A New Technique to Sense Humidity Based on Optical Heterodyne detection

D A Resen	extsuperscript{1}, S A Kadhim	extsuperscript{2} and A T Lateef	extsuperscript{2}, A I Mahmood	extsuperscript{2}

	extsuperscript{1}Institute of Technology, Middle Technical University, Baghdad, Iraq.

	extsuperscript{2}Materials Research Directorate, Ministry of Science &Technology, Iraq.

E-mail: dheyaaaa@gmail.com (D A Resen)

Abstract. A new method of shifting in phase of optical heterodyne detection for humidity sensing have been proposed and demonstrated. In this paper, optical heterodyne techniques by using single source with single Fiber Brag Grating (FBG) were designed and studied. In this work FBG has been used as a light source and sensing element at the same time. FBG used as a laser source to achieve heterodyne detection through combine its reflected light with main laser source. Furthermore a combined lights was generated a beat frequency (\(F_B\)). The simulation results proved the ability of the proposed technique to achieve the requires sensitivity about 0.142 GHz / %RH.

1. Introduction

The optical heterodyne technique (OHT) is one of the most commonly used techniques in recent years. It represents two wavelengths mixed to generate \(F_B\). A phase shift due to frequency shift or optical path changes by environmental changes. Moreover OHT technique can be used in many applications like communications and sensing fields [1]. The OHT as a sensor used in many purposes like, voltage, distance measurement, temperature, biosensor, strain, sensors [2-6].

Furthermore, it is used to detect the phase difference between two signals that are guided by reference and sensing arms, which is caused by some environment changes [7]. In 2017 George Y was presented a humidity sensor using optical microfiber [8]. In 2017 Jia Shi proposed and demonstrated experimentally a Fabry–Perot interferometer (FPI) sensor base humidity, to obtained sensitivity around 0.202 dB/%RH [9].

In 2018 Yu Shao presented a PVA-coated fiber SPR sensor for humidity measurement, with sensitivity of about 4.97 nm/RH% [10]. Current work represents a new approach by using one source with single FBG employing optical heterodyne technique. This contribution will help to reduce cost and system complexity with sensitivity of 0.142 GHz / % RH. The outline of this paper consist of section one theoretical concepts of optical heterodyne detection, section two experimental work of system, section three results and discussion and finally conclusion.

2. Theoretical Concepts of Optical Heterodyne Detection

The OHT is a kind of interferometry detection that used to detect phase shift between two waves. While \(F_B\) is a new wave generated due to mix reference and sensing signals and represent the difference between them, which is caused by the some environmental changes around the sensing arm.

\[
F_B = F_S - F_R
\]  

Where \(F_S\) is the frequency of a sensing arm, \(F_R\) is a frequency of reference.
Both of electromagnetic waves of sensing and reference arms are combined and forwarded to photodetector. The photocurrent of combined signals is given using the total electric field square, as the following [9]:

\[ I(t) = |A_R \cos(\omega_R t + \phi_R) + A_S \cos(\omega_S t + \phi_S)|^2 \]  \hspace{1cm} (2)

Where \( A_R \) & \( A_S \) represent the amplitude of reference and sensing waves, \( \omega_R \& \omega_S \) are the angular frequencies of them, \( \phi_R \& \phi_S \) are the phase of them. The signal phase is given by;

\[ \varphi = \frac{2\pi n_{eff}L}{\lambda_B} \]  \hspace{1cm} (3)

Where \( L \& n_{eff} \) are sensing element length and effective refractive index respectively.

\[ I(\varphi) = A \cos \Delta \varphi \]  \hspace{1cm} (4)

Phase difference represent the sensing signal is subtracted from reference signal as shown in the following equation [11];

\[ \Delta \varphi = \phi_R - \phi_S \]  \hspace{1cm} (5)

\[ I(\varphi) = A \left[ \cos \left( \frac{2\pi n_{eff}L(\lambda_B - \lambda_R)}{\lambda_B \lambda_R} \right) \right] \]  \hspace{1cm} (6)

Phase difference is obtained by ;

\[ \Delta \varphi = \frac{2\pi n_{eff}L \Delta \lambda}{\lambda_B \lambda_R} \]  \hspace{1cm} (7)

Where \( \lambda_R \) is the reference arm wavelength, \( \lambda_S \) is sensing arm wavelength, here \( \lambda_S = \lambda_B \) where \( \lambda_B \) is Bragg wavelength, which represent reflected wavelength, taking into account that the Bragg wavelength acts as a laser source and sensing signal.

3. Experimental Work  

The \( F_B \) shift is a function of shifting in wavelength in this work. The system consist of laser source 1552 nm, optical couplers \( C_1, C_2 \) and \( C_3 \), avalanche photodiode (APD) receiver, Fiber Bragg Gratings FBG and Oscilloscope (OSC) as shown in Figure 1. Here FBG has two functions, the first is a sensing element and the second it work as another source in order to achieve heterodyne in output wave. The first coupler \( C_1 \) split the launched light into two beams along reference and sensing arms. This interferometer achieved due to different wavelengths through reference and sensing arms. The reference arm signal and reflected signal of FBG via \( C_2 \) will be combined using \( C_3 \), finally the output waves process used APD.

![Humidity sensor based heterodyne technique](image_url)
The whole system is shown in figure (2) using OptiSystem. Here OSA used to show the difference between the two signals that represent $F_B$. The difference between them was clear by using APD and OSC.

![System Diagram](image)

**Figure 2.** Humidity sensor based Heterodyne detection system

4. Results and discussion

The system has been achieved utilizing OptiSystem take into account the previous results was obtained by other researchers in this field. Figure 2 shows both of (a) main source wavelength and (b) shifting in $\lambda_B$ for three.

![Graphs](image)

**Figure 3.** (a) main source wavelength (b) shifting in $\lambda_B$

Where $F_B$ was generated due to the difference between main source wavelength and $\lambda_B$. The difference between two signals is measured utilizing heterodyne detection.

When the humidity applies on the FBG the $\lambda_B$ will change and cause shifting in $F_B$. The beat frequency shift is due to the shifting in $\lambda_B$ caused by humidity changes.

Figure 4 shows the beat frequency shift due to Bragg wavelength shift, which caused by applied humidity.
The wavelength shift over the humidity range from 23.8%RH to 83.4%RH at room temperature is linear, and $\Delta \lambda_B$ increases with the rate of about 1.134 to 1.832 pm/%RH [10]. In this work the heterodyne technique plays the main role, where $F_B$ here is as a function of %RH. In this case the Bragg wavelength shift with the rate of 1.134/%RH is used. Figure 5 shows the relationship between $F_B$ and RH%, where the $F_B$ is generated by mixing a different wavelength and represents the subtraction of them. As a result, the beat frequency shift over the range of the humidity from 23.8% to 83.4%RH was 0.1416 GHz/%RH.

![Figure 4](image1.png)  
(a) $F_B$ at $\Delta \lambda_B = 0.1 \text{ nm}$,  
(b) $F_B$ at $\Delta \lambda = 0.3 \text{ nm}$,  
(c) $F_B$ at $\Delta \lambda_B = 0.3 \text{ nm}$.

**Figure 4.** (a) $F_B$ at $\Delta \lambda_B = 0.1 \text{ nm}$, (b) $F_B$ at $\Delta \lambda = 0.3 \text{ nm}$, (c) $F_B$ at $\Delta \lambda_B = 0.3 \text{ nm}$.

**5. Conclusions**

The proposed approach was presented in current work by using a single CW laser and single FBG with a heterodyne technique based humidity sensor. The interferometry has been used utilizing single mode fiber as a reference arm and FBG along sensing arm. OTH provides an optical sensors with conventional receivers like photodiode, furthermore the FBG used as a secondary source and sensing element at the same time. The results has been demonstrated, which possess many unique advantages.
over conventional techniques, it is help to reduce cost and system complexity and obtained sensitivity about 0.142 GHz /%RH. The results shows the propose technique can make improvement respect to other conventional technique. The beat frequency shift is measured in (GHz). This will gives the ability to measure output using conventional detectors, like photodiodes. While the conventional technique needs OSA in order to read output signal, this will leads to more cost and complexity.

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