ISSN 2706-655X Vol.5, Issue 12: 1-7, DOI: 10.25236/IJFET.2023.051201

A Real-time Seating Monitoring System for Smart Campuses Based on Quasi-distributed Weak Fiber Bragg Grating Array

Liu Haolun[1,a,*]

[1]*Tieyi Middle School, Xi'an, China*
[a]*liuhaolun_0124@163.com*
[*]*Corresponding author*

Abstract: *This paper presents a real-time sensing system for seating monitoring in smart campuses based on a quasi-distributed weak fiber Bragg grating (w-FBG) array. We utilize fiber Bragg gratings as the key pressure sensor and design a simple spring-loaded packaging structure. The w-FBG array is placed under the seat to detect pressure changes. By sensing pressure variations, the w-FBG array achieves the purpose of monitoring students' seating conditions. We simulated the grating length, coupling coefficient, and their effects on the grating reflectivity and bandwidth using MATLAB software, providing a design reference for the w-FBG array. The optimal result obtained was a grating length of 25mm and a coupling coefficient of 0.327. This paper presents a low-power, simple, practical, and economically feasible optical sensing seating monitoring system, contributing to the construction of smart campuses.*

Keywords: *Weak Fiber Bragg Grating; Sensor; Quasi-distributed; Smart Campuses*

1. Introduction

With the development of the economy and technology, people also have more profound demands on digital infrastructure construction, public services, and industrial innovation. In today's smart campus construction, an intelligent sensor network that remotely collects students' sitting conditions around the clock can be widely used in various scenarios such as campus classrooms, study rooms, libraries, gymnasiums, and lecture halls. Currently, the mainstream technical solutions used in smart sensor networks are face recognition image processing and monitoring systems based on computer algorithms [1-2], but this technology is not mature enough, and there is a risk of personal information being leaked. On the other hand, traditional electrical sensors consume a lot of energy [3-4], and they are not suitable for low-carbon environmental protection. Considering information security, cost, and energy consumption, the construction of a smart campus sensor network urgently requires an intelligent sensor network that is low in energy consumption, can be reused, is economically convenient, and is safe and reliable. At the same time, it may also be integrated into the Internet in the future.

In recent years, with the rapid development of communication technology, optical fiber sensor technology has also been applied in a wider range of fields. Among them, weak fiber Bragg grating (w-FBG) array sensing technology [5] has the advantages of small size, low energy consumption, quasi-distribution, and at the same time has the advantages of information transmission and sensing, and it also can be used as a technical solution for smart campus sensor network construction.

As a detection element, the fiber Bragg grating (FBG) can quickly and sensitively monitor changes in temperature, pressure, gas, etc. Regarding temperature sensing and monitoring, Chen Wei [6] proposed a high-resolution array fiber grating temperature sensing system based on a narrow line and wide frequency scanning light source. Qi Hua [7] designed a wearable glove pressure-touch sensor based on a fiber grating sensor. The pressure sensor of sensitivity reaches 24pm/N, which can be used very well for human tactile pressure sensing. Currently, the sensing capabilities of fiber Bragg gratings are playing an increasingly important role in various fields.

This paper employs w-FBG array as pressure-sensitive elements to detect changes in pressure on the seat, which are remotely transformed into students' seating conditions for the purpose of class attendance monitoring. The coupling mode transmission equation of FBG is simulated and analyzed by MATLAB software, and the discussions compared with the reflection rate, grating length, and coupling

ISSN 2706-655X Vol.5, Issue 12: 1-7, DOI: 10.25236/IJFET.2023.051201

coefficient of cascaded FBG are indicated. A system is designed that utilizes w-FBG array to achieve monitoring of student seating conditions. Furthermore, a fiber Bragg grating spring packaging structure is utilized for pressure dilution, facilitating stress adjustment. This work proposes a novel application scenario for an array of w-FBG, and the experimental design of the pressure-sealed spring device contributes to the establishment of a remote monitoring system for campus seating conditions, promoting the development of smart cities and smart campuses.

2. Principle

The basic principle is illustrated in Figure 1, where a broad-spectrum light beam propagates through the optical fiber and, after passing through the fiber Bragg grating and certain specific wavelengths of light waves are reflected, forming a narrow-band reflection spectrum. Other wavelengths of light waves continue to transmit. By analyzing the characteristic spectra of reflection or transmission, we can effectively obtain information about changes in the external environmental temperature and pressure. Since the fitting curve is linear according to equation (1), the demodulation process is extremely simple.

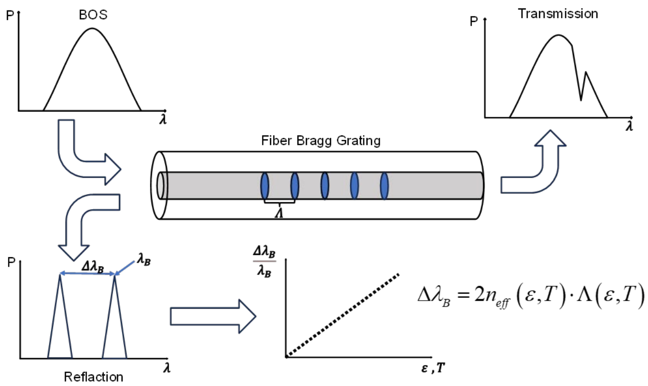

Figure 1: Basic working principle diagram of FBG sensors

The above figure shows a grating structure in which light is periodically modulated by a period refractive index change. According to equation (1), specific wavelengths in the broadband spectrum that satisfy will be selectively filtered by fiber grating. The expression of the reflected wavelength is

$$\lambda = 2n_{\text{eff}}\Lambda \tag{1}$$

Where λ is the central wavelength of the optical fiber grating; $\mathrm{n_{eff}}$ is the effective refractive index of the fiber core; Λ is the length of the modulation cycle of the optical fiber grating. According to the principle of the FBG sensor, the change in temperature and pressure will cause the center wavelength shift. T and ε are the change in the temperature and the strain applied to the FBG. The expression for the wavelength change is shown:

$$\frac{\Delta\lambda}{\lambda} = \left(1-\mathrm{P_e}\right)\Delta\varepsilon + \left(\alpha_\Lambda + \alpha_\mathrm{n}\right)\Delta\mathrm{T} \tag{2}$$

where $\Delta\lambda$ is the change of reflected wavelength; $1-\mathrm{P_e}$ is the strain sensitivity coefficient; $\mathrm{P_e}$ is the effective elastic coefficient; $\Delta\varepsilon$ is the change in the strain due to stress; α_Λ is the coefficient of thermal expansion; α_n is the thermal coefficient of light, and $\Delta\mathrm{T}$ is the amount of change in ambient temperature

$$\Delta\lambda = \mathrm{k_s}\Delta\varepsilon + \mathrm{k_T}\mathrm{T} \tag{3}$$

where $\mathrm{k_s}$ is the strain sensitivity coefficient of the grating and $\mathrm{k_T}$ is the temperature sensitivity coefficient of the grating. Through equation (3), the final wavelength shift of strain expression in our

ISSN 2706-655X Vol.5, Issue 12: 1-7, DOI: 10.25236/IJFET.2023.051201

system can be obtained. The relationship between the wavelength and the stress is

$$\Delta\lambda = \mathrm{k_s}\Delta\varepsilon \tag{4}$$

From the optical fiber grating coupling mode equation [8], we can obtain the transmission matrix of a fiber grating, it is shown as

$$\mathrm{F}_i^B \begin{bmatrix} \cosh(\gamma_B\Delta_z) - i\frac{\hat{\sigma}}{\gamma_B}\sinh(\gamma_B\Delta_z) & -i\frac{\kappa}{\gamma_B}\sinh(\gamma_B\Delta_z) \\ i\frac{\kappa}{\gamma_B}\sinh(\gamma_B\Delta_z) & \cosh(\gamma_B\Delta_z) + i\frac{\hat{\sigma}}{\gamma_B}\sinh(\gamma_B\Delta_z) \end{bmatrix} \tag{5}$$

where Δ_z is the length of the grating region. The coupling coefficient $\hat{\sigma}$ and κ can be obtained from equation (6)-(8). γ_B is the imaginary number of the wavelength. Of these, δ can be obtained from

$$\delta = 2\pi n_{\mathrm{eff}}\left(\frac{1}{\lambda} - \frac{1}{\lambda_D}\right) \tag{6}$$

$$\hat{\sigma} = \frac{2\pi}{\lambda}\delta n_{\mathrm{eff}} \tag{7}$$

$$\kappa = \kappa^* = \frac{\pi}{\lambda}v\delta n_{\mathrm{eff}} \tag{8}$$

The cascaded final transmission matrix of multiple FBGs can be obtained by multiplying each individual FBG transmission matrix, which can be expressed as

$$\begin{bmatrix} R_i \\ S_i \end{bmatrix} = \mathrm{F}_i \begin{bmatrix} R_{i-1} \\ S_{i-1} \end{bmatrix} \tag{9}$$

3. Simulation Experiments

Figure 2 shows a simulated reflection spectrum of a single FBG with the center wavelength at 1550 nm, the effective refractive index at 1.47, L at 2 mm, and κ is 0.327. We can see that his reflectivity is about 10%, which meets the low loss requirements of weakly reflective fiber grating arrays.

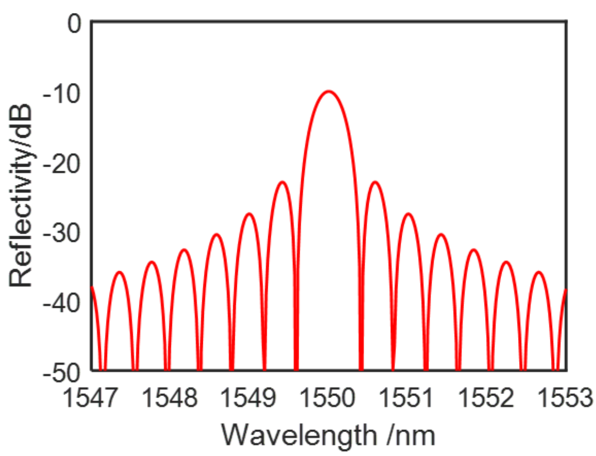

Figure 2: The reflection spectrum of a single FBG

ISSN 2706-655X Vol.5, Issue 12: 1-7, DOI: 10.25236/IJFET.2023.051201

Figure 3 (a)-(d) shows the reflection spectrum of FBG with coupling coefficients that is 0.25, 0.5, 0.75, and 1, respectively. We can find that the coupling coefficients determine the reflectance of FBG.

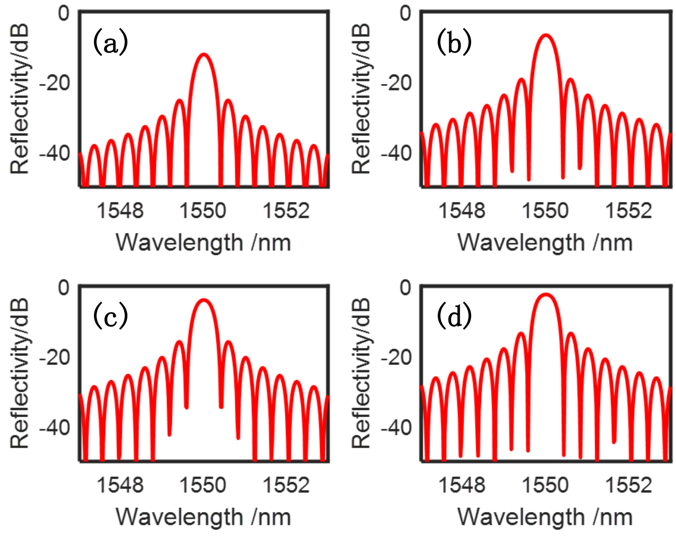

Figure 3: FBG reflection spectra with different κ

Figures 4(a)-(d) show the reflection spectrum of FBG with different grating lengths of 5mm, 10mm, 15mm, and 20 mm; while keeping the other conditions unchanged. We can observe that as the value of L increases, the bandwidth of the FBG reflection spectrum becomes narrower. This indicates that with larger values of L, the sensing precision will significantly improve for the FBG.

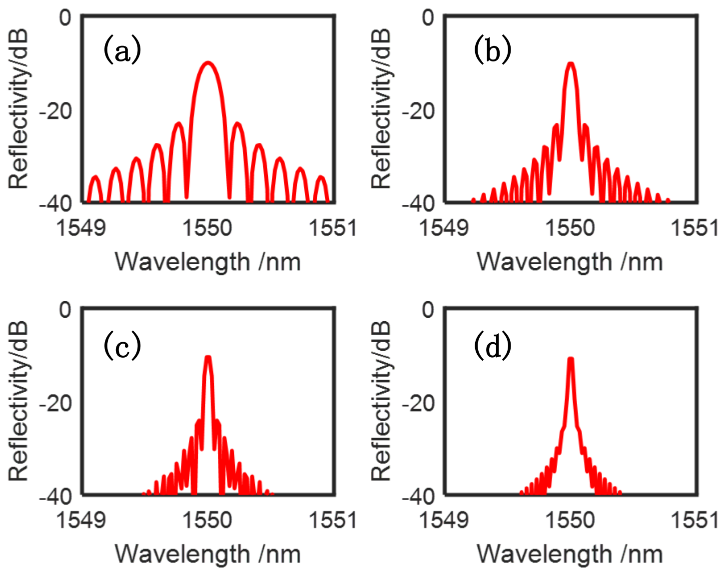

Figure 4: The reflection spectrum of FBG at different gate lengths L

We hope that the reflectivity of the weakly reflective fiber grating designed in this experiment is less than 10%, that is, the transmission loss per FBG is about -10 dB. Through simulation analysis, the larger value of L makes the higher sensing precision of the fiber grating, but the cost also increased sharply, and a special ultra-long phase mask was needed. Commercial FBG mask plates generally have a usable inscribed width of no more than 25mm. Therefore, in order to obtain a larger resolution, the value of L should be 25mm more appropriate. Through continuous simulation testing of the values in the transmission spectrum of the optical fiber grating κ , it was finally discovered that κ is 0.375, which meets the requirements of our cascaded weak reflection fiber grating sensor array.

ISSN 2706-655X Vol.5, Issue 12: 1-7, DOI: 10.25236/IJFET.2023.051201

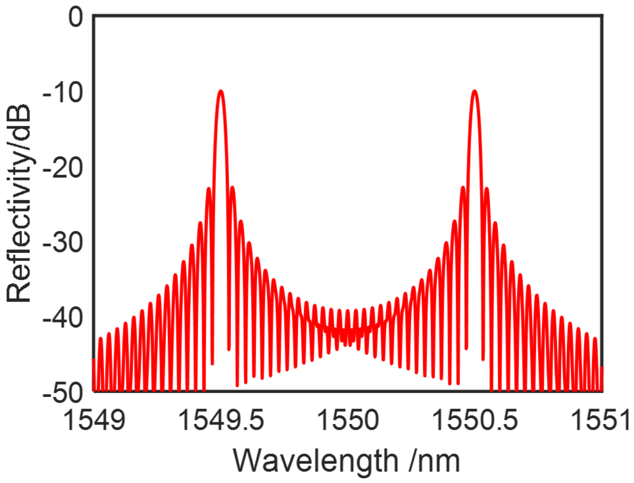

Figure 5: The reflection spectrum of two cascaded FBG

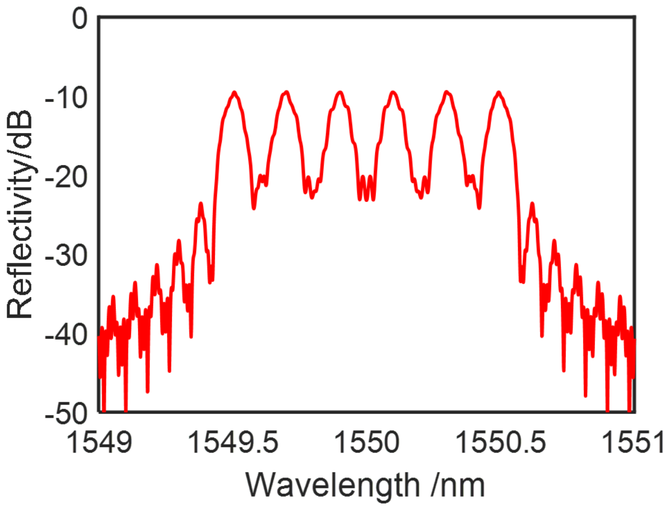

Figure 6: The reflection spectrum of six cascaded FBG

The reflection spectra of two cascaded FBGs and six cascaded FBGs within the range of 1549nm-1551nm are shown in Figures 5 and 6, respectively. When the center wavelengths of the FBGs are too close to each other, a coupling effect occurs between the envelopes of the two peaks, significantly reducing the distinguishability of the center wavelengths. As shown in Figure 6, the waveform becomes distorted and no longer conforms to the Gaussian beam shape. This will severely affect signal reading and the effectiveness of pressure sensing. Therefore, it is particularly important to set the intervals for the center wavelengths in the weakly reflecting fiber Bragg grating array sensing system.

Based on the simulation and calculations, we obtained the optimal transmission parameters from the w-FBG sensing system. By utilizing quasi-distributed technology, we created a network of Bragg gratings, connecting multiple gratings in series on a single fiber. This greatly reduces the amount of fiber cable required for installation and enables high-precision monitoring of multiple targets simultaneously. The design diagram of the optical path is shown in Figure 7. The incident light from a broadband light source passes through port 2 of the circulator and the reflected light from the w-FBG array enters the demodulation module. The wavelength data for each grating is obtained, and the computer control system facilitates message transmission. In real-time, the teacher receives accurate information about the seating arrangement of students.

ISSN 2706-655X Vol.5, Issue 12: 1-7, DOI: 10.25236/IJFET.2023.051201

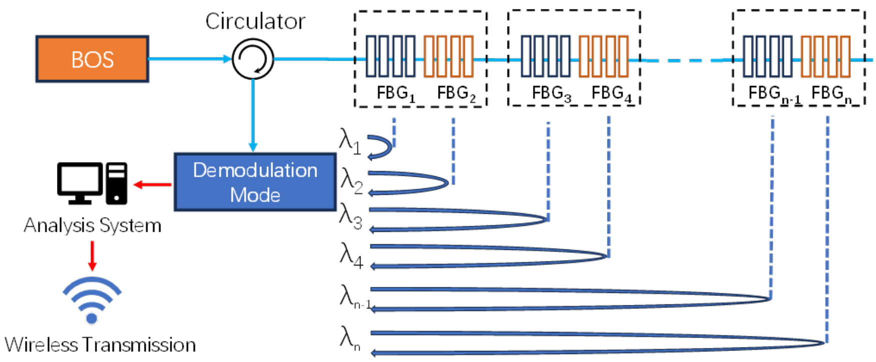

Figure 7: The diagram of a real-time monitoring system for student sitting conditions based on a weak reflective fiber grating array

The Bragg grating package design for a single seat is shown in Figure 8 (a) (b). The device is a spring divider structure, composed of 9, or 16, or more springs. The device can dilute the pressure and be safely paved, avoiding the situation of breaking by too much strain.

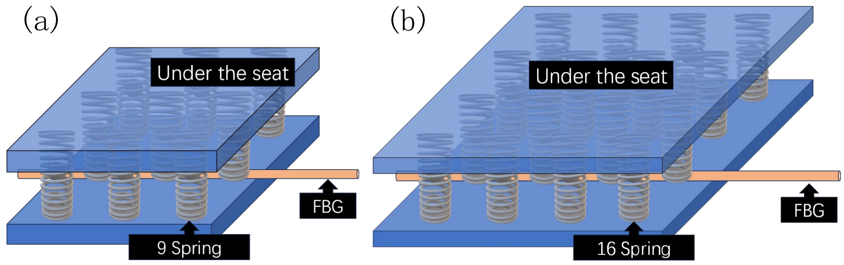

Figure 8: Schematic diagram of a single-seat fiber Bragg grating spring package

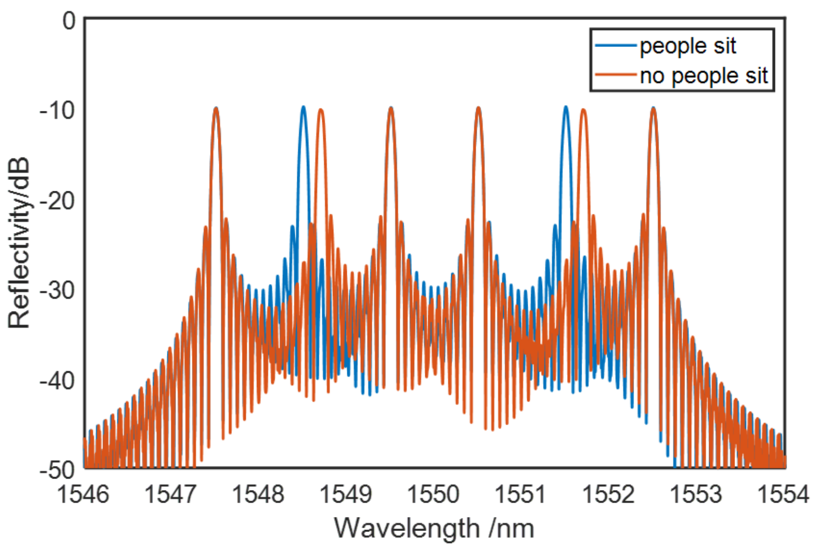

Figure 9: The reflection spectrum of six cascaded FBG when people sit down or not

The schematic diagram of wavelength variation in reflected light due to external stress is shown in Figure 9. The solid orange line represents the reflection spectrum of the weakly reflecting fiber Bragg grating (FBG) array when no one sits, while the solid blue line represents the reflection spectrum when two students sit. It is evident that the center wavelength shifts when there are occupants in the seats. This system offers advantages such as low cost, low power consumption, and network reusability, making it a reliable technical solution for future smart city and smart campus developments.

ISSN 2706-655X Vol.5, Issue 12: 1-7, DOI: 10.25236/IJFET.2023.051201

4. Conclusion

With the deployment of 5G and 6G technologies, fiber optic communication and fiber optic sensing technologies are rapidly advancing. Utilizing fiber optics for sensor network construction offers advantages such as low carbon emissions, environmental friendliness, and high-speed sensing capabilities. In the context of smart cities and smart campus sensor networks, the use of w-FBG arrays as an economically viable technical solution will undoubtedly promote the development and progress of social blockchain and the Internet of Things. In the future, we aim to deploy sensor fibers and introduce fiber optic sensing technology into secondary schools, striving to cultivate a nationwide culture of innovation in bringing science to campuses.

References

[1] Yang G, Huang T S. Human face detection in a complex background[J]. Pattern recognition, 1994, 27(1): 53-63.

[2] Kumar A, Kaur A, Kumar M. Face detection techniques: a review[J]. Artificial Intelligence Review, 2019, 52: 927-948.

[3] Ripka P. Electric current sensors: a review[J]. Measurement Science and Technology, 2010, 21(11): 112001.

[4] Leland E S, Sherman C T, Minor P, et al. A new MEMS sensor for AC electric current [C]//SENSORS, 2010 IEEE. IEEE, 2010: 1177-1182.

[5] Hui L, Hao X, Bing X. Long-distance Sensing System Based on Ultra-weak Fiber Bragg Grating Array [J]. Laser & Optoelectronics Progress, 2023, 11:1-13.

[6] Wei C, Qing L, Yan M, et al. High-Resolution Array Fiber Grating Temperature Sensing System Based on Narrow Linewidth Swept Light Source [J]. Acta Optica Sinica, 2023, 43(09):32-38.

[7] QI Hua, FENG Yan, PAN Ruizhi, et al. Bionic Touch Sensing of Wearable Fingerstall Based on Optical Fiber Bragg Grating[J]. Acta Photonica Sinica, 2023, 52(7):0706003.

[8] Turan Erdogan. Fiber Grating Spectra[J]. J. Lightwave Technol; 1997, 15(08):1277-1294