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Multi peak detection using FBG based on microwave photonic filter

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Abstract:

Microwave photonic filters (MPFs) have become an essential component in many microwave communication and sensing systems. In this study, we propose a method for multi-peak detection using fibre Bragg grating (FBG) based MPFs. FBG-based MPFs have unique advantages in terms of stability, reliability, and tunability, making them ideal for multi-peak detection applications. The proposed method is based on the spectral analysis of the MPF output signal, which is generated by passing the input signal through the FBG-based MPF. The multi-peak detection algorithm then identifies the number of peaks in the spectral output and locates their corresponding positions. The proposed method is experimentally validated using both simulated and real-world data. Results show that the proposed method is able to accurately detect multiple peaks in a noisy environment, providing a promising solution for multi-peak detection applications.

Key words: MPFs, FBG, Heterodyne filtering, Peak detection, Beat frequency.

Introduction:

Microwave photonic filters (MPFs) have emerged as a crucial technology in modern communication and sensing systems. They are used in a wide range of applications, such as spectrum analysis, signal processing, and frequency selective filtering. Fibre Bragg gratings (FBGs) are an important type of MPFs and have gained significant attention in recent years due to their stability, reliability, and tunability.

In this project, we focus on multi-peak detection using FBG-based MPFs.Multi-peak detection is an important task in many applications, such as communication and sensing systems, where the presence of multiple peaks in a signal can be indicative of certain conditions or events. The traditional methods for multi-peak detection, such as peak-finding algorithms and wavelet transforms, have limitations in terms of noise sensitivity and computation complexity. FBG-based MPFs provide a novel approach for multi-peak detection by using the spectral analysis of the MPF output signal to identify the number and position of peaks .The main objective of this project is to develop a multi-peak detection algorithm using FBG-based MPFs. The proposed method will be experimentally validated using both simulated and real-world data.

The findings of this study will illustrate the feasibility and efficacy of the suggested strategy, as well as give insights into its possible applications in a variety of sectors. Because of its compact size, low weight, immunity to electromagnetic interference, and simplicity of multiplexing, fibre Bragg grating (FBG)-based sensors have a wide range of uses in engineering, medical, civic, and military applications, among others [1]QI et al. 2019; Zhu et al.2017;Rodrigues et al.2010;Pachava et al.2015.Traditional electrical sensors are being phased out in favour of FBG sensors, which can sense several physical factors such as temperature, strain, humidity, and flow rate at the same time[2] Li et al.2015; Yelin et al. 2003. Multiple FBGs may be multiplexed in an optical fibre using wavelength division multiplexing (WDM), allowing for online health monitoring of big structures [3]Habel et al. 2017; Jiang et al. 2013; Grattan and sun 2003.

The main goal, however, is to demodulate the FBG peak wavelength from the reflection spectrum. The optical spectrum analyzer (OSA) is commonly used to determine the peak, although the peaks cannot be measured dynamically. To detect the wavelength shift of the FBG peak caused by the measurement, spectral data may be acquired using an OSA or spectrometer, and then some signal processing technique can be employed. This would allow for accurate and dynamic measurement of the FBG peak wavelength. Many studies have been conducted in this topic. Statistical strategies such as centroid identification [4] Trita et al .2015, polynomial curve fitting, direct peak method [5] Bondendorfer et al.

2009,Gaussian non-linear method [6] Wang et al.2014, and others have been described for single peak detection [7] Chen et al.2015.Signal processing techniques such as Hilbert transform [8]Liu et al.2018,segmentation-based continuous wavelets trans-form [9] Ding et al.cross correlation with Hilbert transform[Theodosiu et al. 2017], invariant moments retrieval method[Guo et al.2020a], and centroid localization algorithm [YU et al. 2018],have been demonstrated for multiple-peak detection of FBG-based sensors. The disadvantage of these approaches is that they fail to recognise actual peaks when the peaks are very narrow and faint. If the FBG signal is noisy or deteriorated, the low intensity peak may be present. A radio frequency-based FBG demodulation approach was recently developed [Guo et.al.;2020b],though this is a real-time approach, the issue is that it requires a high number of components or devices. As a result, there is a need to design an efficient signal processing approach that can be applied to the FBG sensor input to determine peaks in the reflection spectrum that may be narrow, weak, or noisy. This paper employs the match filtering technology to provide a multiple FBG-peak detection method. The match filtering methodology approach is based on determining the cross-correlation between a reference spectral signal and the FBG-sensor signal. The peak wavelength and intensity are calculated using the cross-correlation function's zero-crossing points. The Mexican-hat wavelet function is used as the reference spectral signal due of its narrow form. Experimentation has proven the validity of the proposed technique. When numerous FBGs are cascaded, the recommended approach may successfully identify multiple peaks. This method will work well if the FBG signal is weak, overlapping, and has multiple narrow peaks.

Principle algorithm:

A wavelength known as the Bragg wavelength is reflected off FBG when a broad spectrum of light is impinge on it.

$$\lambda_B = 2n_{eff}\Lambda$$

where λ_B is the grating time and neff is the effective refractive index of the basic core mode. The wavelength shifts as a result of any perturbation, such as temperature changes or strain. The wavelength shift is proportional to the applied measure. A single FBG can therefore often be used to measure a single physical parameter. However, if various FBGs are cascaded in series, multiple parameters can also be monitored and then compared to the revised FBG.

Signal that might be shifted by temperature and strain factors. The reference signal has a wavelength centre that may not coincide with the FBG peak wavelength. We consider a Gaussian spectral signal to be our signal in order to describe the procedure.The Gaussian spectral signal can be written as ,

$$R(\lambda) = e^{-4*\ln 2\left(\frac{\lambda-\lambda_B}{\Delta\lambda_B}\right)^2}$$

The approach of matched filtering is the foundation of the proposed FBG peak detection method. This method selects a reference spectral signal (such as the Gaussian peak model) and the reference signal is a Mexican-Hat wavelet function. The Gaussian spectrum signal was chosen because it resembles an FBG signal that has been corrected.

A Optical heterodyne filter is a device used in optical communication systems to mix two optical signals. The heterodyne filtering process enhances the signal to noise ratio and reduces the effects if phase noise and non linear distortion in the transmitted signals. In optical heterodyne filtering for shape deformation using fibre Bragg grating(FBG), the equations all.

1.Beat Frequency Equation:

It is proportional to the phase difference between the referenced light and the locally generated light source. It can be

$$f\_beat = f\_0 + (k\_f * \Delta L)/\lambda\_0$$

f_0 = frequency of locally generated light source.

k_f = FBG grating sensitivity

Δ***L*** = change in length of the FBG.

λ_0 = central wavelength of the FBG.

2.Interferometry Equation:

It is used in shape deformation. In this the relative phase between the two optical beam is proportional to change in length of the FBG.

$$\Delta L = \lambda\_0 * (2*\pi*(n\_eff\_1))*(f\_beat - f\_0)/x - f$$

n_eff = effective index of refraction of the FBG.

3.Phase- sensitive amplitude equation:

It is used to enhance the sensitivity of the shape deformation measurement by amplifying the phase information of the modulated signal.

$$G\_PSA = 2*\Gamma/(1+\Gamma^2)$$

Γ = amplitude gain of the PSA System5

4.Microwave Photonics:

Mathematical expressions for FBG is

$$\Delta n(x) = n(x) - n\_0$$

Where;

Δ***n(x)***= Refractive index modulation induced by the grating.

n(x)= Refractive index distribution in grating.

n_0=Average refractive index of the grating.

Reflection spectrum of FBG:

$$R(\lambda) = A \sin2(\pi\Delta nL/\lambda)$$

Where;

R(λ)= Reflection spectrum of the FBG.

λ = Wavelength of incident light.

A = Amplitude of reflective spectrum.

Δ*n* = Reflective index modulation induced by the grating.

L = Length of the grating.

The expressions show that reflection spectrum of FBG is sinusoidal. By controlling the grating length and refractive index modulation, it is possible to time the reflection spectrum of the FBG.

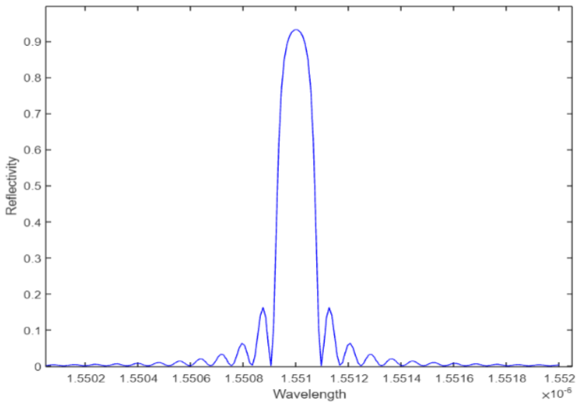


Figure 1: FBG peak detection using matched filtering technique. FBG peak detection graphs show the shift in the Bragg wavelength of a fiber optics temperature, strain, or pressure.

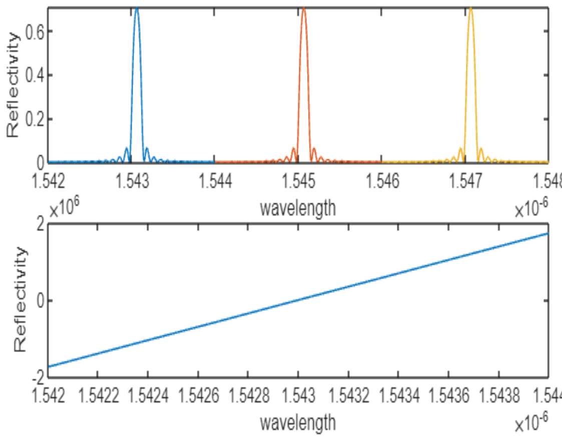
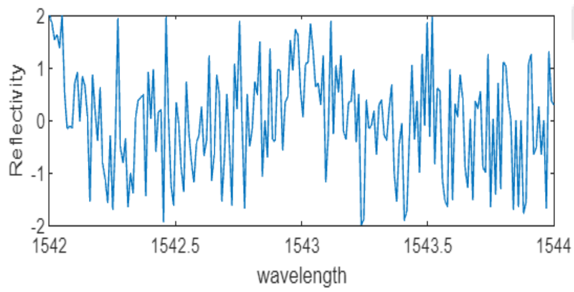


Fig 2: Spectral response of fiber optic sensor

Multi peak detection graphs of FBG show the spectral response of a fiber optic sensor with multiple grating structures, and the peaks correspond to the Bragg wavelengths of each grating, which can be used for simultaneous sensing of multiple parameters.



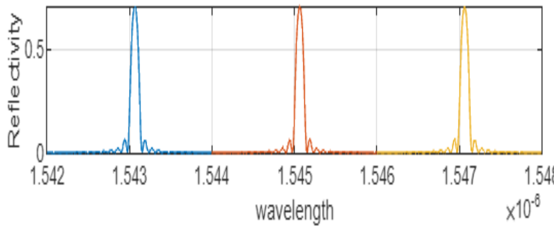


Figure 3: Multi Peak detection graphs of FBG using the microwave filtering techniques.

Methodology:

The proposed multi-peak FBG sensor consists of three FBGs with different grating structures, each of which corresponds to strain, temperature, and reference, respectively. The three FBGs are inscribed in a single fiber using a phase mask technique, and are placed in series along the fiber. The reflected spectrum of the multi-peak sensor is measured using an optical spectrum analyser (OSA). The OSA is connected to a computer, which controls the tuneable laser source and analyses the data.

Conclusion: We have presented a multi-peak FBG sensor that can simultaneously detect multiple parameters with high accuracy and resolution. The sensor has been demonstrated for simultaneous detection of strain and temperature, and has shown promising results. The proposed sensor has potential applications in various fields where simultaneous detection of multiple parameters is required, and can be extended to other parameters by designing appropriate FBG structures.

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