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Online calibration of PZT driven fiber Fabry–Perot filter nonlinearity using FBG array and PSO algorithm

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ABSTRACT

The nonlinearity of a piezo-electrical transducer (PZT) driven fiber Fabry–Perot filter (FFP) is investigated and calibrated using a group of fiber Bragg gratings (FBGs). The peak positions of four series FBGs are used as wavelength references and detected by particle swarm optimization (PSO) algorithm with high accuracy and less computation time. Polynomial fit is employed to model the wavelength–voltage relationship of FFP. The absolute error in wavelength detection using the calibrated FFP is demonstrated by experiments to be as low as 25 pm. The wavelength resolution of FFP has also been studied by scanning the absorption spectrum of acetylene. The proposed approach of online calibrating the wavelength–voltage relationship of FFP has great potentials in applications where FFP is used as wavelength demodulator.

1. Introduction

PZT driven type tunable optical filters (FFP) are among the most commonly used tunable filters. They have been widely used as wavelength demodulator in optical sensing [1,2] and optical spectroscopy [3]. Under a certain applied voltage, the piezo-electric response of PZT would make the cavity length of FFP change and let the light with a certain wavelength to be transmitted through FFP at maximum transmittance. Due to the intrinsic nonlinearity and hysteresis between the displacement and voltage of the PZT, the central wavelength of FFP is nonlinear with the applied voltage. Many researchers have investigated and demonstrated the nonlinearity in the direct and converse piezoelectric properties of PZT in theory [4–6]. However, in applications, most researchers often assume that the wavelength–voltage relationship of FFP is linear or locally linear in a partial region of the free spectral range (FSR) of FFP. However, in applications, like Fiber Bragg gratings (FBG) sensing system, where the FFP is often used as wavelength demodulator [7], the actual relationship between the driven voltage and the central wavelength of FFP must be found accurately, otherwise the measurement results will yield great measurement errors. For another example, in gas sensing system, the transmission light of FFP is used as the probing light to sense the gas concentration [1,2]. The wavelength of FFP is required to be aligned to the absorption peak of the target gases accurately, otherwise the sensitivity of the system will be very low, and the system may even not work at all. In practice, however, because of the nonlinear relationship between the wavelength and the driven voltage of FFP, it is difficult to make the wavelength of the transmission light of FFP be fixed to a constant value, even if the driven voltage applied to FFP is kept to be constant. Therefore, in applications where the FFP is used as wavelength demodulator, the nonlinear wavelength–voltage relationship of FFP must be investigated and calibrated online in each FFP scanning cycle, in order to make the system stable and reliable.

In this paper, a procedure of online calibrating the wavelength–voltage relationship of FFP in each cycle of FFP scanning through its free scanning range (FSR) is proposed. A group of FBGs is used to evaluate the FFP nonlinearity. Particle swarm optimization (PSO) algorithm is employed to identify the spectral position of each reference FBG with less computation time and high accuracy. Thereafter, polynomial fit is adopted to model the

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wavelength–voltage relationships of FFP. The accuracy of wavelength measurement using the identified model of wavelength–voltage relationship of FFP is demonstrated by experiments at last.

2. Measurement of FFP nonlinearity using FBG array

Offering a series of stable wavelength references is essential in calibrating the wavelength–voltage relationship of FFP. In our works, considering that the bandwidth of the reflected light of a FBG is narrow, ~0.1–0.3 nm, and the wavelength of the FBG reflected light is easy to be made stable by fixing the FBG in a temperature controller, a group of FBGs is used as wavelength references to calibrate the FFP. Moreover, comparing with other system using gas absorption line [8] or interferometer [9] as wavelength references, the system using FBG as wavelength references is simple in construction.

The experiment setup is shown in Fig. 1. The light source is 1550 nm SLED with a spectral width of about 50 nm and output power of nearly 30 mW. FFP used in the system is available from Micron Optics Company. FSR of FFP is 100 nm and the bandwidth of FFP is ~0.3 nm. A triangle wave voltage that was applied to FFP for wavelength scanning was generated from the digital-to-analogue (D/A) converter board running under Labview software and amplified by a power amplifier. Light from SLED was filtered by a FFP and then divided into two beams by an optical coupler. The reflected lights of the four reference FBGs were detected by an avalanche photo detector. The four FBGs were fixed in a temperature controller to obtain fixed wavelengths. The wavelength range of the detector is 1000–1700 nm and response sensitivity is 8.5 A/W. The outputs of the photo detector were sampled by an analogue-to-digital (A/D) converter board running under Labview software.

Cyclic triangle wave was applied to FFP for wavelength scanning. Two FSRs of FFP were scanned when the voltage of the triangular wave changed from 10 to 30 V. Then the spectrum of all the four FBGs was scanned on the rising slope of the triangle wave and scanned secondly on the falling slope of the triangle voltage. The obtained spectrum is shown in Fig. 2.

The rising slope of the triangle signal can be modeled as follows:

$$V_i = \frac{a}{K} N_i + V_0 \quad (i = 1, 2, \ldots, K) \tag{1}$$

where, V_0=10 V, a is the peak-to-peak value of the signal, and here is equal to 20 V. K is the number of steps on the rising or falling slope of the applied triangle wave voltage.

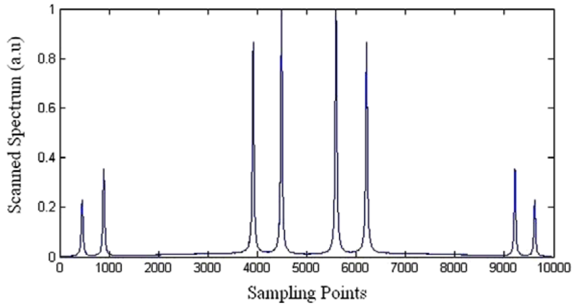

Fig. 2. Combined spectrum of FBGs scanned by FFP.

Obviously, the sampling index, m_k $(k = 1, 2, \ldots, 4)$, at the four FBGs' peak positions have to be detected with high accuracy, which is essential in calibrating the FFP accurately. Certainly, m_k could be achieved by "scanning" the spectrum shown in Fig. 2. In practice, however, the detection error could be much larger due to the existence of various types of noise. In fact, most of the previous wavelength demodulation techniques, including gas cell [8], interferometer [9] or tunable laser techniques [10], also have to solve the problem of detecting the reference or sensing wavelengths from noises with high accuracy.

Traditional digital low-pass filters could be applied to reduce the effects of noise on the FBG's peak positions detection. The improvement is, however, limited because the noise components within the pass band still remain after filtering and affect the measurement accuracy. In this paper, a particle swarm optimizer (PSO) that has the advantages of easy implementation and quick convergence is employed to improve the measurement accuracy of peak position of four reference FBGs.

3. Improvement of the accuracy of wavelength detection of FBG by PSO

PSO is one of the evolutionary algorithms and was originally developed by Kennedy and Eberhart in 1995 [11,12]. It has attractive characters of easy implementation and quick convergence. In the past decades, it has attracted many researchers' attentions and has been applied with success to complex engineering problems, such as multi-objective optimization problems [13], shape optimization [14], control systems [15], and others. In our work, PSO was applied to identify the peak positions of the four reference FBGs.

When FFP scan over the working region of the four FBGs, the obtained spectrum is, in fact, the convolution of

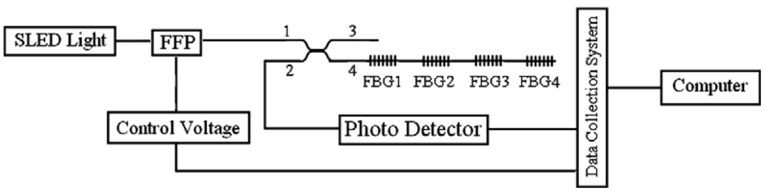

Fig. 1. Optical configuration of system.