods based on neural networks have also been proposed [23,24]. The proposal by Jiang et al. [25], consists in a adaptable window filter that adjusts its size and shape according to the fringes' direction and curvature. The work reported in [26] proposes the nonlocal means and its related adaptive kernel-based methods.

With experience in the field of fringe pattern denoising, we have realized that most oriented filtering methods have the best performance in high-frequency fringes, however, they have a drawback: they underperform in low-frequency regions which causes the filtered fringes present structures that look like the brushstrokes of Vincent Van-Gogh's "The Starry Night" painting. The reason for this drawback is that the filtering is emphasized along a given direction (anisotropic filter), in other words, the filtering is realized in one dimension. This problem gets worse when fringe orientation is bad estimated, which is a common situation in low-frequency fringes. Therefore, to overcome this problem, the filter must become more isotropic as the fringe frequency decreases, which can be achieved by knowing information about the fringe frequency to adapt the wide-band of the filter.

In this paper, a denoising technique based in convolution gaussian filters is proposed. As will be shown, the proposal offers a good performance against noise and adequately overcomes the above mentioned problems in low-frequency fringes while keeping the advantages of convolution filters: easy implementation, low processing time and low computational effort. This will be demonstrated with simulated and real fringe patterns.

2. Materials and methods

In order to introduce the problem of denoising fringe patterns, we start defining the mathematical model of a fringe pattern:

$$I(x,y) = a(x,y) + b(x,y)\cos[\phi(x,y)] + n(x,y). \quad (1)$$

* Corresponding author.
E-mail address: jvillah@uaz.edu.mx (J. Villa).

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