Measurement heart rate based on plastic optical fiber sensor

A Arifin¹*, A K Lebang¹, M Yunus¹, S Dewang¹, I Idris² and D Tahir¹

¹Physics Department, Hasanuddin University, Makassar, 90245 Indonesia
²Physiology Department, Hasanuddin University, Makassar, 90245 Indonesia

*Corresponding author: arifinpide@gmail.com

Abstract. In this research, we measured heart rate by using sensors based on plastic optical fiber. These sensors are made from fiber optic material with three configurations, i.e., straight, sinusoidal, and spiral. Each sensor configuration was tested and paired in three positions of the human body, i.e., hand, chest, and neck. Each configuration and pairing position were tested for fast, normal, and slow heart rate condition. The light from the LED will propagate along the optical fiber sensor. If the sensor detects the heart rates, the intensity of light in optical fiber will be disrupted and causing loss of power so the light intensity will be smaller, it can be detected by the phototransistor and then converted into an electric voltage. The best measurement obtained in spiral configuration mounted on the neck in a slow heart rate condition with a sensitivity value 0.00231 V.s⁻¹ and a resolution 0.43203 s. This sensor has the advantage of easy fabrication, low cost, real-time measurement, high sensitivity, easy to operate and can be monitored via computer.

1. Introduction

The development of technology in the field of electronics to produce instrumentation systems and sensors are important so that it can be implemented in various fields [1]. This development also penetrates the field of health technology which can be used to diagnose diseases, monitoring and treatment of patients more efficiently [2-3]. Sensors can be applied in medical fields such as on measurement and monitoring of breathing, heart rate, blood pressure, or muscle activity. The measurements data from these sensors can be used to correctly identify the health disorder and diagnose the disease. To perform such measurements and monitoring, we need an instrument that can be used as a sensor [4]. With this sensor technology, it is possible to perform monitoring and measurement automatically, effectively and reliably in the level of accuracy and good precision.

The optical fiber is a form of technological development that can be implemented as a sensor for measurement and monitoring systems. Based on this material, the optical fiber consists of the plastic optical fiber (POF) composed of plastic or polymethyl methacrylate (PMMA) and glass optical fiber (GOF) made from glass or silica. In the application of optical fiber to be used as a sensor, the use of POF is better than the GOF because of its flexibility and not easily broken. Fiber optic sensors can be utilized for a variety of measurements, such as temperature, pressure, vibration, load, shift, curvature, voltage, current, and diagnostics a quantity in the medical subject [2,5]. The advantages of using POF are high sensitivity, low cost, easy fabrication, not easily broken compared to GOF, easy connectivity, lightness and flexibility [5-7]. The use of optical fiber as a sensor or monitoring devices applied to biomedical devices or environments has advantages, like insensitive to electromagnetic waves, and not generating heat [3,8-9].
Several studies have been conducted on optical fiber-based sensors to measure various parameters. They are implementing it for load sensors [1], shifting sensors with bending models with imperfections [5], and application in the medical field as a health monitoring sensor [3]. The application of fiber optics as sensors for health monitoring based on fiber bragg grating (FBG) had been done, including body temperature [3,10], respiratory, and heart rate [2-3,10-12]. The use of FBG-based sensors requires high cost and difficult supporting equipment in fabrication [9,13].

In this study, the plastic optical fiber is used as a heart rate sensor with macro-bending and strain methods with variations in configuration, positioning, and heart rate conditions. The principles of this optical fiber sensor are when the heart beats; blood is pumped to arteries which can implicate fluctuations of its volume so that our sensor bent and stretched. This process is responsible for power loss, which makes a difference to the light intensity received in the phototransistor. This work shows a change in output voltage of the amplifier and Arduino Uno microcontroller, then the result of heart rate measurement shows a change in output voltage which is displayed on the computer. The heart rate sensor based on the plastic optical fiber is expected to have high sensitivity, easy fabrication, low cost, real-time measurement, easy operation and can be monitored via computer.

2. Experimental Setup

In this study of measuring and monitoring human heart rate, the sensor used plastic type fiber optic without a jacket. We are using fiber optics with 2.2 mm diameter, 1 mm cladding and 0.98 mm core. Optical fiber refractive index in the cladding layer is 1.402, core 1.492, and numerical aperture (NA) 0.5. The fiber optic sensor is attached to the elastic fabric and mounted on body parts that are sensitive to heart rate measurement. The design of the heart rate sensor based on the plastic optical fiber is made with three types of configuration, i.e., straight, sinusoidal, and spiral as shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Design of heart rate sensor configuration (a) straight, (b) sinusoidal, (c) spiral.

At both ends of the sensor, we are mounting a light source and detector. A light infrared (IR) with light source IF-E91A type and a 950 nm wavelength mounted on one end of plastic optical fiber. Meanwhile, phototransistor as a detector with type IF-D92 and wavelength ranged from 400 to 1100 nm is mounted on the other end. The phototransistor output is connected to a differential amplifier circuit and an Arduino Uno microcontroller and then connected to the computer. The scheme is shown in Figure 2.

![Figure 2](image2.png)

**Figure 2.** POF based heart rate sensor scheme.

The light emitted of the LED will propagate along the fiber optic sensor. If the sensor detects the heart rates, the intensity of light in the optical fiber will be disrupted and may cause loss of power. The change in light intensity due to the loss of power can be detected by phototransistor and then converted into an electric voltage. Phototransistor output in the form of analog voltage is converted to
digital signal by Arduino Uno microcontroller circuit, then the result of the heart rate measurement can be monitored on the computer. Sensor testing is done with a variation of configuration, position of installation, and heart rate condition. Each sensor configuration is tested on three variations of the mounting position: hand, chest, and neck positions using an elastic clothing material. Furthermore, each configuration and position of the mounted sensor is tested in fast, normal, and slow heart rate conditions. In this study, a rapid heart rate condition is obtained after a person performs a strenuous physical activity such as exercise. For normal conditions, that is when the heart rate of a person without doing heavy physical activity. While the condition of slow heart rate is when someone in a rest condition.

3. Results and Discussion
The setup experiments are prepared for measuring and monitoring the heart rate using fiber optic sensors in a variety of configurations, mounting positions, and heart rate conditions. The testing process is carried out with 3 straight, sinusoidal, and spiral sensor configurations. Furthermore, in each configuration tested by installing the sensor on the position of the hand, chest, and neck. In each configuration and position of the sensor is tested on every heart rate condition that is fast, normal, and slow. The measurement results in the output voltage read on the computer is proportional to the heart rate. The result of heart rate measurement with a variation of configuration and condition at hand position as in Figure 3, chest position in Figure 4 and neck position in Figure 5.

Figure 3. Measurement of heart rate at hand position and condition (a) fast, (b) normal, and (c) slow.
Figure 4. Measurement of heart rate at the chest position with condition (a) fast, (b) normal, and (c) slow.

The heart rate measurement results are shown in Figure 3, Figure 4, and Figure 5. Each mounting position, sensor configuration, and heart rate conditions produce different responses for the heartbeats that are successfully measured. The blue line indicates a spiral configuration, for a red line, indicates a sinusoidal configuration, and for a straight configuration represented by a black line. These tools use some heart rate in beats per minute (bpm). In Figure 3 shows the best measurements at hand position with fast condition 28 beats for 15 seconds so that 112 bpm is obtained using a spiral configuration, for the normal condition the best result of the heart rate obtained is 68 bpm with a spiral configuration, while for slow heartbeat condition obtained 52 bpm.
Figure 5. Measurement of heart rate at neck position with condition (a) fast, (b) normal, and (c) slow.

In Figure 4, the results of each condition produce different responses. At the chest position in the fast condition, the best measurement obtained 102 bpm, for the normal condition the results obtained are 80 bpm, while in slow condition obtained 52 bpm which is successfully measured by the sensor using a spiral configuration. The measurements of the chest position experience disrupted by body movement for normal condition. In Figure 5 also obtained a different response at the neck position. For fast, normal and slow heart rate condition, obtained 108 bpm, 72 bpm, and 56 bpm respectively. For each sensor, the position shows different results for the heart rate detected by the sensor. The response from heart rate measurements of various conditions and configurations in three positions produces different characteristics data so that it can be analyzed and monitored.

The data from the heart rate measurement sensors can be analyzed by calculating their sensitivity and resolution. The sensitivity of the sensor can be obtained by dividing the output voltage difference and time measurement. The sensitivity equation of the heart rate sensor is expressed in equation (1).

$$S = \frac{V_{\text{max}} - V_{\text{min}}}{t_{\text{max}} - t_{\text{min}}}$$

(1)

with variable $V_{\text{max}}$ represents the maximum voltage, $V_{\text{min}}$ for the minimum voltage, $t_{\text{max}}$ for the maximum time and $t_{\text{min}}$ for the minimum time.
To obtain the resolution, we can divide the value of the smallest scale, which can be read from the sensor, and sensitivity value. The resolution equation can be expressed in equation (2).

\[ R = \frac{N}{S} \]  

with \( N \) as the smallest measurable value of 0.001 Volt and \( S \) is the sensitivity value of the sensor.

Characteristics of heart rate sensors using plastic optical fibers with varying configurations and conditions on hand position are shown in Table 1. Furthermore, the sensor at the chest position shown in Table 2 and sensors at the neck position in Table 3.

**Table 1.** The measurement result of the heart rate sensor at hand.

| Condition | Straight Configuration | Sinusoidal Configuration | Spiral Configuration |
|-----------|------------------------|--------------------------|----------------------|
|           | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \)     | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \) | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \) |
| Fast      | 0.00122                | 0.81930                  | 0.00163              | 0.61281               | 0.00204               | 0.48976               |
| Normal    | 0.00123                | 0.80945                  | 0.00164              | 0.60941               | 0.00207               | 0.48107               |
| Slow      | 0.00130                | 0.75906                  | 0.00165              | 0.60677               | 0.00208               | 0.47926               |

**Table 2.** The measurement result of heart rate sensor at the chest.

| Condition | Straight Configuration | Sinusoidal Configuration | Spiral Configuration |
|-----------|------------------------|--------------------------|----------------------|
|           | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \)     | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \) | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \) |
| Fast      | 0.00097                | 1.02400                  | 0.00110              | 0.90737               | 0.00162               | 0.61440               |
| Normal    | 0.00099                | 1.00344                  | 0.00111              | 0.89469               | 0.00195               | 0.51200               |
| Slow      | 0.00120                | 0.84450                  | 0.00130              | 0.76807               | 0.00196               | 0.50983               |

**Table 3.** The measurement result of the heart rate sensor at the neck.

| Condition | Straight Configuration | Sinusoidal Configuration | Spiral Configuration |
|-----------|------------------------|--------------------------|----------------------|
|           | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \)     | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \) | \( S \text{ (V.s}^{-1}\) | \( R \text{ (s)} \) |
| Fast      | 0.00123                | 0.77394                  | 0.00194              | 0.51539               | 0.00225               | 0.44330               |
| Normal    | 0.00130                | 0.76800                  | 0.00195              | 0.51200               | 0.00227               | 0.43886               |
| Slow      | 0.00132                | 0.75638                  | 0.00202              | 0.49495               | 0.00231               | 0.43203               |

The sensors test worked to get high sensitivity values and a good resolution. The test had done from three various configurations and also both sensor and heart rate position. From the measurement result of Table 1, it is obtained that the best test is placed in the hand position with spiral configuration and in the slow heart rate. For heart rate measurement in the chest as shown in Table 2, it is known that the best resulting test is also in the spiral configuration and slow heart rate. Meanwhile, for the neck position as shown in Table 3, it is obtained that the best resulting test is in the spiral with a slow heart rate. From this result, we show that the more bending applied for configuration, the more output voltage range that we get so that sensor sensitivity will be higher and the resolution values are better.

The result of heart rate sensor measurement from the difference of the three position shows that the best sensitivity value and its resolution are in the neck position with a spiral configuration and also slow heart rate. Values of the sensitivity and its resolution from the measurement show that the best values are 0.00231 V.s-1 dan 0.43203 s respectively. For the heart rate sensor test, measurements are being done by using tools as a comparison, which is SpO2. These tools use some heart rate in beats per minute (bpm). According to the World Health Organization (WHO), the normal heart rate of the adult patient obtained around 60-100 bpm. The result of the test using an optical fiber sensor, number of heart rate detected by the sensor is 72 pm in normal condition. By using the comparison tools, it is found that the obtained value is compatible with about 72 bpm in the same condition [14].
values are appropriately fit from previous research by Suaste et al. [8] which using plethysmography signals as the heart rate sensor, where the number of heart rate obtained is 75 bpm.

4. Conclusion
Sensors have been created to detect the heart by using plastic optical fibers without jackets. Sensor testing is performed on various configuration, pairing position, and heart rate conditions. The use of macro-bending and strain methods due to heart rate, causing a loss of power in fiber optic sensors. The change in the intensity of light on the optical fiber is proportional to the output voltage, read on the computer. The best cardiac detection sensor results are obtained at the neck position with a spiral configuration under slow heart rate conditions. The sensitivity value obtained is 0.00231 V.s⁻¹, and the resolution value is 0.43203 s. This sensor has the advantages of easy fabrication, low cost, real-time measurement, high sensitivity, easy to operate, and can be monitored via computer.

Acknowledgments
This research was supported by “PDUPT-UNHAS 2018” Contract No. 1634/UN-4.21/PL.00.00/2018.

References
[1] Arifin A, Yusran, Miftahuddin, Abdullah B and Tahir D 2017 The 6th ICTAP AIP Conf. Proc. (Makassar: AIP Publisher)
[2] Zawawi A M, O’Keffe S and Lewis E 2013 Sens Rev 33 57
[3] Fajkus M, Nedoma J, Martinek R, Vasinek V, Nazeran H and Siska P A 2017 Sensors 17 1
[4] Luna P and Alvarado C 2014 11th International Conf. Electrical Eng Comput Sci Automatic Control (CCE) (Campeche: IEEE)
[5] Arifin A, Hatta A M, Muntini M S and Rubiyanto A 2014 Indian J Pure Appl Phys 52 520
[6] Thorat P V, Warulkar S and Thombre P A 2014 Int J Eng Res Rev 2 95
[7] Parola I, Arrospide E, Recart F, Illarramendi A M, Durana G, Guarrotxena N, Garcia O and Zubia J 2017 Fibers 5 1
[8] Suaste E, Hernandez D, Sanchez A S and Villarreal E 2014 Sensors 14 21523
[9] Yang X, Chen Z, Elvin M S C, Janice Y H M, Ng H S, Teo T J and Wu R 2015 IEEE Sensors J 15 757
[10] Nedoma J, Fajkus M, Martinek R and Vanisek V 2017 Opt Optoelectron 15 336
[11] Presti D, Massaroni C, Formica D, Giurazza F, Schena E, Saccomandi P, Caponero M A and Muto M 2017 Instrumentation and Measurement Technology Conf. (Turin: IEEE)
[12] Dziuda L 2015 J Biomed Opt 20 1
[13] Mallick B and Patro K A 2016 Int J Sci Eng Technol Res 5 84
[14] WHO 2011 The WHO Pulse Oximetry Training Manual (WHO Press: Switzerland)