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# Water Temperature Measurement Using Fiber Bragg Grating

Irwan Kustianto[1], Retno Wigajatri Purnamaningsih[1*], Sasono Rahardjo[2], Maratul Hamidah[2], Muhammad Yusha Firdaus[2]

[1] Departemen Teknik Elektro, Universitas Indonesia, Depok, Indonesia.
[2] Pusat Riset Elektronika, Badan Riset dan Inovasi Nasional, Jakarta, Indonesia.

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Corresponding Author:
Retno Wigajatri Purnamaningsih
retno.wigajatri@ui.ac.id

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**Abstract:** Temperature measurement in water is crucial for various applications and technological advancements. Fiber Bragg Grating (FBG) sensors have shown significant potential in measuring water temperature, with advantages in accuracy, reliability, and resistance to extreme environmental conditions. In this study, we conducted a series of experiments to measure water temperature in the range of 4 to 25 degrees Celsius using FBG sensors. Through two experimental analyses of the FBG sensor's response to water temperature changes, we found that the sensitivity of the FBG sensor we used was 0.0101 nm/°C. The results of this research demonstrate that FBG sensors are capable of measuring water temperature with high sensitivity, accuracy, and stability.

**Keywords:** Accuracy; Fiber Bragg Grating (FBG) sensors; Sensitivity; Water temperature measurement

## Introduction

Monitoring water temperature plays a pivotal role in maintaining the equilibrium of aquatic ecosystems and the overall environment. Optimal water temperatures profoundly impact the survival of aquatic organisms, migration patterns, and biochemical processes within. Through the vigilance of water temperature, we can identify fluctuations that might trigger ecosystem degradation, climate shifts, as well as natural disasters such as floods and storms. By comprehending and promptly responding to these temperature changes, we can undertake appropriate measures to safeguard environmental sustainability, preserve water resources, and ensure the safety of communities reliant on a thriving aquatic ecosystem.

With the advancement of technology, various temperature sensors have been employed to monitor water temperature accurately and in real-time (Hong et al., 2021). One of the sensors that shows great potential in water temperature measurement is the Fiber Bragg Grating (FBG) sensor (Wang et al., 2020).

FBG sensors utilize a periodic grating on an optical fiber to reflect a specific wavelength of light. When there is a change in water temperature, the wavelength reflected by the FBG undergoes a shift. This wavelength shift can be converted into water temperature using appropriate calibration. The use of FBG sensors in water temperature measurement offers advantages in terms of accuracy, reliability, and resilience to extreme environmental conditions.

Previously, several types of sensors have been used for water temperature measurement, such as conductivity-based sensors, thermistors, and thermocouples. However, these sensors may have limitations in terms of accuracy, response time, or electromagnetic wave interference.

FBG temperature sensors have been extensively explored in various studies, including low-temperature measurement (Filho et al., 2014; Rajinikumar et al., 2008; Wu et al., 2010), seawater temperature measurement (Amos et al., 2017; Duraibabu et al., 2014; LI et al., 2011; Y. Liu et al., 2018, 2021; Z. Liu et al., 2022; Qu et al., 2017; Wang et al., 2018; Xia et al., 2020; J. Zhao et al., 2022; Y.

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Zhao et al., 2019), and monitoring temperature in underwater pipe networks (Hafizi et al., 2020). The results of these experiments demonstrate that FBG temperature sensing systems have the potential for application due to their high accuracy, fast response time, and immunity to electromagnetic wave interference.

This research focuses on the use of FBG sensors for wide-range water temperature measurement, specifically from 4 degrees Celsius to 25 degrees Celsius. The objective of this study is to examine the capability of FBG sensors in water temperature measurement. Furthermore, an analysis of the FBG sensor's response to water temperature changes will be conducted to evaluate the accuracy, stability, and response time of the sensor in water temperature measurement.

Conducting research on temperature sensors using Fiber Bragg Grating (FBG) technology within the temperature range of 4 to 25 degrees Celsius holds considerable significance. This study has the potential to address a wide range of vital applications spanning different industries. From environmental monitoring to industrial procedures, the capability to precisely measure and analyze temperatures within this particular range holds paramount importance. In environmental contexts like freshwater ecosystems, this research could illuminate the impacts of climate variations and offer valuable insights into the well-being of aquatic organisms. In manufacturing settings, it has the potential to optimize production conditions by ensuring optimal temperature levels. Furthermore, this range corresponds with everyday situations, making it relevant for indoor climate management systems and agricultural practices. On the whole, delving into the realm of FBG temperature sensors within this specific range not only advances our comprehension of various fields but also provides practical solutions for challenges ranging from natural ecosystems to contemporary industrial processes.

## Method

Figure 1 illustrates the working principle of an FBG sensor based on the interference between transmitted and reflected light waves by the grating structure at specific points within the optical fiber. When the measured physical parameter changes, the reflected light wavelength also changes, resulting in a shift in the spectral peak. This spectral peak shift can be detected and correlated with the change in the measured physical parameter.

The Bragg wavelength will be reflected back to the receiver when the grating interacts with a broadband spectrum light source according to the equation given below (Erdogan, 1997).

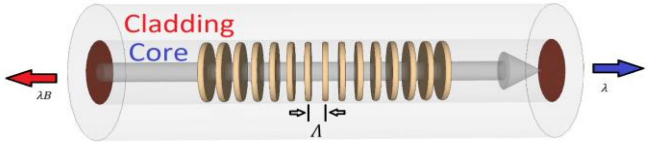


**Figure 1**. The working principle of FBG sensors

$$\lambda B = 2n_{eff}\,\Lambda \quad (1)$$

Where the Bragg grating wavelength, λB, is the central wavelength of the free-space input light that is reflected back from the Bragg grating, $n_{eff}$ is the effective refractive index of the optical fiber core, and Λ is the grating period of the FBG sensor. Essentially, the Bragg wavelength of the FBG is a function of the refractive index of the optical fiber core and the grating spacing. Due to thermo-optic and photoelastic effects, the effective index and grating spacing can be altered by external factors such as pressure or temperature. The relationship between the change in Bragg wavelength and the external measured quantity (e.g., temperature change: ΔT, strain: $\varepsilon_x$) can be derived as follows (Kersey et al., 1997):

$$\frac{\Delta\lambda B}{\lambda B} = (\alpha + \zeta)\,\Delta T + (1 - p_e)\varepsilon_x \quad (2)$$

Where p_e, α, and ζ are the photoelastic, thermal expansion, and thermo-optic coefficients of the fiber optic, respectively. Since in this experiment, the FBG sensor only undergoes temperature changes, the temperature response of the Fiber Bragg Grating has the following characteristics:

$$\frac{\Delta\lambda B}{\lambda B} = (\alpha + \zeta)\,\Delta T \quad (3)$$

In the formula above, ΔT represents the temperature change that occurs.

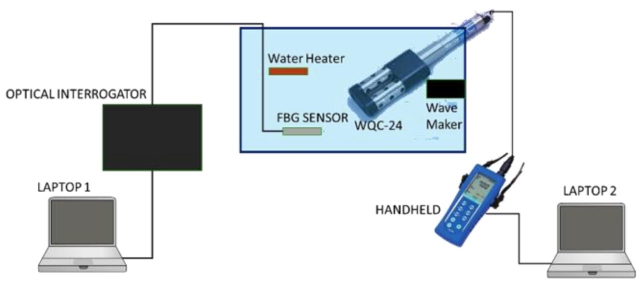


**Figure 2**. Experimental configuration for measuring water temperature using FBG sensor

Figure 2 shows the configuration of the temperature measurement experiment using an FBG sensor. The research is experimental in nature and uses water as the medium, which is contained in an aquarium. Two sensors are used: an FBG temperature sensor and a reference sensor, the WQC-24 water quality sensor, to measure the temperature in degrees Celsius (°C). Both sensors are placed inside the aquarium filled with water, as illustrated in Figures 3 and 4. Prior to the experiment, the water temperature is cooled down to 4°C using ice. The measurements then begin, gradually raising the water temperature to 25°C using a water heater. Additionally, a wave maker is used to enhance heat distribution in the water.

To collect the data, two laptops were used. One laptop was connected to the optical interrogator, and the I-MON USB Evaluation V1_30 software was used to read the temperature measurement data from the FBG sensor. The other laptop, running a Python program, was used to read the data from the WQC-24 sensor. The WQC-24 sensor was handheld, and the data was received via a serial connection, as shown in Figure 3.

**Figure 3**. Photo of the experiment for measuring water temperature using FBG sensor

Figure 4 depicts the FBG temperature sensor used in this experiment. The sensor consists of an optical fiber made of SMF-28 material, coated with a metal layer. It has a center wavelength of 1556 nm.


**Figure 4**. FBG temperature sensor

## Result and Discussion

The measurement was conducted continuously from 4°C to reach a water temperature of 25°C. A water heater was used to heat the water, and a wave maker was utilized to distribute the heat generated by the water heater more evenly throughout the water surface. Based on the data obtained from the first experiment, a scatter plot was generated, revealing that as the temperature increased, the wavelength shift of the FBG sensor also increased. This is illustrated in Figure 5.

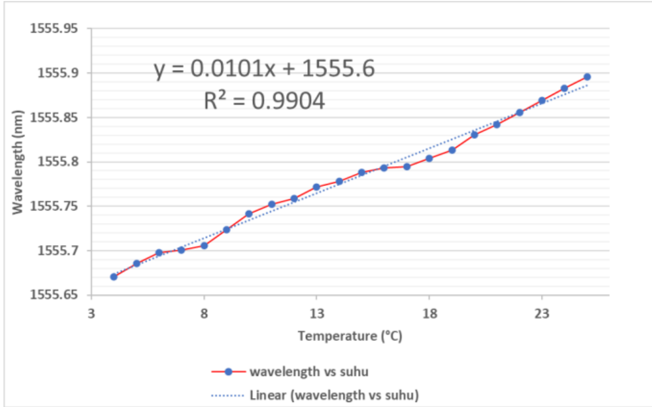


**Figure 5**. Wavelength shift due to temperature change from 4°C to 25°C in the first experiment

Afterward, a second experiment was conducted using the same configuration as the first experiment. The water temperature was initially lowered to 4°C and then heated up to 25°C. The results of the second experiment can be seen in Figure 6 below.

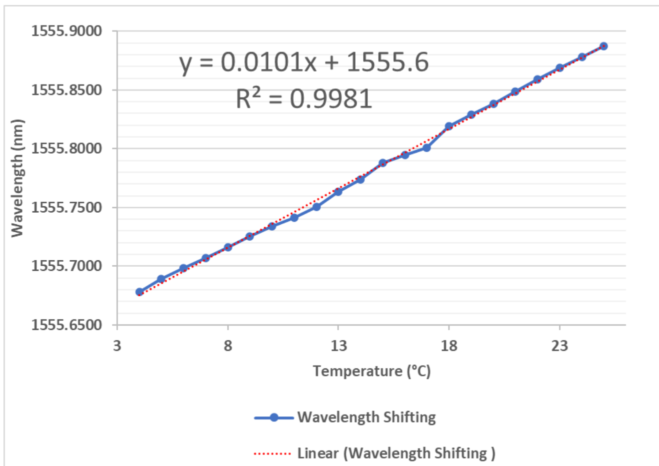


**Figure 6**. Wavelength shift due to temperature change from 4°C to 25°C in the second experiment

From Figure 6, it can be observed that there is a linear relationship between the temperature change and the wavelength shift in the FBG. As the temperature increases, the wavelength shift also increases. The stability of the FBG sensor's response to temperature changes is evident in both the first and second experiments. The sensitivity of the FBG in the first and second experiments is 0.0101 nm/°C with an R2 value of 0.9904 and 0.9981 which indicate sensor stability and accuracy.

Using the formula for strain change due to temperature (3) in an FBG sensor made of SMF-28 material, with a thermal expansion coefficient (α) of 0.55 x 10^-6 /°C and a thermo-optic coefficient (ζ) of 8 x 10^-6 /°C, the average sensitivity (ΔλB/°C) is calculated to be 0.0125 nm/°C. The percentage error between the theoretical and experimental values is 19.2%. The difference in sensitivity between the theory and experimental results may be attributed to the FBG being wrapped with a metal coating, which reduces its sensitivity but enhances its resistance to other parameters such as pressure when deployed in underwater environments.

## Conclusion

In this study, we have investigated the ability of Fiber Bragg Grating (FBG) sensors in measuring water temperature. A series of experiments were conducted to measure the water temperature in the range of 4 to 25 degrees Celsius using FBG sensors. Based on the analysis of the FBG sensor's response to changes in water temperature, we found that the FBG sensor has a sensitivity of 0.0101 nm/°C. The research findings show that the FBG sensor is capable of accurately measuring water temperature with high accuracy and good responsiveness. The FBG sensor demonstrates good stability and fast response time in measuring changes in water temperature. Its advantage in withstanding extreme environmental conditions also makes it a viable choice for applications in industries, environmental monitoring, and water engineering. These findings contribute significantly to the development of water temperature measurement technology. The use of FBG sensors in measuring water temperature can facilitate accurate and real-time monitoring in various applications. However, further research is needed to broaden our understanding of the FBG sensor's performance in different environmental conditions and wider temperature ranges. This conclusion highlights the potential of FBG sensors as a reliable solution for water temperature measurement. It is expected that these research findings will encourage further adoption of FBG sensor technology in water temperature measurement and motivate further advancements to enhance the performance and applications of FBG sensors in the future.

### Author Contributions

Conceptualization, Irwan Kustianto; methodology Irwan Kustianto, Retno Wigajatri Purnamaningsih, Sasono Rahardjo, Maratul Hamidah, Muhammad Yusha Firdaus; validation, Retno Wigajatri Purnamaningsih; formal analysis, Irwan Kustianto, Retno Wigajatri Purnamaningsih, Sasono Rahardjo, Maratul Hamidah, Muhammad Yusha Firdaus; investigation, Irwan Kustianto, Retno Wigajatri Purnamaningsih, Sasono Rahardjo, Maratul Hamidah, Muhammad Yusha Firdaus; data curation, Irwan Kustianto; writing—original draft preparation,Irwan Kustianto; writing—review and editing, Irwan Kustianto, Retno Wigajatri Purnamaningsih; supervision, Retno Wigajatri Purnamaningsih, Sasono Rahardjo.

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### Conflicts of Interest

The authors declare, there was no conflict of interest.

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