An Efficient Method to Determine Strain Profiles on FBGs by Using Differential Evolution and GPU

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***Abstract*—This paper shows the application of the Differential Evolution algorithm to the recovery of the deformation profile applied to a fiber Bragg grating sensor (FBG). The method uses only the sensor reflectivity, without the need of phase information, and has been shown to be highly parallelizable. The method was specially implemented to run the complex computations required by the fitness function using a Graphical Processing Unit (GPU). This provided an enhancement of 3 orders of magnitude in the computation time when compared to similar methods shown in literature. Three experiments were performed to evaluate the computational performance of the DE algorithm, and its convergence of the solution to the target deformation profile. Overall, the method is very promising and it can be applied to problems that require a fast response, such as the online monitoring of FBG sensors.**

I. Introduction

A fiber Bragg grating (FBG) is a device produced in the core of an optical fiber that reflects light at a particular wavelength band. FBGs are widely known and used in sensing applications due to its immunity to external electromagnetic fields, natural wavelength multiplexing capabilities, convenience for transmitting data over long distances and high sensitivity to mechanical deformations and temperature changes.

FBG sensors are interrogated by illuminating them with a broadband light source and detecting the spectral position of the reflected band which is related to the measurand. Changes in the measurand are then determined by traditional methods [1] used to detect spectral shifts in the central wavelength of the reflected band. These methods are highly efficient when the external parameters affects uniformly the whole device. Nevertheless, such methods are useless when the FBG sensor is subjected to non uniform perturbations along its length. To solve this drawback, some methods were already proposed in the literature. However, all they have own advantages and limitations, such as requiring the use of phase information of the signal [2]–[6] and using two sensors simultaneously while having a processing time in the order of hours [7].

To circumvent these issues, a method based on the Differential Evolution (DE) algorithm [8], [9] was proposed by Negri et al [10], enabling the recovery of the mechanical deformation profile applied to the FBG. For its application, the method requires only information about the magnitude of the band reflected by the FBG sensor. Although this method has reduced the processing time from hours to tens of seconds, its processing time remained the limitation for applications that require higher acquisition rates or that is aimed at continuous monitoring of the FBG sensor.

This paper proposes important improvements to the DE method previously developed. To take the advantage of the parallel processing capabilities commonly found in Graphical Processing Units (GPUs), the DE method was re-implemented as a parallel procedure. When compared to the earlier method, a significant reduction in the processing time (from tens of seconds to tenths of seconds) was observed.

II. Methodology

The DE algorithm is used to determine mechanical deformation profile applied to an FBG sensor. The profile determination is performed by using the magnitude of the FBG reflection spectrum that can be easily obtained with interrogation methods [1]. This experimentally obtained light spectrum (magnitude only, no phase information) is referenced here as *target spectrum*, and contains enough information about the perturbation in the sensor structure.

The proposed method maintains a population of candidate solutions, where each individual of this population corresponds to one deformation profile. This population is iteratively improved by using DE until a suitable deformation profile is found, whose reflection spectrum matches the target spectrum. This evolutionary process is guided by the fitness evaluation of each individual, that is computed as the error between the target spectrum and the one simulated from the candidate solution. The transfer matrix method was used to simulate the reflection spectrum of each individual.

Among the steps of the proposed evolutionary process, the fitness evaluation is the one which takes more time due to the computational cost of the transfer matrix method. Computing the reflectance of an FBG from its parameters by using the transfer matrix method requires, for each evaluated wavelength, a series of matrix multiplications and, eventually, solving algebraic equations to produce the simulation parameters. To reduce the required computation time, a GPU with capacity of running multiple parallel processes was employed. In this way, fitness evaluation of each individual can occur in parallel taking advantage of the easy parallelization feature of the DE method. Further, the reflectance spectrum computed

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