RESEARCH ARTICLE | MAY 02 2023

Sensitivity enhancement of muscle contraction sensors at various configurations on plastic optical fiber

Arifin Arifin; Noviana Noviana; Annamaintin Kobong Lebang; Muhammad Yunus; Irfan Idris; Nurlindah Hamrun; Bidayatul Armynah

AIP Conference Proceedings 2719, 020001 (2023)
https://doi.org/10.1063/5.0133541

Sensitivity Enhancement of Muscle Contraction Sensors at Various Configurations on Plastic Optical Fiber

Arifin Arifin[1,a)], Noviana Noviana[1], Annamaintin Kobong Lebang[1], Muhammad Yunus[2], Irfan Idris[3], Nurlindah Hamrun[4] and Bidayatul Armynah[1]

[1]Department of Physics, Faculty of Mathematical and Natural Sciences, Hasanuddin University, Makassar, Indonesia
[2]Department of Physics, Faculty of Mathematical and Natural Sciences, State University of Gorontalo, Gorontalo, Indonesia
[3]Department of Physiology, Faculty of Medicine, Hasanuddin University, Makassar, Indonesia
[4]Department of Oral Biology, Faculty of Dentistry, Hasanuddin University, Makassar, Indonesia

[a)] Corresponding author: arifinpide@gmail.com

Abstract. Research about the sensitivity enhancement of muscle activity sensors at various configurations, diameters, and the number of bends using a plastic optical fiber (POF) has been conducted. Measurement process by using various configurations methods by sewn it on an elastic cloth, it affixed on biceps and triceps muscle surfaces. A Light Emitting Diode (LED) and a phototransistor connect to each end of the POF. Optical fiber sensors experience strain and pressure when the muscle is active by increasing the load and impact to the light intensity along the core of optical fiber becomes smaller. The phototransistor received the light intensity that propagates from LED into the optical fiber, and it's displayed on the computer. The best result acquired at the spiral configuration at 0 diameters using 4 bends placed on the biceps muscle mounting position with the sensitivity value of 0.072 V/N and the resolution value of 0.013 N. Sensor can be used to measure muscle contraction with low cost, higher sensitivity, better resolution, can be monitored via computer, easy to fabric and operate.

INTRODUCTION

The muscle is the most abundant tissue structure in the body that functions to support the body and protect vital organs [1]. Besides, the skeleton muscles have an essential role in moving integrated actions with bones, tendons, ligaments, joints, heat production by way of cell respiration, and disposal of glucose in the blood. The primary function of skeletal muscle is a force generator in the body [2]. Muscles are stimulated for energy transfer between nerves, which produce electrical current from the central nervous system, causing muscles to contract [1]. Muscle contractions can be detected through electromyography (EMG) by monitoring the electrical activity of contracted muscles [3]. The utilization of electronic devices as sensors has developed for the measurement of muscle contractions that can use optical fiber [4,5].

Optical fiber based on its material consists of plastic and glass optical fiber (GOF). POF is a type of optical fiber that is suitable for use as a sensor compared to GOF because it has high sensitivity, secure connectivity, high flexibility, and low cost [6-10]. The application of optical fiber in various fields, such as in the medical field, is monitoring heart rate, blood flow, and blood pressure, as well as in other fields such as monitoring groundwater, measuring temperature, voltage, current, displacement, strain, protein, vibration, etc. [8-15].

The previous study of muscle contraction sensors uses silica optical fibers to measure triceps muscle strength caused by hand movements [5]. There is also research on optical fiber sensors to identify hand postures by using silica

The 3rd International Seminar on Science and Technology 2021
AIP Conf. Proc. 2719, 020001-1–020001-7; https://doi.org/10.1063/5.0133541
Published by AIP Publishing. 978-0-7354-4519-2/$30.00

optical fibers [4]. However, the results of previous studies are difficult to apply because they use silica optical fibers that are less flexible than POF. It requires special treatment because of its small size, fragile, and high cost [10]. This research will develop a muscle contraction sensor by using POF with variations in configuration, position, diameter, and number of bending. Each sensor is then measured and analyzed to obtain the sensor's characteristics. This sensor is expected to have the advantages of low cost, easy to fabric, and simplicity in the measurement system, and can be connected to a computer.

EXPERIMENTAL SET-UP

In this research, a muscle contraction sensor is made by using POF with variations in load, configuration, position, diameter, and the number of bending. The main materials and tools of the sensor consist of LEDs, POF, and phototransistors. The type of LED used is IF-E91A, while the IF-D92 type is used as a phototransistor. The material of the POF is polymethyl methacrylate (PMMA) with the layer consisting of jacket, cladding, and core. Whereas the numerical aperture (NA) value of 0.5.

The research's main process is the manufacture and measuring of muscle contraction sensors using POF without the jacket's layer. Each sensor is sewn on elastic clothing and affixed both on the biceps and triceps muscle surfaces alternately. The LED and phototransistor are connected at each end of the optical fiber. The muscle will be active and contract cause of increasing the load. The increasing load leads the strain to the POF which is mounted on the biceps and triceps muscle surface. The strain on the sensor impacts the LED's light that propagates in the POF distracted. The intensity of light received by a phototransistor as the detector. The differential amplifier circuit amplifies the output from the phototransistor. While the output from a differential amplifier in the analog signal and next converted by the microcontroller. It aims to convert analog signals into digital signals and then the output in form of the output voltage displayed on the computer. Sensor's scheme for muscle contraction based on POF, as shown in Fig. 1.

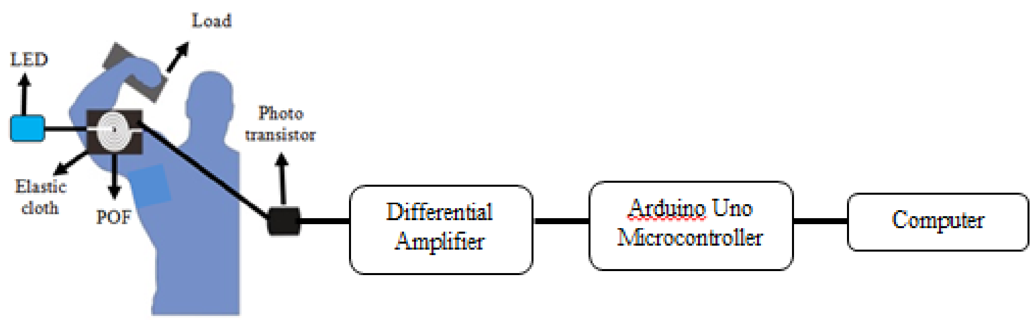
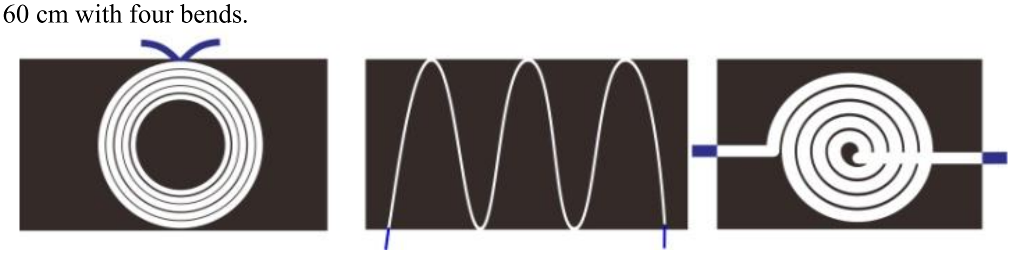


FIGURE 1. The muscle contraction sensor's scheme using POF

The sensor's manufacture and testing were carried out with a variety of configurations, positions, number of bends, and diameters. The sensor has been made in three configurations, namely loop, sinusoidal, and spiral shown in Fig. 2. In the sinusoidal configuration, the amplitude of POF was set at 3 cm, and the length of 60 cm. In the loop configuration, the POF's length was used of 60 cm with four loops. While the spiral configuration uses the POF's lengths of 60 cm with four bends.



(a) (b) (c)

FIGURE 2. The design of muscle contraction sensor with (a) loop; (b) sinusoidal; and (c) spiral configuration

Furthermore, the muscle contraction sensor is sewed on an elastic cloth and mounted on the biceps and triceps muscle surfaces. The measurements process using loads within a range from 0 kg to 5 kg and an increment of 0.5 kg for each sensor were made. The force that works on the muscle is proportional to the load that had been given multiplied by gravitational acceleration. In this study, either biceps or triceps muscle was tested with three configurations i.e., spiral, loop, and sinusoidal. For the variation of diameter has been used spiral configurations with 1 cm, 0.5 cm, and 0 cm. While for the number of bends variation using two, three, and four bends.

RESULTS AND DISCUSSION

Measurements were made using various configurations, bends, and loads. The sensor's testing process was done with a loop, sinusoidal, and spiral configuration. Each configuration was mounted and tested on the biceps and triceps muscle position. The results as the voltage are read and displayed on the computer. The increase of load is proportional to the increase of force and implicates the strain along in the POF. Each measurement is resulting in different responses. The response of force on the sensor at various configurations on the biceps and triceps muscle positions is shown in Fig. 3.

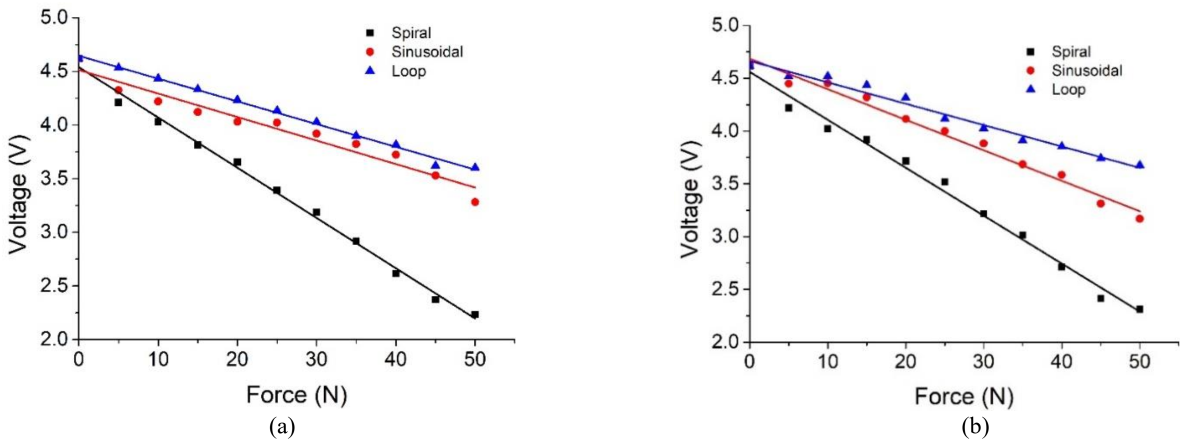


FIGURE 3. Graphics of the output to force at various configurations on (a) biceps; and (b) triceps muscle position

The result of muscle contraction sensor variety of configuration and load are shown in figure 3. The muscle contraction sensor on the biceps and triceps muscle surface was successfully measured. Furthermore, the biceps muscle is often called the upper arm, and the triceps muscle is called the lower arm. The difference in sensor's placement aims to get the best position in measuring the load to the output voltage of the sensor. The biceps muscle has more muscle mass and the pressure has greater load when compared to the triceps muscle.

In this section, each position uses the same sensor. The sensors that have been made consist of loop, sinusoidal and spiral configurations. The loop configuration uses 4 bends with a constant diameter of 3 cm. The sinusoidal configuration uses a constant amplitude of 3 cm and a period distance of 3 cm. While the spiral configuration uses an inner diameter of 3 cm with 4 bends. Variety of load and configuration also results in a different response to the sensor's output. The more applied number of bending due to the configurations and the increasing of force impacting the change of strain and pressure on the sensor. This change causes the light's intensity along the sensor being distracted and causes power losses. The decreasing of the sensor's power received by the phototransistor proportional with the sensor's output, then displayed on the computer.

The response of the muscle contraction sensor is analyzed by looking for the sensor's characteristics. Sensor's characteristics consist of resolution and sensitivity value. The sensitivity value is obtained by dividing the voltage difference toward the difference in force. The sensitivity can be expressed in Equation (1) and using V/N units [7,9,14]:

$$S = \frac{V_{max} - V_{min}}{F_{max} - F_{min}} \qquad (1)$$

where V_{max} = the maximum voltage (V)
V_{min} = the minimum voltage (V)
F_{max} = the maximum force on the muscle (N)
F_{min} = the minimum voltage (N)

Furthermore, a resolution is the sensor's ability to record the smallest change during the measurement process. The resolution value is stated in Equation 2. The resolution value state in Equation 2 [7,9,13-15]:

$$R = \frac{N}{S} \tag{2}$$

with R = the sensor's resolution (N)
N = the smallest scale of the microcontroller (V)
S = the sensitivity value of the muscle contraction sensor (V/N)

The variation in the output resulting different sensor characteristic. The increase of load causes the muscle to contract and affects the change in the POF [9, 13-15]. The change in the sensor resulting in the difference of characteristic value for each sensor. Characteristics results of muscle contraction sensors at the various configuration on biceps and triceps positions are shown in Table 1.

TABLE 1. Characteristic result of muscle contraction sensors at various configurations.

Positions	Configurations	Sensitivity (V/N)	Resolution (N)
Biceps Muscle	Loop	0.020	0.049
	Sinusoidal	0.026	0.037
	Spiral	0.047	0.020
Triceps Muscle	Loop	0.018	0.053
	Sinusoidal	0.028	0.034
	Spiral	0.046	0.021

In Table 1, the sensor's characteristics result in biceps and triceps muscle position. Characteristic results are obtained from the operation of mathematical equations in equations (1) and equation (2). The best characteristic results are indicated by the highest sensitivity value and the lowest resolution value for each variation [16]. In this section, the characteristic results are grouped by position variation. In this section, the characteristic results are grouped by position variation. The characteristic values of each configuration of the biceps muscle position are compared with each configuration in the triceps muscle position. The best results were obtained in the spiral configuration on the biceps muscle mounting position, with the sensitivity value of 0.047 V/N and a resolution value obtained of 0.020 N. Biceps muscle position and spiral configuration become the best measurement because the more bending applied on this configuration than the loop and sinusoidal configuration, likewise biceps muscle position cause more strain on optical fiber than triceps muscle surface. The sensor's characteristic result was compared and shown in Fig. 4.

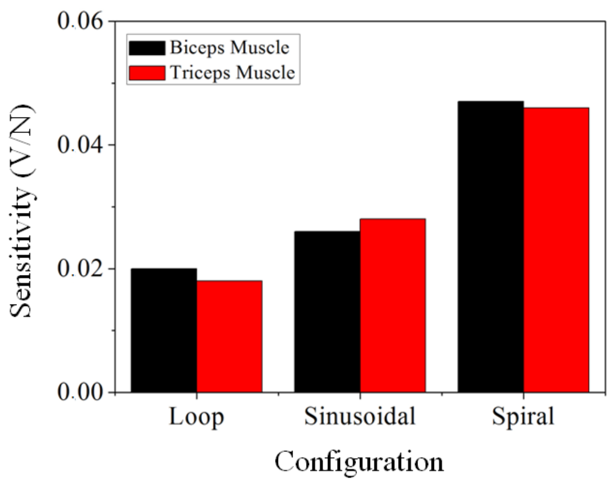


FIGURE 4. Graph of sensitivity values comparison on the biceps and triceps muscle with a variety of configurations

Fig.4 containing the graph's comparison with a variety of configurations, both the biceps and triceps muscle position. The highest value is shown in the spiral configuration on the biceps muscle position. The research continued on the best position and using the best configuration from the previous section. Measurements were made in the biceps muscle position using a spiral configuration of 4 bends with various diameters. Variations in the inner diameter of the sensor consist of 0 cm, 0.5 cm, and 1 cm, while the distance between one bend and another bend is made 0 cm. This variation is used to observe the effect of the diameter value on the output voltage of the sensor and read on the computer. The response of diameter and force variation using spiral configuration on the biceps muscle position can be seen in Fig. 5.

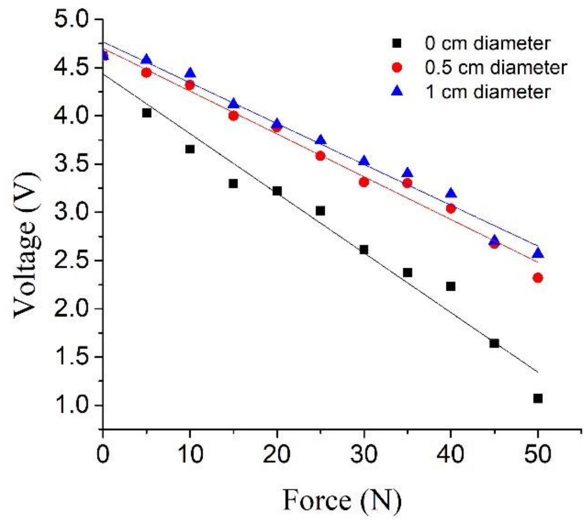


FIGURE 5. Graph of the voltage due to the addition of forces with various diameter on the biceps muscle position

Fig. 5 shows the result of the diameter variation and resulting in different responses. In Fig. 5, the best measurement was obtained at 0 cm. The smaller the sensor diameter and the increase in force impact in strain and pressure due to POF. The strain and pressure result in change light propagation along the POF and cause power losses. This change causes decrease of the output voltage. The last research will use the best variation in the previous section by providing additional variations in the form of bends. The variation number of bends consist of 2, 3 and 4 bends with constant inside diameter of 0 cm and the distance between one bend to another bend is made 0 cm. The response of number of bends and force variation using spiral configuration on the biceps muscle position can be seen in Fig. 6.

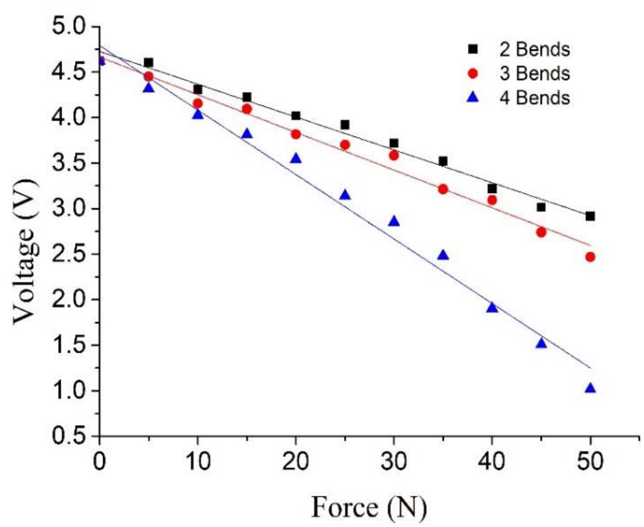


FIGURE 6. Graph of the voltage due to the addition of forces with various numbers of bends on the biceps muscle position

Fig. 6 shows the difference in sensor's output voltage depending on a number of bends. Each sensor using 0 cm diameter with variation of numbers 2, 3, and 4 bends. The addition of bends, causes strain and loss of power increase, so that output voltage decreases. The best results in the number of bends variation obtained at the number of 4 bends. The characteristics of muscle contraction sensor using plastic optical fiber with varying diameters and the number of bends are shown in Table 2.

TABLE 2. Sensor's characteristics result with variety of diameters, and numbers of bends on the biceps muscle position.

Variations		Sensitivity (V/N)	Resolution (N)
Diameter	0 cm	0.071	0.014
	0.5 cm	0.046	0.021
	1 cm	0.041	0.024
Bend	2	0.034	0.029
	3	0.043	0.023
	4	0.072	0.013

Table 2 shows the characteristics of the muscle contraction sensor with a variety of diameters and the numbers of bends. Each sensor using a spiral configuration on the biceps muscle position. For diameter variation, the best measurement and testing results were obtained with the sensitivity value of 0.071 V/N, likewise, the resolution value of 0.014 N. Whereas, for a variety of numbers of bend gets the best outcome using 4 bends. Respectively, the value of sensitivity and resolution were obtained of 0.072 V/N and 0.013 N.

The sensor testing and measuring aim to get better resolution and higher sensitivity. The measurement result of the muscle contraction sensor produces a different response. The measuring process begins with a variety of positions on biceps and triceps using three configurations i.e., loop, sinusoidal and spiral. From this section resulting sensor's characteristics in table 1 and obtained the best position on biceps muscle with spiral configuration. Furthermore, the research continued by using the best previous position and configuration with an addition a variety of diameter i.e., 1 cm, 0.5 cm, and 0 cm. The best result for a variety of sensor's diameter obtained at 0 cm. The last process on this research using the best previous diameter of 0 cm with an additional variation in number of bending which consist of 2, 3, and 4 bends. All section in this research obtained different output voltage and sensor's characteristics.

Variations in position, diameter, force, configuration and number of bends result in micro and macro bending on the sensor. The sensor is sewn on the elastic fabric. The smaller the sensor diameter and the increase in force impact in strain and pressure due to POF. The strain and pressure resulting in change light propagation along with the POF cause power losses and the output voltage decreases. The best result obtained the sensitivity and resolution value are on the biceps positioning using spiral configuration with diameter of 0 cm and 4 bends. Respectively, the sensitivity and resolution values were obtained of 0.072 V/N and 0.013 N. The research was consistent with the previous studies conducted by E. Fujiwara et al., which states that the higher the force exerted on the hand, the light intensity and the output voltage decrease [5]. The POF can be used as a muscle contraction sensor with simple process, easy fabrication, higher sensitivity, low cost, and better resolution.

CONCLUSION

In this paper, the sensor can be used to detect and measure muscle contraction based on POF. Sensor testing and measurement processes vary in configuration, position, force, diameter, and bends number. The increase of force and the more bending applied to the sensor causes a change in strain and pressure along with POF. This change is due to the intensity of light disturbed, and impacts the sensor's output voltage become smaller. The change of force for each variation was inversely proportional to the sensor's output voltage. The best measurement result was obtained at the spiral configuration with 0 diameters using four bends on the biceps muscle mounting position with the value of sensitivity and resolution, respectively 0.072 V/N and 0.013 N. In summary, the sensor has the advantages that can be used to measure muscle contraction based on POF with low cost, easy to operate, easy fabrication, higher sensitivity, and can be connected to the computer.

ACKNOWLEDGMENTS

This research was supported by "PD-UNHAS 2021" Contract No. 752/UN-4.22/PT.01.03/2021.

REFERENCES

[1] I. I O, *Int. Res. J. Med. Med. Sci.* **06**, 151–155 (2015).
[2] S. Đorđević, S. Tomažič, M. Narici, R. Pišot, and A. Meglič, *Sensors (Switzerland)* **14**, 17848–17863 (2014).
[3] D. Gamet, and O. Fokapu, "Biomaterials and biomedical engineering", (2008).
[4] E. Fujiwara, Y.T. Wu, M.F.M. Santos, E.A. Schenkel, and C.K. Suzuki, *IEEE Sens. J.* **17**, 951–958 (2017).
[5] E. Fujiwara and C.K. Suzuki, *J. Sensors* **2018**, (2018).
[6] M.H. Reddy, *J. Basic Appl. Eng. Res.* **1**, 86–89 (2014).
[7] A. Arifin, A.M. Hatta, M.S. Muntini, and A. Rubiyanto, *Indian J. Pure Appl. Phys.* **52**, 520–524 (2014).
[8] M.A. Zawawi, S. O'Keffe, and E. Lewis, *Sens. Rev.* **33**, 57–67 (2013).
[9] A. Arifin, Yusran, Miftahuddin, B. Abdullah, and D. Tahir, *AIP Conf. Proc.* **1801**, (2017).
[10] P.V Thorat, S. Warulkar, and P.A Thombre, *Int. J. Eng. Res. Rev.* **2**, 95–105 (2014).
[11] G. Rajan, "Optical fiber sensors: Advanced Techniques & Applications", CRC Press, London (2015).
[12] E. Schena, D. Tosi, P. Saccomandi, E. Lewis, and T. Kim, *Sensors (Switzerland)* **16**, 1–20 (2016).
[13] A. Arifin, A.K. Lebang, M. Yunus, S. Dewang, I. Idris, and D. Tahir, *J. Phys. Conf. Ser.* **1170**, (2019).
[14] A. Arifin, A. Samsu, M. Yunus, B. Abdullah, and D. Tahir, *J. Phys. Conf. Ser.* **1341**, (2019).
[15] Anisfaizurrahmah, A. Arifin, and B. Abdullah, *J. Phys. Conf. Ser.* **1341**, (2019).
[16] A.K. Lebang, A. Arifin, and B. Abdullah, *Indonesian Phys. Rev.* **4**, 166–180 (2021).