Sensors and Actuators A 242 (2016) 32–42

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Fiber sensing scanner system based on A-thermal fiber bragg gratings

Yu-Lung Lo [a,b,*], Tsung-Hen Tsai [a], Pin-Fan Shih [a]

[a] Department of Mechanical Engineering, National Cheng Kung University, Tainan, Taiwan
[b] Advanced Optoelectronic Technology Center, National Cheng Kung University, Tainan, Taiwan

ARTICLE INFO

Article history:
Received 5 November 2015
Received in revised form 20 January 2016
Accepted 13 February 2016
Available online 20 February 2016

Keywords:
FBG sensor
Interrogation system
FP scanner
PZT transducer
Third-order polynomial curve function

ABSTRACT

This study is to achieve a new interrogation system for fiber Bragg grating (FBG) sensors, wavelength demodulation is commonly performed using a Fabry-Pérot (FP) scanner. However, for the thermal effects to a FP scanner, using a single A-thermal FBG as the reference to extract the correct sequence index and position of FBG sensors is introduced. In addition, a third-order polynomial curve fitting function is used to account for the nonlinear relationship between the FP driving voltage and the FP transmission wavelength. To enhance the accuracy of the FP scanning system, an additional interrogation structure based on four A-thermal reference FBGs is also proposed and the proposed interrogation system can accurately extract the Bragg wavelength down to 7.2 pm. Also, the performance of a FP scanning system with a high-end or low-end FP scanner is discussed.

1. Introduction

Fiber-optic sensors based on FBGs have numerous applications in the strain and temperature sensing fields [1]. However, to facilitate the broad use of this class of sensors, small, rugged and low-cost wavelength demodulation systems are required [2]. These references contain various proposals for cost-effective and time-efficient FBG interrogation methods [3,4]. Broadly speaking, existing methods for FBG wavelength demodulation can be classified as either wavelength-division-multiplexing techniques or fiber Fabry-Pérot (FFP) techniques [5]. Typically, these methods include the use of Mach–Zehnder interferometers [6], holographic-grating-based spectroscopic charged-coupled devices (CCDs) [7], linearly wavelength-dependent optical filters [8], and arrayed waveguide gratings (AWGs) [9,10]. Tsai, et al. [11] presented a free-spectral-range-matched interrogator system comprising an electrically tunable FFP scanner followed by a multichannel band-pass filter for the low-cost, fast scanning rate, large dynamic range, and high-precision wavelength interrogation of FBG sensing systems. Also, Pfrimer et al. [12] proposed a method for extracting the temperatures controlled by a feedback-loop in tracking the photodiode current of the convolution value of the tunable FBG. In the recent years, a novel fast phase correlation (FPC) peak detection algorithmto determine the peak position of Bragg wavelength was proposed by Lamberti et al. [13]. As compared to the maximum detection and cross-correlation algorithms, the FPC method proved the precision and accuracy comparable with those of cross-correlation algorithm and higher than those of the maximum detection algorithm. Also, Tosi [14] proposed an algorithm based on main eigenvalue analysis of Karhunen-Loeve transform (KLT) for accurately tracking FBG sensorsand it providesits accuracy superior to correlation-based algorithms.

In many applications, e.g., real-time environmental monitoring and structural stability analysis, the sensing system comprises an array of FBG sensors deployed over the field of interest. For such applications, wavelength interrogation is commonly performed using an FP scanning system. However, to ensure the accuracy of the sensing results, some form of wavelength calibration method is required to compensate for the effects of noise (e.g., changes in the ambient temperature, non linearity and hysteresis of the PZT transducer, and so forth). Accordingly, Fu et al. [15] proposed a calibration system consisting of two reference FBG elements and an FFP tunable filter driven by a triangular waveform voltage. Bao et al. [16] presented an FFP interferometer in an A-thermal manner in which multiple wavelength references were used to estimate the wavelengths of the sensing FBGs. In utilizing an FFP scanner for FBG wavelength interrogation, it is found that the PZT transducer tends to exhibit a nonlinear response (e.g., creep and hysteresis) over successive scanning cycles, and consequently the accuracy of the extracted wavelengths cannot be guaranteed. To address this problem, Liu et al. [17] proposed the use of a third-order polynomial curve fitting technique to minimize the random error in the wavelength measurements.

The present study proposes a method for mitigating the effects of temperature change on the performance of an FFP scanning system by using one or more A-thermal FBGs for reference purposes.

* Corresponding author.
E-mail address: loyl@mail.ncku.edu.tw (Y.-L. Lo).

http://dx.doi.org/10.1016/j.sna.2016.02.027

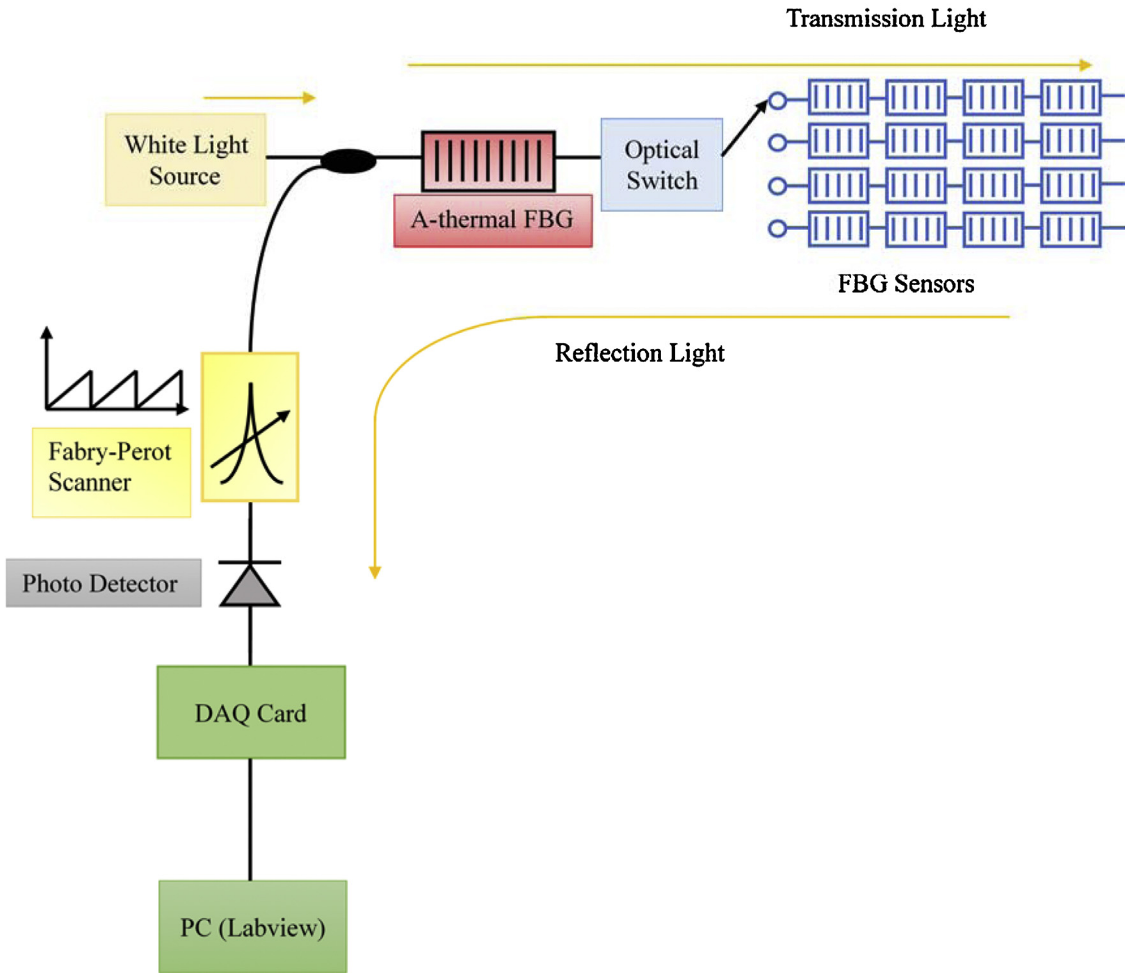

Fig. 1. Interrogation system based on a single A-thermal FBG with a high-end FP scanner.

Notably, compared to existing methods based on A-thermal FP filters [16], the proposed method simplifies the signal processing task involved in locating the peak positions of the FBG spectra. Furthermore, the effects of the nonlinear response of the FP scanner are mitigated by using a third-order polynomial curve fitting technique.

2. Proposed FFP interrogation systems

2.1. Use of single A-thermal FBG as reference

Fig. 1 shows the basic architecture of the proposed FFP interrogation system based on a single A-thermal FBG. As shown, the A-thermal FBG is illuminated by a white light source and is connected in series with an array of FBG sensors via an optical switch with four channels. The light reflected by the FBGs is launched into an FP scanner driven by a saw-tooth voltage signal. The output from the scanner is directed into a photodetector to convert the optical signal to an electrical signal. Finally, the electrical signal is acquired by a personal computer for further data processing, storage and display. Notably, the A-thermal FBG is chosen such that its reflectivity is around twice that of the sensor FBGs. As a result, the intensity of the reflected A-thermal FBG signal is much higher than that of the FBG sensors, and is thus easily distinguished in the scanning signals. Furthermore, the A-thermal FBG has a wavelength drift of less than 0.1 nm over the temperature range of 0–75 °C. Consequently, the peak position of the FBG reflection spectrum remains approximately constant as the FP scanner encounters thermal variations, and can thus be used as a reference to extract the peak positions of the FBG sensor spectra.

2.2. Use of four A-thermal FBGs as reference

The architecture described above provides a reliable approach for detecting the peak positions of the FBG sensor spectra in the case where the FP scanner has good stability and repeatability. In other words, a high-end (and hence expensive) FP scanner must be required. But, to reduce the cost of the interrogation system, the problem of the non-stability and non-repeatability in a low-end FP scanner and the accuracy of the interrogation system need to be solved. Thus, four A-thermal FBG reference data that can be used to position the other FBG sensors instantaneously and accurately is shown in Fig. 2.

As compared with the basic scheme shown in Fig. 1, there are additional two photodetectors implemented in the system. The photodetector linked after the coupler with a light source is to check if the light source intensity is stable or not and the photodetector linked after the coupler with the reflected FBG light is to make sure if the reflected FBG light intensity is stable or not before they transmit to a FP Scanner. It is noted that two additional photodetectors are used to compensate for the effects of light source instability and lead-in/out fiber disturbances, respectively.