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Reflectivity of Bragg grating fiber on human respiration using InGaAs photodiode converter system

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ABSTRACT

Respiration is a vital process characterized by exchanging oxygen and carbon dioxide. Indicators such as respiratory rate are essential for detecting pathological conditions, such as pneumonia and heart failure. This research aims to develop a respiratory sensor system based on fiber Bragg grating (FBG) as an innovative alternative in high electromagnetic field environments. The system utilizes FBG optical fibers to detect strain changes due to respiratory activity, providing a sensitive, safe, and highly electromagnetic environment-compatible solution. The study used FBG with variations in reflectivity of 30%, 50%, 70%, and 90%. FBGs are installed inside oxygen masks at five different points to monitor wavelength changes during respiratory activity. The measurement method involves an optical system with an interrogator and an electrical method using an InGaAs photodiode converter to convert an optical signal into an electrical signal visualized in LabVIEW. Respondents were tested in three activities: stillness, walking, and running. Variations in sensor reflectivity and position in masks were evaluated to determine sensitivity to respiratory changes. The data is collected as a graph of wavelength against time. The result showed that the change in the wavelength of the FBG correlated with the intensity of respiratory activity. The reflectivity of 90% results in the highest sensitivity, allowing for more accurate detection of strain changes. The position of the sensor at the center point of the mask demonstrates the most linear results, indicating optimal sensitivity. Physical activity, such as running, produces the greatest strain on the optical fiber. This study proves the potential of FBG as a precision medical sensor for respiratory monitoring applications.

Keywords: Fiber Bragg grating; InGaAs; optical fiber; reflectivity; uniform

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INTRODUCTION

Breathing is the exchange of oxygen and carbon dioxide between the body's cells and the environment [1]. Measuring respiratory rate is an important indicator of the body's systems because it is highly sensitive to pathological changes in humans, such as pneumonia, heart disease, and clinical deterioration [2]. Therefore, appropriate technological solutions for measuring respiratory rate have important implications for healthcare, the workplace, and sports.

Several studies have been conducted on measuring respiratory rate using optical sensors using FBGs. The FBG is placed on the chest surface, utilizing the FBG's sensing properties. When humans breathe, movement occurs on the chest surface, and the FBG measures the resulting strain changes [3]. The FBG, as a respiratory sensor, is placed under the nose using a V-shaped rubber band and a sensor holder attached to the nose. The FBG is connected to a Micron Optics data acquisition device to monitor airflow in and out of the nose. Respiratory patterns can be viewed on the device as a strain-versus-time curve [4].

Another study conducted by Liang et al., 2006, utilized the FBG's temperature parameter to measure respiratory rate [5]. The FBG was placed on the nose with the aid of an oxygen mask and connected to a laser source and then a detector to read the output signal on an oscilloscope. The results of this study indicate that respiratory flow rate can be estimated from the sensor's response in the form of a voltage-time graph. Previous FBG research has used only one optical method and has minimal variation in the activity and placement of the FBG among respondents.

This study developed a respiratory rate sensor system using an FBG with a wavelength of 1550 nm and varying reflectivity (30%, 50%, 70%, and 90%). The optical signal from the FBG was converted into an electrical signal using an Indium Gallium Arsenide (InGaAs) photodiode, which has high sensitivity and fast response in the 1100 – 1700 nm range [6]. Data from the sensor was analyzed using LabVIEW software, and respiratory patterns were observed through changes in the FBG's wavelength.

LITERATURE REVIEW

Respiratory System

The human respiratory system consists of the airways and lungs, which are responsible for gas exchange. Respiratory monitoring is important in the diagnosis and treatment of respiratory diseases, as well as for monitoring patient condition during physical rehabilitation. One way to monitor respiration is by using sensors that can detect changes in pressure or wavelength associated with body movement due to breathing [7].

FBG-based sensor systems have been widely used for these applications due to their ability to detect strain in optical fibers caused by body movement. When a person breathes, chest and abdominal movements can change the wavelengths reflected by the FBG, which can be measured to obtain information about breathing patterns [8].

Fiber Bragg Grating (FBG) Technology

Fiber Bragg Grating (FBG) is an optical sensor technology that works by altering the wavelength of light reflected by an optical fiber when changes occur in the fiber, such as strain or temperature. FBGs offer advantages in accuracy and resistance to electromagnetic interference that often plagues traditional sensor technologies [9].

FBGs are used in a variety of applications, including temperature, pressure, and strain sensors. In respiratory applications, FBGs can be used to detect small movements generated by changes in air volume during breathing. This technology has proven particularly useful in medical applications and mechanical measurements [8].

Indium Gallium Arsenide (InGaAs) Photodiodes

InGaAs photodiodes are semiconductor devices sensitive to infrared wavelengths and are used in applications requiring light detection in this wavelength range. These photodiodes perform better in FBG-based sensor systems due to their superior ability to detect weak signals originating from the optical wavelengths used [10].

InGaAs photodiodes are used in various optical communications and remote sensing applications due to their ability to detect wavelengths longer than visible light.

RESEARCH METHODS

This study used an experimental method by testing an FBG-based sensor system mounted on an oxygen mask to detect wavelength changes during breathing activity. The system consists of an FBG optical fiber attached to an oxygen mask worn by the test subjects. The testing process recorded wavelength changes that occurred while the subjects were stationary, walking, and running.

The research design involved several steps, starting with a light source (TLS), followed by an OSA (Optical Light Sensor) to observe the FBG reflectivity spectrum, and then installing the FBG sensor on the mask (as shown in Figure 1). This data was then analyzed, as shown in Figure 1, to capture data during breathing activity. The resulting data were then analyzed in the form of a wavelength versus time plot displayed in LABView. The obtained data were analyzed to evaluate the sensor system's sensitivity to human respiration. (See Figure 2 for the research design)

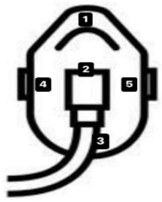

Figure 1. Illustration of the FBG position on the mask.

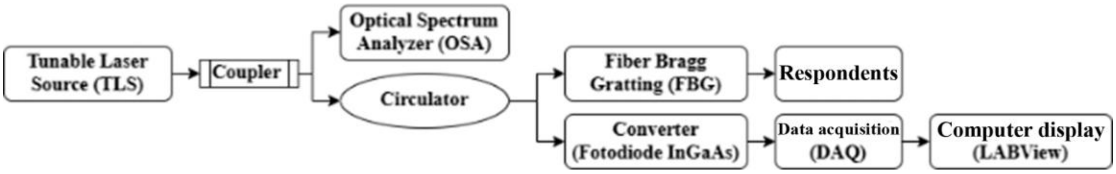

Figure 2. Research design.

RESULTS AND DISCUSSION

Test Results

Test results showed that the FBG sensor with 90% reflectivity produced a higher reflection intensity, as seen in the reflectivity spectrum, indicating that the sensor system was more sensitive to wavelength changes. The placement of the FBG on the mask also affected the linearity of wavelength changes across each respondent's activity. Running resulted in the largest wavelength changes, followed by walking and standing still.

Discussion

The discussion of the test results showed that the FBG sensor with an InGaAs photodiode performed well in detecting wavelength changes during human breathing. The influence of reflectivity on the sensitivity of the sensor system also showed significant results, with higher reflectivity improving the system's detection capability. Figure 3 shows the wavelength changes at each reflectivity level, with reflectivity levels of 30%, 50%, 70%, and 90% symbolized by A, B, C, and D, respectively.

The wavelength changes based on the FBG placement point show that position 2, in the center of the mask, shows a linear trend as the respondent's activity increases. The figure shows testing conducted at 50% reflectivity.

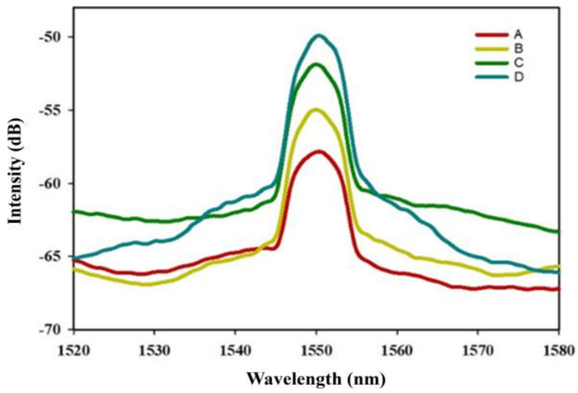

Figure 3. FBG reflectivity spectrum.

The FBG strain value is determined using the following equation:

$$\varepsilon = \frac{\Delta\lambda_B \ activity}{1550 \ nm \ (1 - 0.22)} \quad (1)$$

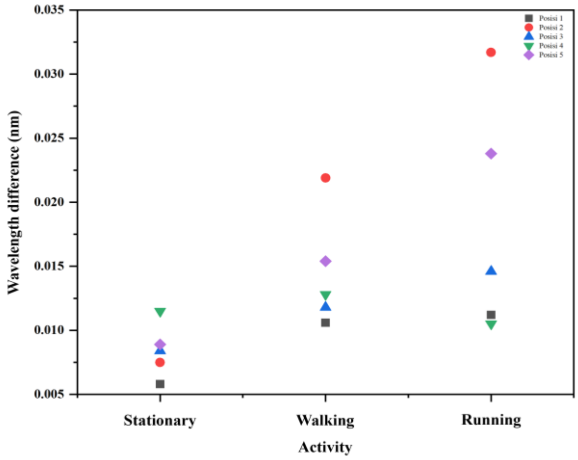

Figure 4. Difference in wavelength changes based on activity.

The respondent's activity influences the wavelength changes in the FBG. The strain values for each measured activity indicate that running has the greatest FBG strain value (see Figure 4). The strain values and graph based on activity are shown in Table 1 and Figure 5.

Table 1. FBG strain values based on respondent activity.

FBG	Strain value (10^{-5})		
	Stationary	Walking	Running
A	1.16	1.28	1.91
B	0.62	1.81	2.62
C	0.70	1.34	2.10
D	1.01	0.97	1.43

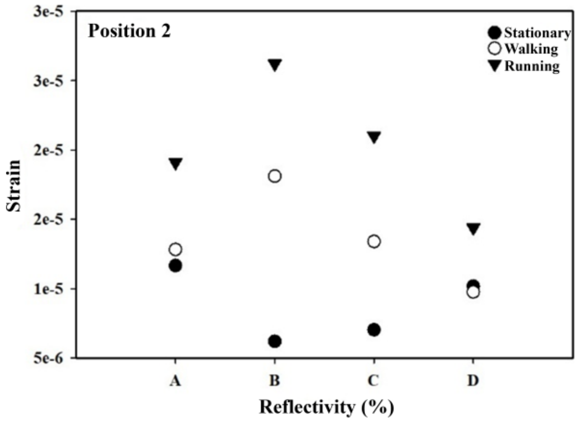

Figure 5. FBG strain between activities.

Increased activity causes an increase in lung pressure and volume, which directly affects the changes in wavelength detected by the FBG sensor.

CONCLUSION

This research has successfully developed an FBG-based sensor system with an InGaAs photodiode that can detect wavelength changes during human breathing. This system has great potential for medical applications, particularly for respiratory monitoring in patients with respiratory disorders.

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