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# Multi-peak detection algorithm based on the Hilbert transform for optical FBG sensing

Fang Liu, Xinglin Tong*, Cui Zhang, Chengwei Deng, Qiao Xiong, Zhiyuan Zheng, Pengfei Wang

*National Engineering Laboratory for Fiber Optic Sensing Technology, Wuhan University of Technology, 430070, PR China*

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ABSTRACT

A multi-peak detection algorithm based on the Hilbert Transform is proposed to overcome the shortage of traditional single peak detection algorithms, which can extract the Bragg wavelengths from the reflection spectrum in WDM systems. This algorithm introduces the thought of Divide and Conquer, including splitting the reflection spectrum and single peak detection. The multi-peaks can be pre-positioned by splitting the input reflection spectrum after the Hilbert Transform and derivation. Besides, theoretical analysis and the experimental results show that this algorithm using zero as threshold of splitter can greatly enhance the algorithmic portability under different dimensions as well as improve demodulation speed and accuracy. This implies that the proposed algorithm provides a precise demodulation algorithm for the distributed FBG sensor network.

## 1. Introduction

Fiber Bragg gratings (FBGs) sensors, as a vital branch of optical fiber sensors, have been widely used in various engineering monitoring areas for nearly 30 years, such as civil engineering, petrochemical industry, aerospace industry, and so on [1–3]. More conventional electric sensors have been gradually substituted by FBG sensors, mainly because FBG sensors not only have the common advantages of optical fiber sensors, such as intrinsic safety, immunity to electromagnetic interference, high resistance to corrosion, adaptability to harsh environments, high temperature resistance, remote measurement, small size, and so on, but they also have the unique advantages of simple optical properties and good linearity, which make the sensor system easy to multiplex [4,5]. Thousands of FBGs can be written in a fiber and be located through the Wavelength-Division-Multiplexing (WDM) technique [6,7], so a distributed FBG sensing network has the ability to monitor the online health of large structures. The general principle of distributed FBG sensing demodulation systems is that the relative shift of the central wavelength reflected by each FBG changes with the monitored physical parameters, such as temperature, strain, and others [8]. Therefore, the multi-peak detection algorithm must be designed to accurately obtain each Bragg wavelength from the reflection spectrum, which helps to improve the accuracy of the measurement system. Although there are many kinds of single peak detection algorithms, such as direct peak (DP), centroid detection, polynomial fitting, Gaussian nonlinear fitting, and so on [9], they are mainly adapted to detect the reflection spectrum of single FBG. Because the reflection spectrum of a WDM system contains more than one peak, none of the above algorithms can work directly in WDM systems.

Aiming at solving this problem, we must make adjustments based on the traditional single peak detection algorithms to dynamically adapt to different applications and to maintain the accuracy of the measurement process. In this paper, a multi-peak detection algorithm based on the Hilbert transform is proposed to solve the above problem. The proposed algorithm introduces the thought of Divide and Conquer, which can accurately detect all Bragg wavelengths from the input reflection spectrum of multi-FBGs. The algorithm mainly consists of two sections. The first section splits the reflection spectrum of multi-FBGs and pre-positions multi-peaks after the Hilbert transform and derivation. The second section chooses one suitable single peak detection algorithm to extract the Bragg wavelength from each split spectrum. Finally, the monitored physical parameter of each point can be demodulated through the Bragg wavelength without de-noising.

## 2. Theory

### 2.1. Theoretical FBG model

FBG is a typical reflective grating, equivalent to a narrow-band reflector. When the incident light in the fiber travels through the FBG, it will reflect the light that meets the Bragg phase condition, and reflection is weak to the light that doesn't meet the Bragg phase condition [10]. From the perspective of the reflection spectrum, FBG plays a role as a wavelength selector. FBG demodulation systems are mostly

* Corresponding author.
*E-mail address:* tongxinglin@whut.edu.cn (X. Tong).

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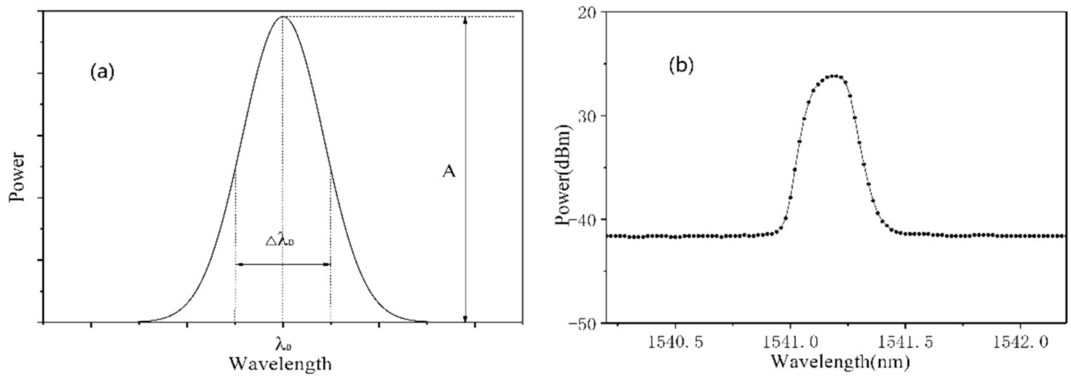


**Fig. 1.** (a) Theoretical model of the reflection spectrum; (b) The reflection spectrum signal of a single FBG.

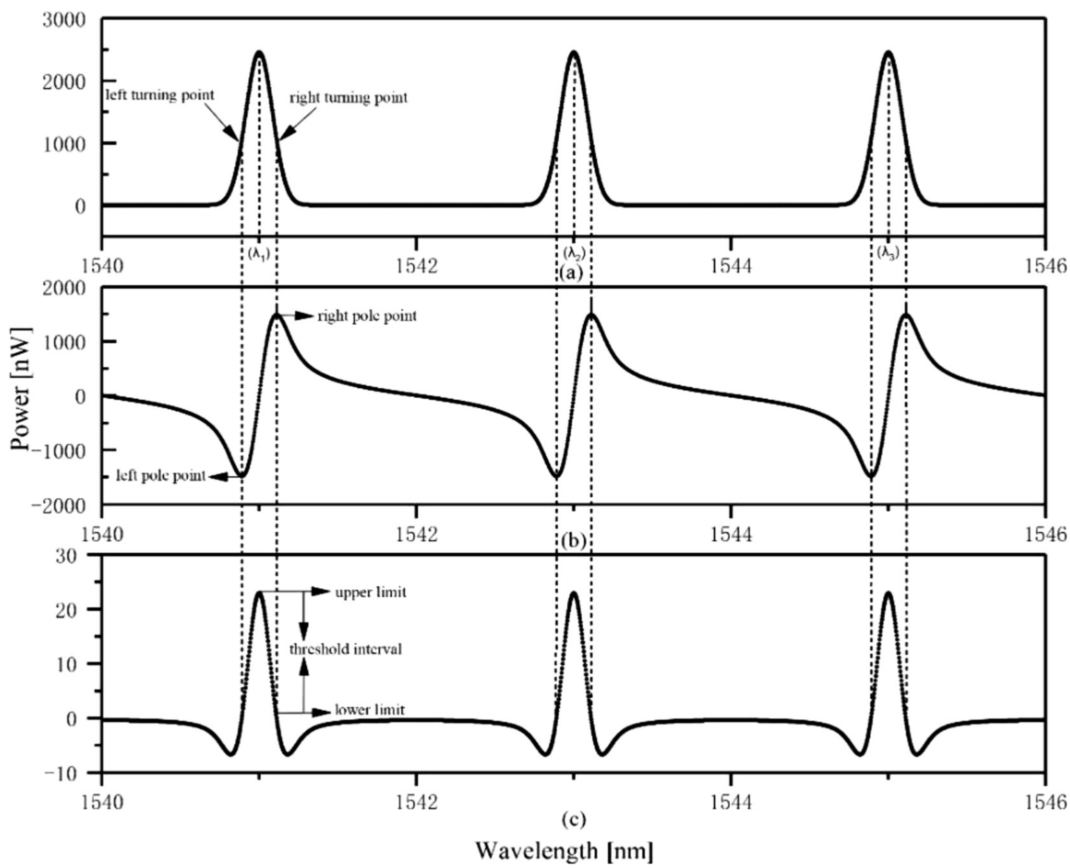


**Fig. 2.** (a) The reflection spectrum of 3 FBGs; (b) The Hilbert transform; (c) The first derivative of the transformed signal.

backward demodulating, and the key to its demodulation is to detect the shift of its Bragg wavelength. The Bragg wavelength corresponds to the peak position of its reflection spectrum, so it is important for the peak detection algorithm to improve the wavelength resolution and detection accuracy of the system. The theoretical model for the reflection spectrum of single FBGs is approximate to Gauss distribution [11], which can be expressed as Eq. (1):

$$I(\lambda) = A\exp\left[-4\ln 2\left(\frac{\lambda-\lambda_B}{\Delta\lambda_B}\right)^2\right] \tag{1}$$

where I(λ) is the intensity of the reflection spectrum, A is the amplitude, $\lambda_B$ is the Bragg wavelength, and $\Delta\lambda_B$ is the 3 dB bandwidth.

The reflection spectrum of the single FBG in Fig. 1(a) has several typical characteristics, such as narrow-band, high reflectivity, steep on both sides, and having a Gauss curve. Affected by the actual production process, application environment, sensor package structure, fluctuation of the light source, and so on, the reflection spectrum shape has some common features, such as top fluctuation, spectral broadening, asymmetry and side lobe [12]. The reflection spectrum signal of a single FBG is shown in Fig. 1(b). It is suggested that smooth de-noising should effectively eliminate top fluctuation. The high temperature annealing and apodization are the common technologies for suppressing side lobe. From the point of signal spectrum analysis, a window function is added to suppress the side lobes in the pre-processing.

However, the distributed FBG sensing network generally contains multi-FBGs according to WDM, and the Bragg wavelength spacing of adjacent FBGs is generally at least 2 nm in practical applications.

### 2.2. Principle of the Hilbert transform

The Hilbert transform in the time domain is a convolution integral