Conference Paper

Optimization of Bending Angle of Fiber Optic Sensor for Non-Invasive Blood Glucose Measurement

Ikhsan and Muldarisnur

Physics Department, faculty of mathematics and Natural Sciences, Andalas University, Padang, West Sumatera, 25163, Indonesia

Corresponding Author:
Muldarisnur
muldarisnur@sci.unand.ac.id

Received: 19 February 2019
Accepted: 5 March 2019
Published: 16 April 2019

Publishing services provided by Knowledge E

Abstract

The angle of fiber optic bending has been optimized to obtain the highest sensitivity and accuracy of blood glucose level sensor. The bending angle was varied between 0° (straight sensor) and 180° (u-shaped sensor) with a step of 30°. The fiber optic was used to guide light from red diode laser source (λ=650 nm) to a photodiode detector. Interactions of evanescent wave and glucose molecules in urine were enhanced by partial removing of fiber optic cladding. The length of fiber optic cladding removal was varied between 1 – 5 cm with a step of 1 cm. The difference in evanescent wave penetration depth as bending angle and cladding removal influences the sensitivity and the accuracy of the designed sensor. The highest sensitivity of 0,37 mV/(mg/dL) was obtained for sensor bending angle of 180° and the length of cladding removal of 3 cm. The sensitivity increases with the fiber optic bending angle. The designed sensors show measurement accuracy well above 90%. Clarke error grid analysis indicates that all of the measured data lie within the area of small error meaning that the developed blood glucose sensor is accurate and reliable.

Keywords: blood glucose sensor, bending angle, evanescent wave, sensitivity, accuracy

1. Introduction

Diabetes is a metabolic disorder where pancreatic gland cannot produce any or enough insuline or body cannot use the produced insuline effectively [1]. The number of people with diabetes is very high and tend to increases very rapidly. In 2017, more than 425 million adults lives with diabetes where 12 million are Indonesian [2]. This number puts Indonesia in the sixth place globally behind China, India, USA, Brazil and Mexico. Diabetic patients are susceptible to infection and complication that in extreme cases may cause death. About 4 million people die every year due to diabetes and its complications.

Diabetes cannot be cured completely. The best one can do is controlling sugar blood level within a normal range to avoid complications [3]. Therefore, regular monitoring that is a few times in a day is a must for patients. Blood sugar level measurement is usually based on reaction of blood sample with a specific enzyme. This method is inconvenient and relatively unsafe because obtaining blood sample by finger pricking may lead to infection because of insuline deficiency. Therefore, non-invasive means for blood glucose measurement is highly demanded.

Non-invasive measurement can be carried out using other body fluids like urine, saliva, sweat, and tears [4]. Compared to other fluids, urine is preferred because it is easy to collect and its glucose content correlates well with that of blood sample. Measurement of blood glucose level using urine sample was initially based on color change. Color of urine after reaction with benedict solution and heat treatment changes depend on sugar level. Color based estimation is not so accurate, therefore measurement based on light attenuation after passing through urine sample is used often. Infrared and Raman spectroscopies suffer from strong water molecule absorption or long measurement time [5]. Evanescent wave based fiber optic sensor offers several advantages for example high accuracy and sensitivity.

The sensitivity of evanescent wave sensor depends on bending radius and the length of cladding stripping [6]. The authors found that u-turn (bend) fiber optic is more sensitive and accurate than the straight one even though there is no detailed explanation. In this work we report the dependency of sensitivity and accuracy on bending angle of fiber optic sensor. Bending affects penetration depth of evanescent wave into urine sample, hence influences the performance of fiber optic.

2. Materials and Methods

2.1. Material preparation

The developed glucose sensor consists of a fiber optic, a photodiode, a red laser diode (λ=650 nm), Arduino UNO microcontroller, and a LCD. The fiber optic is used as sensing and light guiding medium from the laser source to be detected by the photodiode. Output voltage of the photodiode is converted to digital data by the Arduino UNO microcontroller and then displayed on the LCD panel. To enhance fiber optic sensor sensitivity, the interaction of evanescent wave in fiber optic and glucose molecule in urine is enhanced by partial removing of fiber optic cladding. The length of cladding removal was varied between 1 - 5 cm with a step of 1 cm. Removal of fiber optic cladding was carried out using following procedure: (1) coating removal with a cutter, (2) cladding removal with a smooth sandpaper, (3) polishing with acetone, and (4) drying with soft tissue.

2.2. Urine sample preparation

Urine samples from diabetic patients were obtained from Dr. Reksodiwiryo Hospital, Padang. Prior to measurement, urine samples were reacted with benedict solution with a volume ratio of 1:1 [7]. Urine samples were then heated for 30 seconds using a bunsen burner until color change was observed. The data of glucose level of diabetic patients measured in the hospital laboratory were used as reference values.

2.3. Characterization of fiber optic sensors

Fiber optic sensors were characterized based on the change in output voltage as a function of glucose level. The bending angle of fiber optic was varied from 0° to 180° with a step of 30°. The radius of optical fiber sensors were kept constant at 5 cm, while the length of cladding removal was varied. The sketch of fiber optic bending angle is shown in Fig. 1.

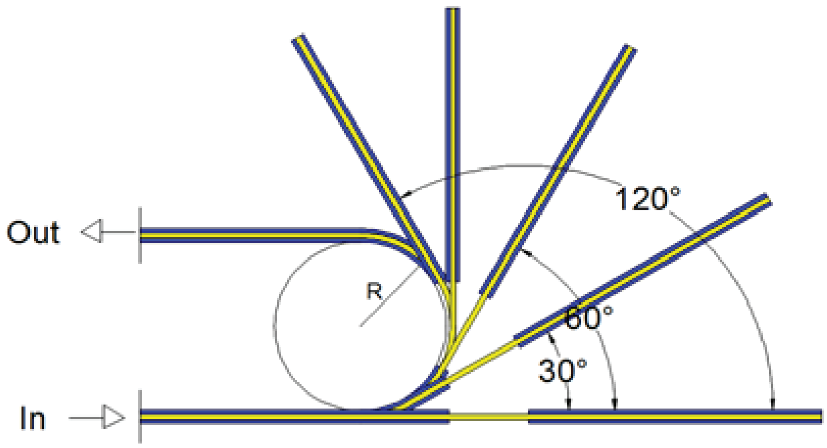

Figure 1: The sketch of fiber optic sensor of varying bending angle.

2.4. Measurement of blood glucose

Transfer function of fiber optic sensor for each bending and cladding removal was obtained from the correlation of photodiode output voltage and glucose concentration. The transfer function is in the form of a linier equation where the output voltage decrease with increasing glucose levels. It was inserted into Arduino UNO control program and used to convert measured photodiode output voltage from urine samples into glucose level that will then be displayed on LCD panel. After each measurement, sensing area of the fiber optic sensor is cleaned using soft wet tissue to remove the remaining specimens. Accuracy of the fiber optic sensor was determined by comparing the measured glucose level using the fiber optic sensors with the reference data obtained from hospital laboratory. Measurement set up of blood glucose is shown in Fig. 2.

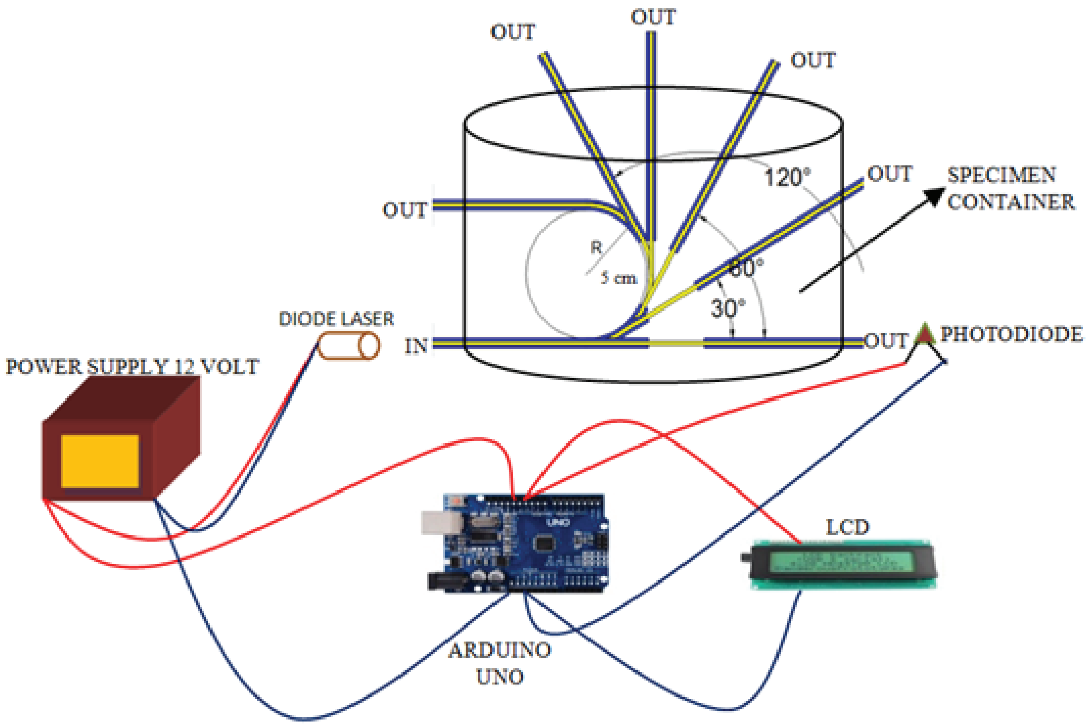

Figure 2: Experimental set up for measurement of blood glucose.

3. Results and Discussion

3.1. Transfer function of fiber optic sensor

Characteristic of sensor output versus glucose concentration is shown in Fig. 3. The graphs show that photodiode output voltage decreases linearly with glucose concentration. The output voltage also decreases with bending angle of fiber optic and the length of cladding removal. The slope of photodiode voltage decrease depends on the length of cladding removal and fiber optic bending angle.

The decrease of photodiode voltage can be explained as a result of stronger interaction of evanescent wave of fiber optic with glucose molecules in urine when glucose

DOI 10.18502/keg.v1i2.4440

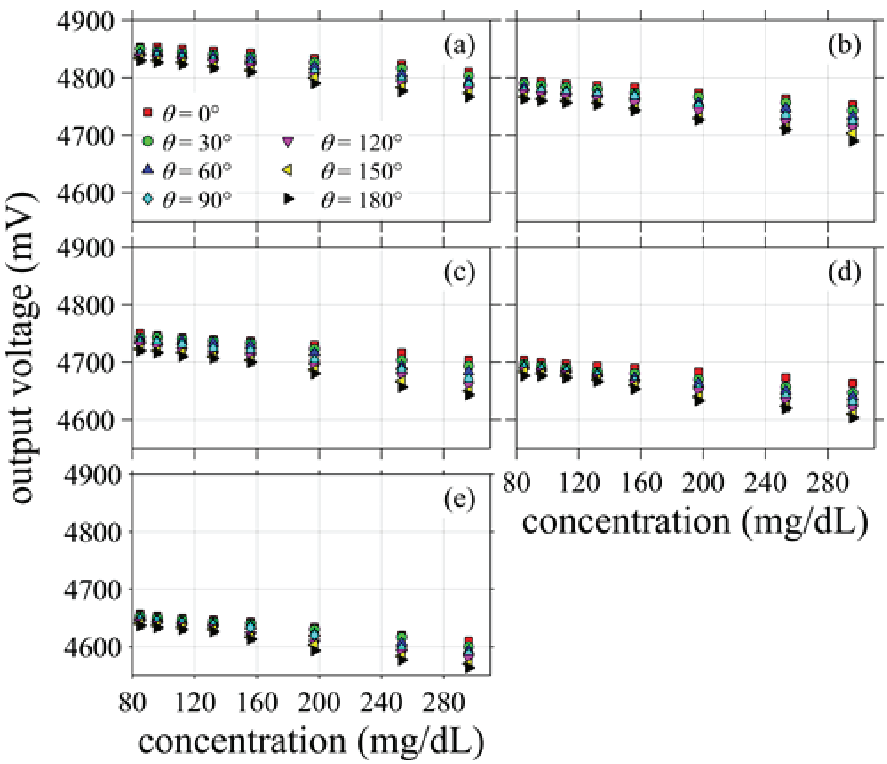

Figure 3: Photodiode output voltage versus glucose concentration for various length of cladding removal, (a) 1 cm, (b) 2 cm, (c) 3 cm, (d) 4 cm, and (e) 5 cm.

concentration increases. Stronger interaction leads to a higher attenuation of guided light in the fiber optic manifested by lowering of photodiode output voltage. The absorption and scattering of evanescent waves are proportional to glucose concentration due to an increase in the penetration depth evanescent wave. The decrease of photodiode output voltage with the length of cladding removal is caused by longer interaction between evanescent wave and glucose molecules.

3.2. Sensitivity of fiber optic sensor

Sensitivity of the fiber optic sensors is obtained from the slope of photodiode output voltage versus glucose concentration. Fig. 4 shows linear increase of the sensitivity of glucose level sensor as a function of fiber optic bending angle for different cladding removal length. It is also visible that the highest slope of the sensitivity increase is obtained for cladding removal length of 4 cm.

The increase of sensitivity with bending angle corresponds to the increase of evanescent wave penetration depth. Larger penetration depth means a higher interactions between evanescent wave and glucose molecules in urine. Stronger interaction causes higher attenuation of guided light in fiber optic core that can be detected by photodiode.

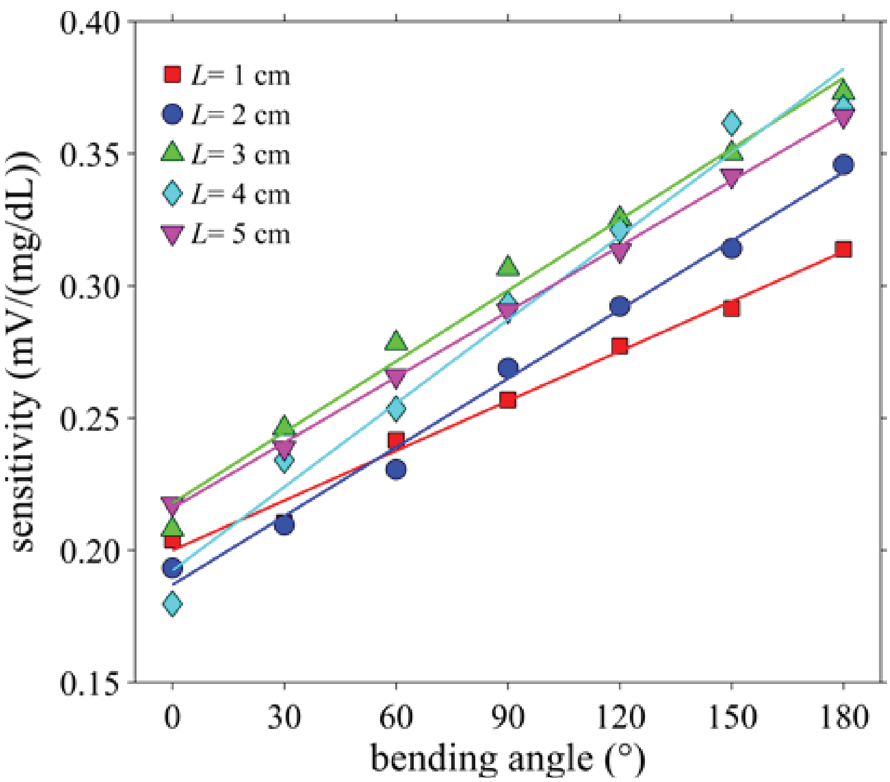

Figure 4: Dependence of sensitivity on fiber optic bending angle for different length of cladding removal.

The fiber optic sensor with 4 cm cladding removal shows the strongest dependency on bending angle. This is likely due to the balance of interaction and radiation losses. When cladding removal is too long, loss is so severe that sensitivity declines.

3.3. Accuracy of sensor analysis

Fig. 5 shows the accuracy of fiber optic sensor as a function of bending angle for different length of cladding removal. The accuracy of all developed fiber optic sensors is higher than 90%. The accuracy slightly (about 1-2%) increases with bending angle. The highest accuracy of 98.57% is obtained for sensor with cladding removal of 1 cm. The lowest average accuracy of 91.60% is obtained for sensor with cladding removal of 3 cm.

High accuracy can be explained as a result of strong interaction of evanescent wave and glucose molecules in urine. Slight dependency of accuracy on bending angle can also be explained due to an increase in the penetration depth of evanescent wave.

DOI 10.18502/keg.v1i2.4440

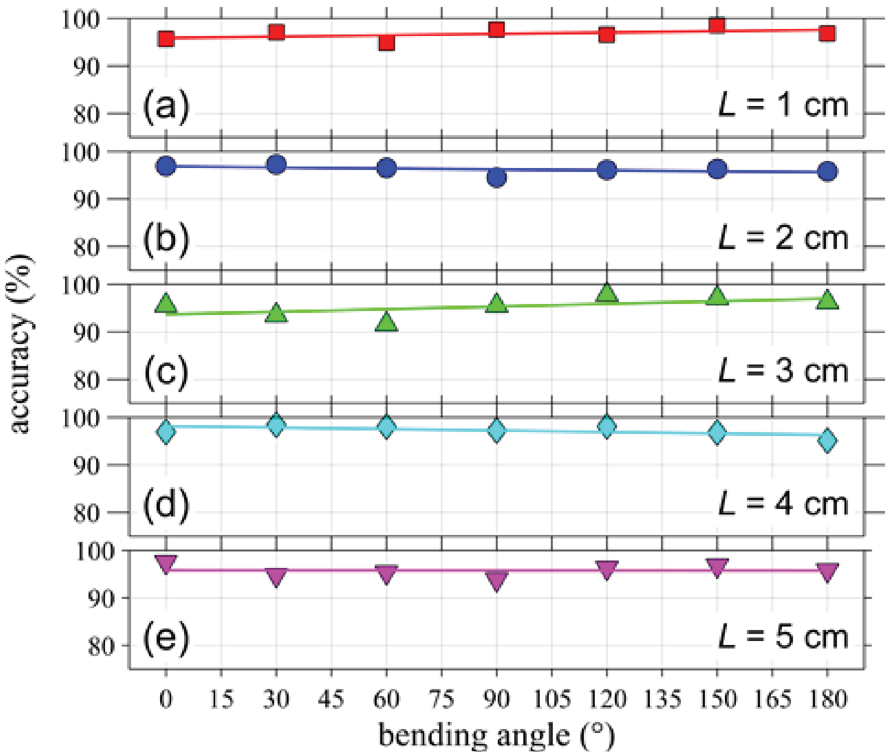

Figure 5: Dependency of fiber sensor accuracy with bending bangle for different length of cladding removal, (a) 1 cm, (b) 2 cm, (c) 3 cm, (d) 4 cm, and (e) 5 cm.

3.4. Clark error grid analysis

The accuracy of fiber optic sensor to measure glucose level is shown as Clark Error Grid plot in Fig. 6. The plot displays correlation of measured glucose level from fiber optic sensor and glucose level from standard laboratory test. The plot is divided into several areas A, B, C, D and E which gives information about the reliability of measurement data. Accurate measurement is obtained if most of the data lie in region A and no data in region C, D, and E.

The glucose level data measured using developed fiber optic sensors lie almost 100% in area A, and only two data points are in area B. This means that fiber optic sensor is accurate and measured data are reliable to be used by diabetic patients.

4. Conclusions

We have shown that the sensitivity of fiber optic sensor for glucose level measurement is very accurate and sensitive. The sensitivity of fiber optic sensor increases linearly on bending angle and the length of cladding removal. Fiber optic sensor with large bending angle is suggested to obtain high measurement sensitivity and accuracy. The highest

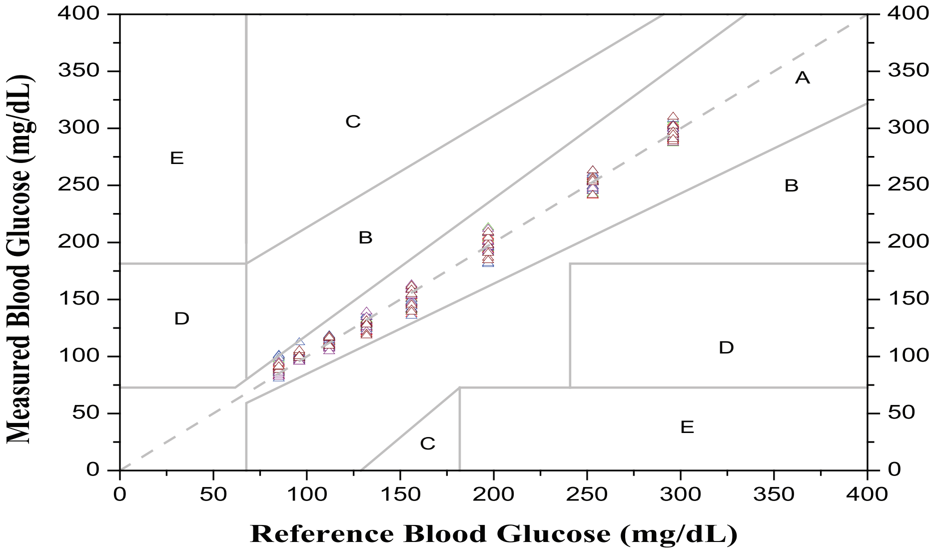

Figure 6: Clark Error Grid analysis for all fiber optic sensors.

sensitivity of fiber optic sensor is 0,37 mV/(mg/dL). The accuracy of all developed fiber optic sensors is above 91%. Clarke error grid analysis indicates that fiber optic sensor fulfill the requirement to be used by diabetic patients.

Acknowledgments

This research was supported by the Grant from the Faculty of Mathematics and Natural Sciences of Andalas University with contract no.35/UN.16.03.D/PP/FMIPA/2017.

References

[1] America Diabetes Association, 2012, Diabetes Care, Vol.35, No.1.

[2] International Diabetes Federation, 2017,IDF Diabetes Atlas, Edisi 8, Brussel,Belgium.

[3] Kudo, S.,Mapawanang, A.K.,Sangadji, A.S., Mapawanang, F., Sondakh, N.L., Sinsuw, E.M., Syahputra, F., Turangan, C.B., Tumurang, M.N., Sultoni, S., 2016, Effects of Gedi Leaves Stew on The Decrease of Blood Sugar Levels in Patients with Diabetes Mellitus.International Journal of Health Medicine and Current Research, Vol.1, No.1, hal 40-45.

[4] Sorvoja, H. dan Risto, M., 2006, Noninvasive Blood Pressure Measurement Methods, Optoelectronics and Measurement Techniques Laboratory, Vol.27, hal. 239-264.

[5] Yadav, J., Rani, A., Singh, V., dan Murari, B. M., 2015, Prospects and Limitations of Non-invasive Blood Glucose monitoring using Near-infrared Spectroscopy, Biomedical Signal Processing and Control, vol. 18, p. 214.

[6] In Indonesia: Fridayanti N., Muldarisnur,M., Harmadi, H., 2018, Analysis of the Effect of Macrobending Optical Fiber on Glucose Sensors with the Evanescent Method, Jurnal Ilmu Fisika, vol.10 No.1, p.46-52.

[7] King, S., 2008, Urinalysis, Davis Company, Philadelphia.