Application of Fiber Bragg Grating Sensor System for Simulation Detection of the Heart Rate

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Abstract. Fiber Bragg grating (FBG) is also widely used to detect the heart because it can be received in the form of pressure that results in changes in strain. FBG was chosen because it has a high sensitivity to strain. Heart rate detection can be done in several ways such as using a telescope, but using FBG has a high degree of accuracy and is sensitive to strain. Heart detection is still developing because of the serious problem with human life behavior so that efforts are needed to find other ways to more easily detect the heart. Currently, heart detection can be done without having to go to the hospital, such as by using a cellphone, watch, and others. This study aims to design and measure changes in the output power of FBG and to analyze the effect of strain change on FBG by loudspeaker vibration. The Bragg wavelengths used are 1310 nm and 1550 nm with a power of 1 mW as a diode laser source and the output is measured by an optical power meter. The highest change in output power at a wavelength of 1310 nm Bragg is equal to 0.471 µW, while at a wavelength of 1550 nm it is equal to 0.032 µW. The highest shift of the Bragg wavelength is at the Bragg 1310 nm wavelength, which is 0.598 nm, while the Bragg wavelength of 1550 nm is 0.552 nm. The highest change in strain was at 1310 nm Bragg wavelength valued at 576.186 µε, while at 1550 nm Bragg wavelength was 432.113 µε. This shows that the response at the Bragg wavelength of 1310 nm is more sensitive than the Bragg wavelength of 1550 nm.

1. Introduction

Heart rate measurement is an important factor that can provide information about changes in blood circulation and cardiac activity, so it is often measured in a medical setting. Currently, measurements are carried out such as electrocardiogram electrical signals, acoustic signals, changes in blood pressure in the circulatory system, changes in tissue volume as a result of volume changes in the circulatory system, changes in tissue impedance associated with changes in blood volume in certain tissue sections or changes in blood flow velocity [1]. The most common approach to assessing cardiac and respiratory signals simultaneously is the polysomnogram. Typically, this includes the polysomnogram system but is not limited to electrocardiogram, electroencephalogram, electrooculogram, electromyogram, as well as attempts at breathing, airflow, and oxygen saturation (SpO2) [2].

Practitioners and doctors who study heart monitoring rely heavily on electrocardiograms. Heart monitoring is usually performed to obtain data on heart muscle activity over a longer period of time.
This can provide sufficient data to identify the problem at hand and aid in diagnosis. The abnormality detected can be a determining factor for both the patient's or the specialist's decision. It can have several unique characteristics, but the cause must be known for sure, whether it is caused by genes or is caused by a disease that affects the heart or other heart problems. An electrocardiogram records the electrical activity of the heart muscle and then displays the data as a linear graph on a screen or on paper. Normal electrocardiogram results can be obtained from subjects with heart problems if the symptoms do not affect the electrical activity of the heart muscle [3].

Although the measurement and diagnosis of the heart through the electrical approach as above has been successful, the mechanical approach has also continued to develop, such as the use of optical fibers such as fiber Bragg grating (FBG) which is relatively simple, accurate, sensitive and safe. FBG is also widely used for detection in medical systems including in the heart because the human heart rate works in the form of pressure which results in energy with changes in position, oscillation, and strain [4-6], and this is not only for strain but also has high sensitivity with respect to temperature [7,8]. For example, the use of FBG on magnetic resonance imaging (MRI) is increasingly widespread, among others, to monitor the patient's breathing and cardiac activity during the scanning process, which does not cause any adverse effects on the patient's body either during or after undergoing MRI scanning [9,10].

FBG is an optical fiber that has a grid on its segments. This grid reflects light that passes through it at a certain wavelength and passes the rest. FBG is widely used as a sensor because it is resistant to electromagnetic interference, has high accuracy, is safe and fast because the information travels at the speed of light. FBG as a sensor has been widely used in monitoring the health of structures, recently it has been proposed for monitoring vital signs in medicine. Use of the FBG sensor for simultaneous measurement of respiratory rate and heart rate [9,11,12]. Although its development is quite significant, light-based technology with wavelength detection parameters is still relatively complex, not economical enough for sensor fabrication and instrumentation, but in terms of function and usefulness, this sensor remains an alternative choice for diagnosis in the medical world.

In terms of research interests, the FBG sensor system can be built, modified, and deployed by combining several components and interrogating the sensor [13-15], enabling economically valuable sensor operation to be developed on breath and heart rate sensors. This low-cost fiber optic sensor is generally based on the principle of intensity variation, whereby the optical power attenuation with an infrared source is transmitted directly into the optical fiber and interacts with body movements during cardiac oscillation and respiration [16-18].

For this reason, this study aims to design an application for the FBG sensor system. The FBG is designed on a grid for a specific wavelength with power on the milliwatt scale. Heart rate is detected by simulating the heart using a handphone to investigate the vibrations generated by a video of the heart rate. The resulting pressure oscillation is amplified by an amplifier, which is then evaluated against the output power of the source.

2. Theoretical Consideration

Determining the heart rate using acoustic signals (phonocardiography) usually uses a sensitive microphone located in and around the chest area. The algorithm is then applied to the resulting signal [19]. Blood pressure varies during cardiac activity and fluctuates between two values, namely the upper limit of systolic pressure and maximum arterial pressure during systole, while the lower limit of diastolic pressure and the lowest arterial pressure during diastole.

The principle of measuring heart rate using the FOI probe is based on phonocardiography. The mechanical and acoustic activity of the heart and its function causes changes in the refractive index of the core and changes in the length of the optical fiber placed on the body and microscopic changes in this optical path to appear in the delay phase $\phi$ in Equation (1) and the difference $\Delta\phi$ in Equation (2), where $\lambda$ is the wavelength of the radiation source, the refractive index $n$ of the optical fiber core, $L$ the physical length of the fiber. These changes were then evaluated by an interferometric measurement system [20].
The activity of the heart is associated with the creation of a large number of its characteristic sounds. This sound occurs due to changes in the speed (or character) of blood flow and the closing or opening of each valve. Therefore, this diagnostic method based on sensing the acoustic signal (heart sound) described above accompanies mechanical vibrations that originate in the heart and blood vessels. A conventional electrocardiogram describes the electrical activity of the heart, whereas a phonocardiogram describes its mechanical (acoustic) activity.

FBG with a lattice structure is utilized in periodic or quasi-periodic refractive index changes in the optical fiber core which correlates with changes in distance and is converted to strain and temperature due to the response of mechanical stress, strain, vibration, pressure, or temperature in light reflection. This can be seen from the shift in the original wavelength before and after the sensor region has passed. The center wavelength of the reflected light is called the Bragg wavelength. The wavelength of the Bragg is determined by the periodic change in the refractive index \( \Lambda \) and the effective refractive index as follows.

\[
\lambda_B = 2n_{eff} \Lambda
\]  

FBG sensors can be easily used in the types of multiplexing techniques wavelength-division multiplex and time division multiplex \([21,22]\).

Deformation and strain dependence is given by the wavelength of the center FBG and its parameter values. To determine the sensitivity to the object, the deformation coefficient, and normalized temperature are used. The normalized deformation coefficient is given by the following relationship,

\[
\frac{1}{\lambda_B} \frac{\Delta \lambda_B}{\Delta \varepsilon} = 0.78 \times 10^{-6} \mu e^{-1}
\]  

and the normalized temperature coefficient is given by the following relationship,

\[
\frac{1}{\lambda_B} \frac{\Delta \lambda_B}{\Delta T} = 6.778 \times 10^{-6} ^{\circ}C^{-1}
\]  

where \( \lambda_B \) is the wavelength of Bragg, \( \Delta \lambda_B \) is the shift in wavelength of Bragg, \( \Delta \varepsilon \) is the change in deformation and \( \Delta T \) is the change in temperature \([23]\).

This wavelength shift can be determined by calculating the difference between the output power displayed on the optical power meter (OPM) when given a temperature change treatment and when it is not treated it is stated in Equation (6) below \([24]\),

\[
\Delta P = 18,7 \ exp \left[ -0,111 \left( \Delta \lambda_{B,0} \right)^2 \right] - 18,7 \ exp \left[ -0,111 \left( \Delta \lambda_{B,1} \right)^2 \right]
\]  

where \( \Delta \lambda_{B,0} \) is the shift in the Bragg wavelength when not treated and \( \Delta \lambda_{B,1} \) is the shift in the Bragg wavelength when given the treatment. The value of \( \Delta \lambda_{B,0} \) can be determined by calculating from the temperature data at the reference state in the study.

The output power on the FBG channel can be determined by the mathematical equation between the power read in the OPM in Watts (\( P_o \)) and the reference power of 1 mW (\( P_{ref} \)) which is stated in the following equation.

\[
P = 10 \log \frac{P_o}{P_{ref}}
\]
3. Research Methods

This experimental method is carried out by sending infrared light, 1mW from the source and through the FBG that is induced by a simulated object of the resulting heart vibration. Furthermore, partially reflected infrared signal and partially transmitted to the OPM detector. The output power of the FBG strain oscillation to the sample is measured. The sample object is simulated from the heart rate of a handphone. The resulting simulated cardiac vibrations were evaluated for changes in FBG strain.

This study uses FBG with a wavelength of 1310 nm and 1550 nm and a video heart rate from the Heart Sounds application. The laser source used as the input power is a diode laser with a wavelength variation of 1310 nm and 1550 nm while the output power uses OPM with a wavelength variation of 850 nm, 1300 nm, 1310 nm, 1490 nm, 1550 nm, and 1650 nm. The sound of the heartbeat is identified via video. There are 2 types of heartbeat sounds used in normal conditions, namely lub and dub. The factor that affects the sound of the heartbeat is the volume of the sound taken from Heart Sounds with a duration of 1 minute 13 seconds.

![Figure 1. Set up the FBG sensor system application.](image)

After doing the set-up, FBG with various wavelength variations is measured as a result of the reference output power. Meanwhile, the output power of the heart rate object is shown in Figure 1. Observations were made on the measurement results of the output power to the OPM wavelength.

The data collected is calculated on the amount of strain by calculating the Gaussian FBG width ($\alpha_B$), Gaussian LD width ($\alpha_L$), changes in output power ($\Delta P_o$), Bragg wavelength at 20 °C ($\lambda_{B,0}$), the shift in the wavelength of Bragg due to temperature treatment ($\Delta\lambda_{B,t}$), and strain ($\varepsilon$). The measurement and calculation results are displayed in a graphical form showing the relationship between the change in output power data, the shift in the Bragg wavelength, and the change in strain to the OPM wavelength.

4. Results and Discussion

Figure 2 shows that the results of the measurement of the reference output power against the OPM wavelength with the highest value of -5.945 dBm and the lowest of -7.81 dBm. The blue and red color graphs are for diode laser sources at 1310 nm and 1550 nm wavelengths with FBG component at 1310 nm wavelengths, while the green and purple color charts for diode lasers with wavelengths of 1310 nm and 1550 nm with FBG components of the wavelength of 1550 nm.

Almost all given sources have a trend toward uniform wavelength changes, which only differs the intensity of the FBG power response. FBG which has a wavelength of 1550 nm has greater power than 1310 nm. This happens that the wavelength of 1550 nm has relatively greater energy than 1310 nm, but for the four data after 1550 nm the entire graph has a sharp decline. This is due to the loss of power because FBG does not work in the 1550 nm range.
Figure 2. FBG reference output power.

Figure 3 shows that the results of the measurement of output power after a simulated cardiac vibration treatment at the OPM wavelength with the highest and lowest values are -5.945 dBm and -7.8 dBm. The same data have similarities with Figure 2, and the power difference of the two images is the effect of the simulated heart rate.

Figure 3. FBG output power.

The reference and sample output power values both increase and decrease. If the OPM wavelength is set to a large value, the resulting output power will be smaller, and vice versa if the OPM wavelength is set to a small value, the resulting output power will be greater. If the OPM wavelength is set to equal or close to the LD wavelength, the output power value will be even greater. This can occur because there is no difference in frequency and phase so that wave interference can be neglected.

Figure 4. Changes in FBG output power.
Figures 2 and 3 show that the results of measurements carried out with variations in the Bragg wavelength of 1310 nm and 1550 nm have the same FBG output power results from the highest to the lowest, respectively with the OPM wavelength of 1300 nm, 1310 nm, 1490 nm, 850 nm, 1550 nm, and 1650 nm, but some data are not displayed because the power change display cannot be detected where the output power is limited and is affected by the OPM wavelength.

The change in the output power of FBG is the difference between the sample output power (after vibration) and the reference output power (before vibration). Figure 4 shows the measurement results of the change in FBG output power to the OPM wavelength with the highest and lowest values, respectively, 0.736 µW and 0.009 µW.

The 1310 nm Bragg wavelength is more sensitive than 1550 nm because the 1310 nm wavelength has greater attenuation than the 1550 nm wavelength. The wavelength used affects the modes of wave propagation as a function of the refractive index of FBG.

The shift in the Bragg wavelength changes when given a vibration treatment at FBG and is different for each Bragg wavelength. Figure 5 shows the shift in the Bragg wavelength with the highest and lowest values being 0.589 nm and 0.287 nm, respectively. When there is a change in strain (including the effect of external disturbances) it causes the refractive index value to change, so that the reflection spectrum will also shift [25,26].

The shifting of the Bragg wavelength is greatly influenced by vibrations. If the resulting vibration is large, the change in wavelength is greater, and vice versa, where the response of the Bragg wavelength shift is influenced by the vibration generated by the heart rate.

The reference power in this measurement is when the FBG is connected to the side of the amplifier and is not stretched (no vibration is given). Figure 6 shows the highest and lowest strain values are
576.186 µε and 267.294 µε. When dynamic stretching occurs by vibrations, the reflection spectrum of FBG shifts periodically in the wavelength domain.

5. Conclusion
The design and measurement of the FBG output power against the OPM wavelength of the heart vibration have been detected. The measurement of output power has in common with the highest to the lowest values, namely at the OPM wavelengths of 1300 nm, 1310 nm, 1490 nm, 850 nm, 1550 nm, and 1650 nm. The change in FBG output power is inversely proportional to a given OPM wavelength. The shift of the Bragg wavelength and the change in strain both fluctuate under the influence of the vibrations given by the amplifier. This measurement shows that the 1310 nm Bragg wavelength is more sensitive than 1550 nm to strain. The strain obtained is insufficient to explain the video vibrations of the heart rate as the measurement is only carried out on the amplifier. Vibration and strain can be understood in more detail by measuring the strain experienced by other materials on a heart rate video. The measurement accuracy is limited by the OPM resolution used and the loss experienced by the system.

Acknowledgements
The author would like to thank Riau University for supporting the completion of this research at the Plasma and Photonics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, University of Riau, Pekanbaru for the financial assistance and facilities provided.

References
[1] Zourob S, Hayatleh K, Barker S, Nagulapalli R, Yassine N, Ramsbottom R and Lidgey J 2018 Increasing signal to noise ratio and minimizing artefacts in biomedical instrumentation systems Analog Integr. Circuits Signal Process. 95 403–8
[2] Rodriguez C L and Foldvary-Schaefer N 2019 Clinical neurophysiology of NREM parasomnias Handb. Clin. Neurol. 161 397–410
[3] Turnip A, Andrian, Turnip M, Dharma A, Paninsari D, Nababan T and Ginting C N 2020 An application of modified filter algorithm fetal electrocardiogram signals with various subjects Int. J. Artif. Intell. 18 207–17
[4] Hongyao W 2011 Coal mine disasterrescue life sign monitoring technology based on FBG and acceleration sensor Procedia Eng. 26 2294–300
[5] Tahir B A, Ali J, Saktioto, Fadhal M, Rahman R A and Ahmed A 2008 A study of FBG sensor and electrical strain gauge for strain measurements J. Optoelectron. Adv. Mater. 10 2564–8
[6] Chaudhary K, Rosalan S, Aziz M S, Bohadoran M, Ali J, Yupapin P P, Bidin N and Saktioto 2015 Laser-induced graphite plasma kinetic spectroscopy under different ambient pressures Chin. Phys. Lett. 32 43201
[7] Mishraa V, Lohar M and Amphawan A 2016 Improvement in temperature sensitivity of FBG by coating of different materials Optics 127 825–28
[8] Saktioto T, Syahputra R F, Punthawanunt S, Ali J and Yupapin P 2017 GHz frequency filtering source using hexagonal metamaterial splitting ring resonators Microwave Opt. Technol. Lett. 59 1337–40
[9] Dziuda L, Skibniewski F W, Krej M and Baran P M 2013 Fiber Bragg grating based sensors for monitoring respiration and heart activity during magnetic resonance imaging examinations J. Biomed. Opt. 18 057006
[10] Ali Z, Lee S, Ismail F D, Saktioto, Ali J and Yupapin P P 2011 Radiation self absorption effect in Ar gas NX2 mather type plasma focus Procedia Eng. 8 393–400
[11] Dziuda L, Skibniewski F W, Krej M and Lewandowski J 2012 Monitoring respiration and caridac activity using fiber Bragg grating-based sensors IEEE Trans. Biomed. Eng. 59 1934–42
[12] Okfalisa, Anugrah S, Anggraini W, Absor M, Fauzi S S M and Saktioto 2018 Integrated analytical hierarchy process and objective matrix in balanced scorecard dashboard model for performance measurement Telkomnika 16

[13] Marques C A F, Webb D J and Andre P 2017 Polymer optical fiber sensors in human life safety Opt. Fiber Technol. 36 144–54

[14] Mitatha S, Moongfangklang N, Jalil M A, Suwanpayak N, Saktioto T, Ali J and Yupapin P P 2011 Proposal for Alzheimer’s diagnosis using molecular buffer and bus network Int. J. Nanomed. 6 1209

[15] Saktioto, Ali J and Fadhali M 2009 Simplified coupling power model for fibers fusion Opto-Electron. Rev. 17 193–9

[16] Nishyama M, Miyamoto M and Watanabe K 2011 Respiration and body movement analysis during sleep in bed using hetero-core fiber optic pressure sensors without constraint to human activity J. Biomed. Opt. 16 17002

[17] Sartiano D and Sales S 2017 Low cost plastic optical fiber pressure sensor embedded innmattress for vital signal monitoring Sensors 17

[18] Saktioto T, Irawan D, Yupapin P P and Phatharacorn P 2015 A single eye 3D image perception device using vertical double ring resonator construction Microwave Opt. Technol. Lett. 57 1802–5

[19] Hen G, Imtiaz SA, Aguilar-Pelaez E and Rodriguez-Villegas E 2015 Algorithm for heart rate extraction in a novelwearable acoustic sensor Healthcare Technol. Lett. 2 28–33

[20] Nedoma J, Kepak S, Fajkus M, Cubik J, Siska P, Martinek R and Krupa P 2018 Magnetic resonance imaging compatible non-invasive fiber-optic sensors based on the Bragg gratings and interferometers in the application of monitoring heart and respiration rate of the human body: A comparative study Int. J. Sensors 18 3713

[21] Fajkus M, Navruz I, Kepak S, Davidson A, Siska P, Cubik J and Vasinek V 2015 Capacity of wavelength and time division multiplexing for quasi-distributed measurement using fiber Bragg gratings Adv. Electr. Electron. Eng. 13

[22] Fajkus M, Nedoma J, Kepak S, Rapant L, Martinek R, Bednarek L, Novak M and Vasinek V 2016 Mathematical model of optimized design of multi -point sensoric measurement with Bragg gratings using wavelength division multiplex Opt. Modell. Des. IV 9889

[23] Kersay A D, Davis M A, Patrick H J, LeBlanc M, Koo K P, Askins C G, Putnam M A and Friebele E J 2010 Tunable erbium-doped fiber lasers using various inline fiber filters Engineering 2 1442–63

[24] Zhang L, Wu G, Li H and Chen S 2020 Synchronous identification of damage and vehicle load on simply supported bridges based on long-gauge fiber Bragg grating sensors J. Perform. Constr. Facil. 34 04019097

[25] Jung Y, Brambilla G and Richardson D J 2008 Broadband single-mode operation of standard optical fibers by using a sub-wavelength optical wire filter Opt. Express, 16 14661–7

[26] Zairmi Y, Veriyanti V, Candra W, Syahputra R F, Soerbakti Y, Asyana V, Irawan D, Hairi H, Hussein N A and Anita S 2020 Birefringence and polarization mode dispersion phenomena of commercial optical fiber in telecommunication networks J. Phys.: Conf. Ser. 1655 012160