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Computational hybrid phase shifting technique applied to digital photoelasticity

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ABSTRACT

Conventional phase shifting techniques have emerged as a powerful tool for evaluating the stress field in digital photoelasticity. However, the quantity of image acquisitions they require makes the process complex and tedious. In this paper, a computational hybrid method was developed for reducing the quantity of the image acquisitions in conventional phase shifting techniques. This study provides a novel approach to complete the set of acquisitions by performing some of them experimentally and simulating the remaining computationally. The accuracy of the results demonstrated that conventional phase shifting techniques could evaluate the stress field by performing fewer acquisitions and integrating computational procedures. These achievements represent a further step towards evaluating time-varying phenomena since the reduction of the acquisition time.

1. Introduction

Digital photoelasticity achieves the simultaneous evaluation of the main stress direction (Isoclinic) and main stress difference (Isochromatic) when using phase shifting techniques (PST) [1]. This fact encourages researchers to work for improving every stage in this kind of methods. PST also highlight because they evaluate the stress maps in whole field by using traditional optic arrangements with simplex devices of image acquisitions [2]. Such advantages make users in different engineering areas adopt PST for validating new proposals in digital photoelasticity.

In conventional photoelasticity studies, PST evaluate the stress field by processing a set of phase-shifted images [3]. The main disadvantage in this method consist in that introducing a shifting into the phase map, it requires rotating the optics elements that integrate the polariscope [4]. Which beside to introduces an optic misalignment problem, it represents a time-consuming task that limits it for time-dependent applications. In previous studies such as presented in [5,6], authors show some dynamic applications in which the acquisition time in conventional PST could represent a limitation for validating the results.

In the past two decades, a number of researchers have shown that reducing the quantity of acquisition, or performing them simultaneously are two key strategies for overcoming disadvantages we mentioned previously [7]. With respect to the acquisitions, literature reports a significant number of conventional PST. In those methods, users usually evaluate the stress components through the processing of sets of ‘twelve’, ‘ten’, ‘eight’, ‘six’, or ‘four’ phase-shifted images [8]. In all cases, the acquisition stage represents a limitation for implementing the methods [9]. Notwithstanding, there is a significant number of works that demonstrate high accuracy for evaluating the stress by using PST of six acquisitions [10].

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On the other hand, the simultaneous acquisition in PST consists in to acquire the complete set of phase-shifted images at the same time. These proposals implicate to use multiple optic elements for obtaining the set of polariscope configurations, and with this, to observe the set of images at the same frame. Although these studies have contributed significantly in digital photoelasticity [11–13], many of the users do not adopt them because their implementation is complicated, and they require several devices with special features [14,15]. Furthermore, there are other technical limitations associated to maximum field of view users can obtain, the image resolution, and the extra-procedures required for making the simultaneous images correspond spatially. Such limitations make researchers be still interested in using the conventional PST, but it is under the expectation of improving the acquisition stage.

This paper proposes a new methodology for reducing the acquisition quantities in conventional PST. Our study is not intended to reduce the phase-shifted images required traditionally. On the contrary, it accounts for maintaining the existent ones, but modifying the process to obtain them. Reducing the quantity of images in the acquisition process, but obtaining results related to the standard set of images had been explored earlier, as proposed in [16] and [17]. However, such studies did not consider computational fitting of the intensities for avoiding the acquisition of the light source and background light. For that reason, we evaluate the stress with fewer image acquisitions.

Our proposal comes up with the specific objective to avoid image acquisitions in a conventional PST by replacing such process with computational operations. It means to introduce a new process in which users only acquire some experimental images, and simulate the remaining computationally. To achieve this goal, two methods were developed. The first one completes the set of phase-shifted images by acquiring some of them, the light source and background light. The second method acquires a part of the phase-shifted images, and simulates the remaining by inverting the images acquired previously.

In order to validate the proposed methods, this study was initially applied to a PST of six acquisitions. After that, it was extended to two additional methods. In all cases, we considered a database of synthetic images generated from two benchmark models: disk and ring under diametric compression, respectively [18,19]. We additionally considered two conditions for spatial light distribution, homogeneous and Gaussian, respectively. Moreover, we consider a third case for a light source with Speckle noise.

The importance of this study is that it makes the conventional PST become into a hybrid process. It integrates computational procedures for replacing experimental stages in digital photoelasticity. These methods allow users to evaluate the stress field using conventional PST, but avoiding acquisitions in the process. With the acquisition reductions, there are more possibilities to evaluate dynamic experiments by using conventional PST. For this paper organization, next section presents a brief explanation of the conventional six-acquisitions PST. It will then go on the new PST proposal. After that, it will describe the strategy for making a synthetic validation of the proposed method. Posterior sections will present the results and discussion, and the conclusions, respectively.

2. Methods and procedures

2.1. Conventional PST in digital photoelasticity

Digital images in photoelasticity studies contain the spatial information of the stress distributed within a birefringent body [20]. This phenomenon is possible due to the stress optic law, as presented in (1). There, the principal stress difference at every point in the model is proportional to the difference between the refractive indexes. Such relationship makes the stress components modify the optical response to the light transmission at every point of the stressed body, as presented in (2).

$$n_1(x,y) - n_2(x,y) = C\left[\sigma_1(x,y) - \sigma_2(x,y)\right] \tag{1}$$

$$\delta(x,y) = \frac{2\pi hC\left[\sigma_1(x,y) - \sigma_2(x,y)\right]}{\lambda} \tag{2}$$

Where, 'σ_1' and 'σ_2' are the principal stress components, 'C' is the stress optic coefficient, 'n_1' and 'n_2' represent the refractive indexes, '$\delta(x,y)$' is the phase delay introduced by the stress components in a light ray traveling into the birefringent body, 'λ' is the light wavelength, and 'h' accounts for the body thickness. When observing the birefringent body through a polariscope arrangement, as presented in Fig. 1, the emergent light intensities become in functions of the light sources, the stress components and the rotations of the optical elements, as shown in (3) for a circular polariscope, and it can be demonstrated using the Jones calculus [2].

$$I(x,y) = I_a(x,y)+I_b(x,y)[1+\sin 2(\beta-\varphi)\cos(\delta(x,y))-\sin 2(\theta(x,y)-\varphi)\cos 2(\beta-\varphi)\sin(\delta(x,y))] \tag{3}$$

Where, '$I(x, y)$' represents the emergent intensity in every spatial position the evaluated body, '$I_b(x, y)$' is the light source, '$I_a(x, y)$' accounts for background light, 'φ', 'β' are the rotation angles in the second quarter wave plate and polarizer, respectively. Above expression did not show 'ρ' and 'γ' because they were assumed as '90°' and '45°', respectively [3]. For experimental cases, í$I_b(x, y)$' is associated to the maximum intensity we can get in a fringe pattern. Nevertheless, '$I_a(x, y)$' is the offset that users catch as the minimum light transmission through polariscope. It is the minimum intensity modulated within a fringe pattern. These parameters change with the environmental conditions during the experiment, and with quality of the optic elements.