ISSN Online: 2821-1693

Transactions on Machine Intelligence

Journal Homepage: https://tmachineintelligence.ir/index.php/TMI

Design of an Interrogation System for FBG Sensors Using TDM Technique for Applications in Oil and Gas Industries

O. Entezar[1], Z. Alaie[2,*]

[1] M.Sc. Student, Faculty of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[2] Assistant Professor, Faculty of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran

ARTICLE INFO

Article History:
Received 3 March 2018
Received in revised form 20 April 2018
Accepted 9 May 2018
Available online 23 June 2018

Keywords:
Interrogation System, Fiber Bragg Gratings, Time-Wavelength Division Multiplexing

ABSTRACT

In this paper, we design and simulate an interrogation system for Fiber Bragg Grating (FBG) sensors using the time-wavelength division multiplexing (TDM) technique. Interrogation systems enable the determination of the environmental conditions surrounding each sensor. Environmental changes such as temperature and strain alter the Bragg wavelength. The relationship between wavelength shifts and measurable quantities is linear. Given the linear equation and the Bragg wavelength of each sensor, it is possible to measure the environmental quantities around each sensor. The strain and temperature sensitivities for each sensor are 0.78/με and 9.15×10^{-6}/°C, respectively. The designed system, due to its amplification capability without the use of amplifying fibers, not only reduces the system design costs but also increases the speed of detecting changes in the measurable quantities. Furthermore, due to the lack of reduction in sensor reflectivity and the appropriate spacing between the Bragg wavelengths of each sensor, the measurement range for the measurable quantities has increased. Additionally, the reflectivity of each sensor in the output of the interrogation system does not decrease, which reduces errors in this system.

1. INTRODUCTION

After nearly two decades of development, structural health monitoring systems have now become a prominent area of research and have numerous applications in extensive urban infrastructures worldwide. Accurate damage analysis, especially damage localization using global information, remains a significant challenge [1-5].

A major advantage of external sensors is their ability to operate in inaccessible locations while providing excellent protection for the measured signal against noise [6-12]. There are many applications, such as measuring temperatures inside jet engines using fibers to transmit radiation to an external radiometer. External sensors can also be used to measure internal temperatures of electric transformers, where strong electromagnetic fields render other measurement techniques impractical.

* Corresponding Author: alaie.zahra@yahoo.com
Assistant Professor, Faculty of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran

http://dx.doi.org/10.47176/TMI.2018.92

FBG sensors offer several advantages over conventional sensing systems, including immunity to electromagnetic fields and interference, resistance to harsh environments, long-term stability, the ability to multiplex many sensors, small size, and impermeability. These features make FBG technology suitable for smart structures by integrating a distributed fiber optic sensing system into a large structure [13, 14].

Recent studies indicate that sensitivity to strain and temperature is critically important in various industries. Consequently, the ability to network a large number of sensors for timely detection is of great importance [15].

In this paper, we design and simulate an interrogation system for FBG sensors and measure the wavelengths of each sensor.

2. DESIGN OF THE INTERROGATION SYSTEM

A Fiber Bragg Grating (FBG) is a periodic structure created by exposing a fiber to ultraviolet light. Several gratings can be placed along a single optical fiber. When light from a broadband source interacts with the grating, one wavelength, known as the Bragg wavelength, is reflected back, while the rest of the signal is transmitted [1].

The Bragg wavelength (Equation 1) depends on the physical and geometrical properties of the grating:

$$\lambda_b = 2\Lambda n_{eff} \tag{1}$$

where n_{eff} is the effective refractive index of the propagation mode along the fiber, and Λ is the period of the FBG. Both the effective refractive index and the grating period change with applied strain $\Delta\varepsilon$ and temperature ΔT. The applied strain and temperature change the Bragg wavelength through the expansion or contraction of the grating period and the photoelastic effect [16].

Assuming external longitudinal strain and temperature effects on the grating, we have [16]:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - P_e).\varepsilon + (\alpha_{TE} + \alpha_{TO})\Delta T \tag{2}$$

Next, we proceed with the design of the interrogation system. We have employed the time-wavelength division multiplexing technique to design an interrogation system with four sensors.

A white light source is used to generate the optical pulse. Figure 1 shows the schematic of the designed interrogation system. The first, second, and third sensors measure temperature variations, while the fourth sensor is sensitive to both strain and temperature changes. The distance between the sensors is considered to be 20 km.

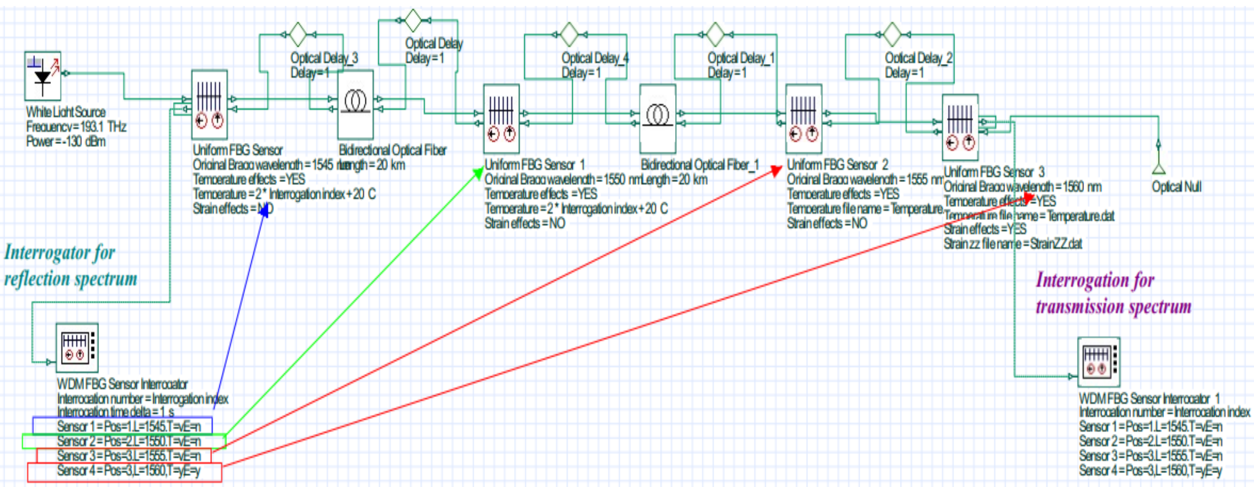
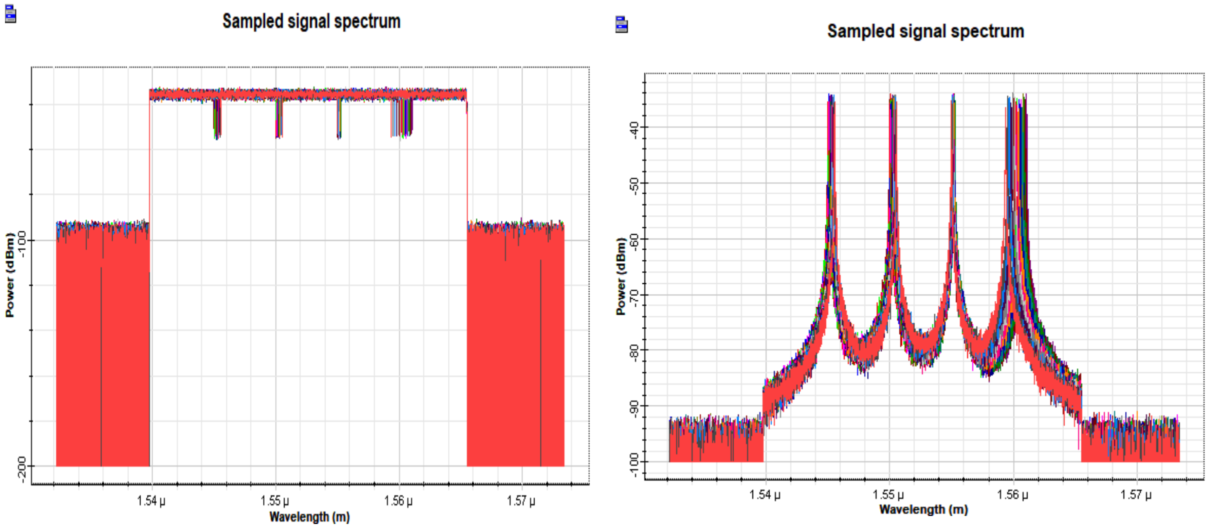


Fig. 1. Schematic of the Designed Interrogation System

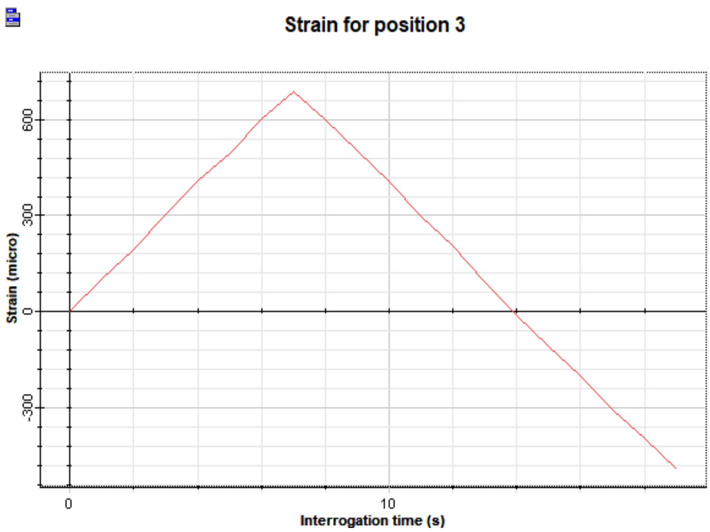
Nonlinear effects and dispersion are also considered along the fiber. Figure 2-(a) shows the reflectivity intensity, and Figure 2-(b) shows the transmissivity intensity of the sensors under applied temperature and strain changes. As observed, with increasing temperature and strain, the Bragg wavelength shifts, and by examining these changes, the environmental conditions around the sensor can be determined.



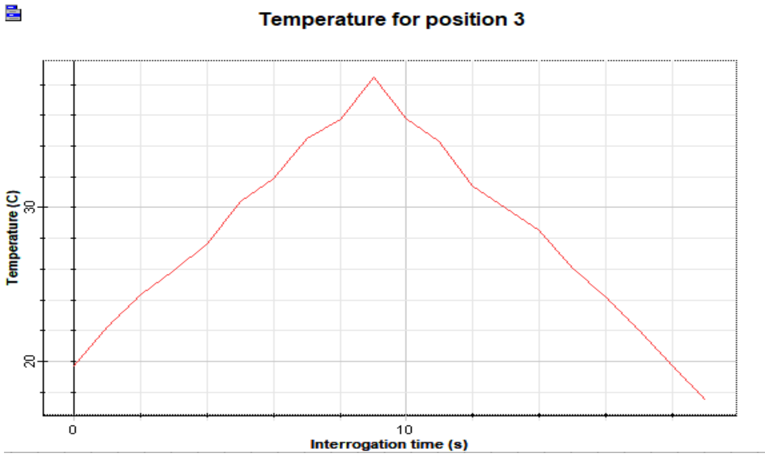
(b) **(a)**

Fig. 2. (a) Reflectivity Intensity and (b) Transmissivity Intensity of the Interrogation System with Four Sensors

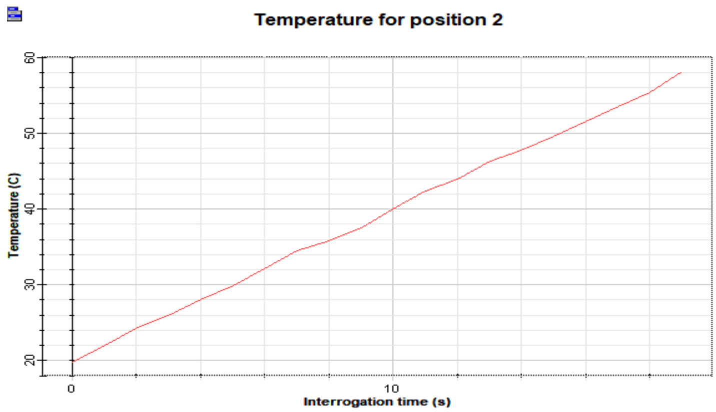
The changes in temperature and applied strain intensity for each sensor are shown in Figure 3. The temperature changes for the first two sensors are considered identical.



(a)



(b)

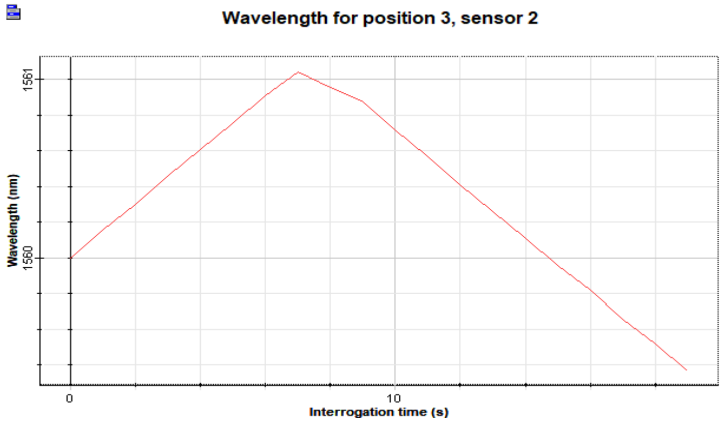


(c)

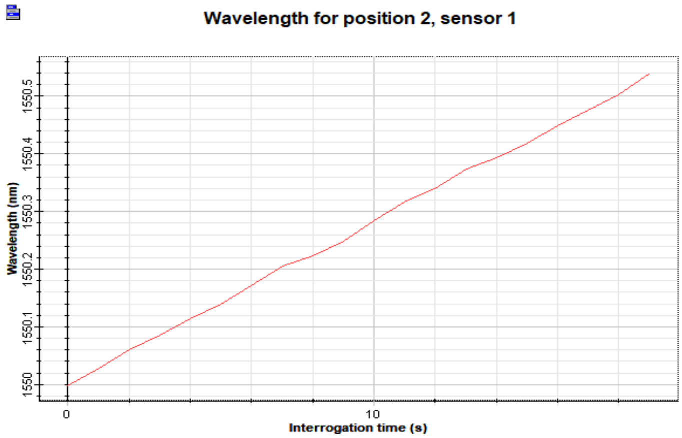
Fig. 3. (a) Applied Strain Changes to the Third Sensor, (b) Applied Temperature Changes to the Fourth Sensor, and (c) Applied Temperature Changes to the First and Second Sensors

Now, the Bragg wavelength changes for each sensor are examined. Figure 4 shows the changes in the Bragg wavelength concerning the applied temperature and strain. The Bragg wavelength changes in the first and second sensors are identical due to similar temperature changes, with the difference being the Bragg wavelengths of the two sensors.

(a)



(b)



(c)

Fig. 4. Bragg Wavelength Changes Concerning Applied Temperature and Strain for (a) the Third Sensor, (b) the Fourth Sensor, and (c) the Second Sensor

3. CONCLUSION

According to the simulation results, it is observed that the interrogation system using a white light source appropriately covers a distance of 60 kilometers. Given the use of nonlinear fibers, it is expected that the reflectivity intensity would decrease during the interrogation of the sensors. However, due to the use of the wavelength-division multiplexing technique, the reflectivity intensity does not decrease. This non-reduction in reflectivity intensity enhances the measurement accuracy around each parameter and significantly reduces errors. The designed system is capable of remote sensing applications, synthesizing FBG sensors, temperature, strain, and pressure detection, and can be applied in civil engineering projects such as bridges, pipelines, and structures, as well as multidirectional data detection. Another advantage of the designed system is the absence of a need for an amplifier due to the use of a fiber loop mirror, which amplifies the reflected light within the system.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

Acknowledgments

We would like to express our gratitude to all individuals who contributed to this project.

Declaration of Interest

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

REFERENCES

[1] Annamdas, K. K. K., & Annamdas, V. G. M. (2010). Review on developments in fiber optical sensors and applications. In Fiber Optic Sensors and Applications VII (Vol. 7677, p. 76770R). International Society for Optics and Photonics. https://doi.org/10.1117/12.849799

[2] Kawabata, Y., Kamichika, T., Imasaka, T., & Ishibashi, N. J. A. C. A. (1989). Fiber-optic sensor for carbon dioxide with a pH indicator dispersed in a poly (ethylene glycol) membrane. Analytica Chimica Acta, 219, 223-229. https://doi.org/10.1016/S0003-2670(00)80353-0

[3] Annamdas, V. G. M., Yang, Y., & Liu, H. (2008). Current developments in fiber Bragg grating sensors and their applications. In Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2008 (Vol. 6932, p. 69320D). International Society for Optics and Photonics. https://doi.org/10.1117/12.775715

[4] Fu, H., et al. (2008). Pressure sensor realized with polarization-maintaining photonic crystal fiber-based Sagnac interferometer. Applied Optics, 47(15), 2835-2839. https://doi.org/10.1364/AO.47.002835

[5] Chen, J., Liu, B., & Zhang, H. J. F. o. O. i. C. (2011). Review of fiber Bragg grating sensor technology. Frontiers of Optoelectronics in China, 4(2), 204-212. https://doi.org/10.1007/s12200-011-0130-4

[6] Ren, P., & Zhou, Z. (2017). Strain estimation of truss structures based on augmented Kalman filtering and modal expansion. Advances in Mechanical Engineering, 9. https://doi.org/10.1177/1687814017735788

[7] Aspell, P., Bravo, C., Dabrowski, M., Lentdecker, G., Robertis, G., Firlej, M., ... & Tuuva, T. (2018). VFAT3: A Trigger and Tracking Front-end ASIC for the Binary Readout of Gaseous and Silicon Sensors. 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC), 1-8. https://doi.org/10.1109/NSSMIC.2018.8824655

[8] Sekihara, K. (2018). Signal Space Separation Method for a Biomagnetic Sensor Array Arranged on a Flat Plane for Magnetocardiographic Applications: A Computer Simulation Study. Journal of Healthcare Engineering, 2018. https://doi.org/10.1155/2018/7689589

[9] Sekiya, H., Maruyama, O., & Miki, C. (2017). Identification of Cause of Displacement-Induced Fatigue in Steel Bridges Based on Displacement Measurements Using High-Performance Micro-electromechanical Systems Sensor. Sensors and Materials, 29, 140. https://doi.org/10.18494/SAM.2017.1420

[10] Zuluaga, J. A. F., Bonilla, J. F. V., Pabon, J. D. O., & Rios, C. M. S. (2018). Radar Error Calculation and Correction System Based on ADS-B and Business Intelligent Tools. 2018 International Carnahan Conference on Security Technology (ICCST), 1-5. https://doi.org/10.1109/CCST.2018.8585728

[11] Li, J., & Hao, H. (2016). A review of recent research advances on structural health monitoring in Western Australia. Structural Monitoring and Maintenance, 3, 33-49. https://doi.org/10.12989/smm.2016.3.1.033

[12] Mäki, A.-J., Ryynänen, T., Verho, J., Kreutzer, J., Lekkala, J., & Kallio, P. (2018). Indirect Temperature Measurement and Control Method for Cell Culture Devices. IEEE Transactions on Automation Science and Engineering, 15, 420-429. https://doi.org/10.1109/TASE.2016.2613912

[13] Felli, F., Paolozzi, A., Vendittozzi, C., Paris, C., & Asanuma, H. (2016). Use of FBG sensors for health monitoring of pipelines. In Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2016 (Vol. 9803, p. 98031L). International Society for Optics and Photonics. https://doi.org/10.1117/12.2222151

[14] Vikas, S. D., & Grover, A. J. A. E. T. A. (2015). Fabrication and applications of fiber bragg grating-A Review. Advances in Engineering Technology and Applications, 4(2), 15-25.

[15] da Silva Marques, R., et al. (2015). Corrosion resistant FBG-based quasi-distributed sensor for crude oil tank dynamic temperature profile monitoring. Sensors, 15(12), 30693-30703. https://doi.org/10.3390/s151229811

[16] Kashyap, R. (2009). Fiber Bragg Gratings. Academic Press. https://doi.org/10.1016/B978-0-12-372579-0.00007-7