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Development of Natural Hydrogel Optical Fibers for Continuous Glucose Monitoring

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Abstract:*Continuous glucose monitoring is crucial to enable tight control of blood glucose concentrations in diabetes patients and intensive care cases. One of the methods employed for glucose detection is using fiber optics. This research aims to measure glucose levels with varying concentrations using fiber optics. Glucose solutions were varied into 6 different concentrations, including 5%, 10%, 15%, 20%, 25%, and 30%. The study's results indicate that as the concentration of the solution increases, the output intensity decreases. Higher sugar concentrations result in greater absorption of incident light, leading to a decrease in light intensity. Changes in the refractive index will alter the effective refractive index and reduce the output intensity. The study can serve as a valuable reference for future research endeavors aimed at further developing natural hydrogel optical fibers.*

Keywords:*Glucose Concentration, Optical Fiber, Hydrogel, Natural*

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I. INTRODUCTION

Currently, measuring glucose levels, whether in humans, animals, or plants, is a highly important activity aimed at improving a healthier lifestyle (Alexander Fleming et al., 2020). Glucose is a type of simple carbohydrate or monosaccharide compound. Glucose serves as an energy source for brain cells, nerve cells, and red blood cells. Human blood contains glucose at a constant concentration, which is typically 70-100 mg/dL (Satish et al., 2016). In cases of low blood sugar, referred to as hypoglycemia, the body may lack an energy source, potentially leading to fatal consequences. Conversely, high blood sugar, known as hyperglycemia, can lead to diabetes (Rusdi, 2020)

Diabetes is a rapidly growing disease, making it a significant global health issue. Regular monitoring of blood glucose concentrations is crucial to prevent serious diabetes complications (Myhre et al., 2018). The normal range of blood glucose concentration in people is between 80 and 120 mg/dL (4.4 to 6.6 mM) (Sherwin et al., 1976). Anyone with a fasting level above 126 mg/dL or 200 mg/dL two hours after a meal is considered hyperglycemic, while those with levels below 54 mg/dL are considered hypoglycemic.

The most commonly used conventional sensor for glucose control is the glucometer (Vashist et al., 2011). Commercial glucose monitoring systems require a lancet to puncture the skin and collect a blood sample, which is then applied to a test strip for analysis (Kondepati and Heise, 2007). However, fingerstick tests may be less accurate compared to venous blood samples; for instance, postprandial glucose concentrations in capillary blood can be 35% higher than in venous blood (Yang et al., 2012). Therefore, noninvasive or minimally invasive systems would eliminate the discomfort and pain associated with blood glucose monitoring. To address these clinical needs, implantable electrochemical glucose sensors have been developed for short-term continuous glucose monitoring. However, these sensors have several limitations: (i) instability in vivo due to enzymatic reactions causing signal drift, (ii) oxygen-dependent activity, (iii) inaccuracy in low glucose concentrations, and (iv) unsuitability for long-term continuous glucose monitoring (Heo et al., 2011).

One method used for glucose detection is through fiber optics. Fiber optics are waveguide devices made of dielectric media that generally function as a medium for transmitting light waves in cylindrical form. Fiber optics can be employed as sensors for measuring solution concentrations, breath sensors in the medical field (Lau et al., 2013), and for blood glucose measurement (Myhre et al., 2018; Whiting et al., 2011). Presently, minimally invasive glucose measurement with contact lenses has been introduced to assess glucose concentration in tears. However, the glucose concentration in tears may not accurately correlate with blood glucose levels (Elsherif et al., 2019). Fiber optic probes as minimally invasive sensors have been developed for

in vivo glucose monitoring to provide continuous quantitative analysis (Yetisen et al., 2017). Surface plasmon resonance probes have emerged as the most promising for use. Nevertheless, they still undergo complex fabrication processes and convoluted reading procedures (Cao et al., 2018). Additionally, interferometric fiber probes have been developed for in vivo glucose sensing. Reading these probes is intricate, and the output signals are processed to detect volumetric responses inherent at the fiber tip. Moreover, silica fiber probes are not biologically compatible for in vivo implementation as they elicit immune responses leading to inflammation and patient discomfort.

Hydrogel fibers have been introduced as a promising technology for in vivo glucose sensing due to their biocompatibility and their ability to incorporate functional groups (Choi et al., 2013). Functionalizing hydrogel fibers with glucose recognition motifs, such as phenylboronic acid (PBA) derivatives, modulates the optical properties of the fibers through glucose-boron complexation. For example, hydrogel-based fiber probes with fluorescence have been reported for quantitative glucose measurements, where the glucose recognition motif, diboronate acid, and fluorescent dye (anthracene acid) are incorporated (Heo et al., 2011). On the other hand, glucose monitoring using fiber optics is often hampered by a lack of sensitivity due to variations in optical measurements. Isolating changes caused by glucose alone and using them to predict glucose concentrations presents its own challenges. Solution concentration is the ratio of the solute to the solvent. The mass of the solute affects the density of the solution, whereby a greater mass of solute results in a higher density, assuming a constant volume. This study aims to measure glucose levels with different concentrations using fiber optics.

II. EXPERIMENTAL PROCEDURE

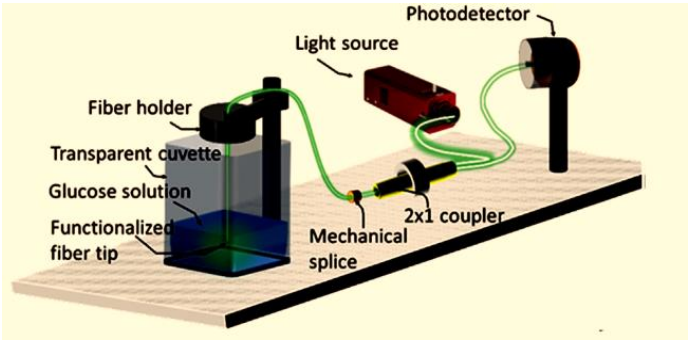
The experimental activity conducted in the Physics laboratory at Universitas Negeri Yogyakarta. The equipment used in this research includes a power supply, intensity meter, magnetic stirrer, beaker, hot plate, and a scale. Meanwhile, the materials used are glucose and distilled water. The OMRON S8FS-C power supply and OMRON E3X-HD11 are shown in Figure 1.

Figure 1. The experimental equipment (a) OMRON S8FS-C; (b) OMRON E3X-HD11

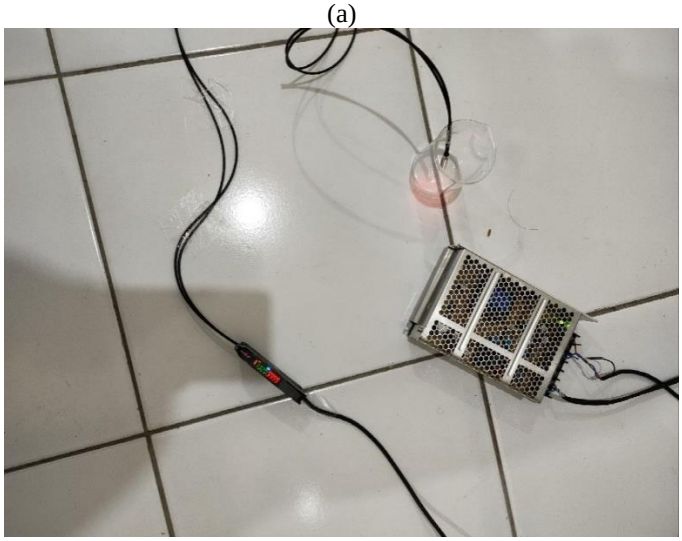
(a) **(b)**

The steps performed in this research begin with preparing glucose solutions with various concentrations, comprising 5%, 10%, 15%, 20%, 25%, and 30%. To make a 5% glucose solution, 5 grams of glucose are required in 100 mL of distilled water (aquades). Here are the detailed steps: (1) weigh 5 grams of glucose using a scale; (2) add the weighed glucose to 30 mL of aquades; (3) stir the mixture with a magnetic stirrer at a temperature of 100°C for 15 minutes until the glucose completely dissolves, indicated by a clear solution; (4) after the glucose has dissolved in 30 mL of aquades, add an additional 70 mL of aquades and (5) the varied glucose solutions are then tested. The experimental setup used in this study is depicted in Figure 2.

Figure 2. Set-up Experiment (a) Experimental design; (b) Experimental design of the study



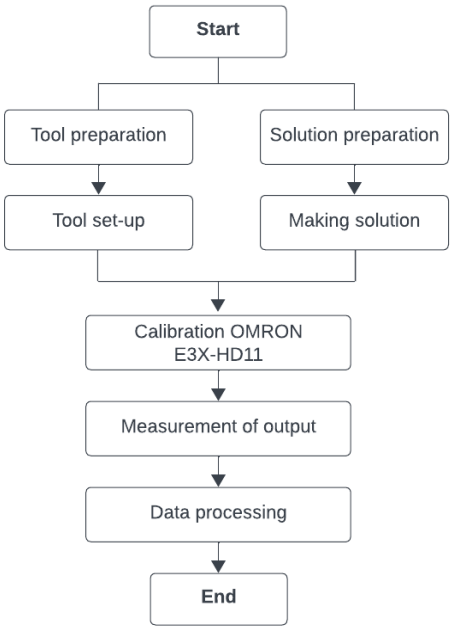
(a)



(b)

This scheme of the experimental design is employed to interrogate the solutions in a reflectance configuration, which is the desired mode for glucose analysis. The research flowchart for this study is shown in Figure 3.

Figure 3. The research flowchart



III. RESULTS AND DISCUSSIONS

This research aims to obtain optical fibers containing hydrogel for glucose detection. Glucose serves as an energy source for brain cells, nerve cells, and red blood cells. The study commences with the characterization and identification of glucose with its varied concentrations.The results of the glucose solutions are presented in Figure 4.

Figure 4. Results of the glucose solutions

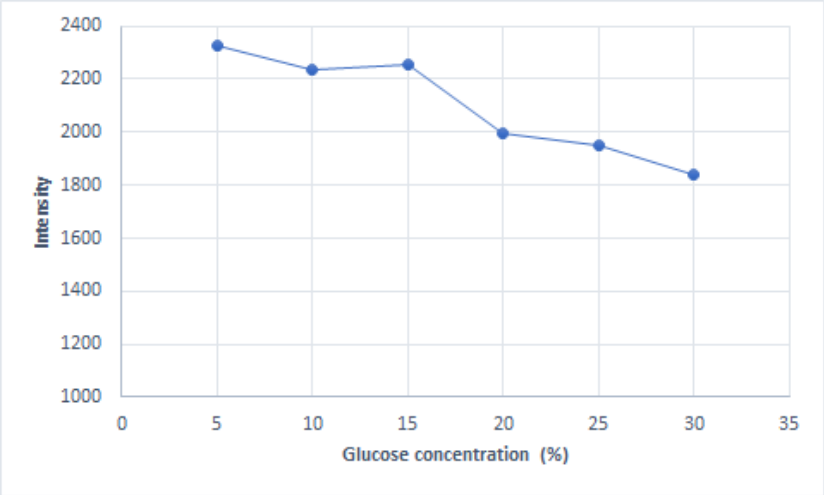
This study utilized the OMRON E3X-HD11, which is an optical fiber sensor comprising a light source and a detector. The light source in the E3X-HD11 is a red LED with a wavelength of 650 nm. The measurement results in this study are presented in Table 1. To identify the relationship between glucose concentration and intensity, a graph was created, as shown in Figure 5.

Table 1. Result of measurements of this study

No.	Glucose Concentration (%)	Intensity
1	5	2325
2	10	2235
3	15	2253
4	20	1997
5	25	1953
6	30	1837

The results of this study demonstrate that as the concentration of the solution increases, the output intensity decreases, as seen in Figure 2. Solution concentration represents the ratio of solute to solvent, with glucose as the solute and aquades as the solvent in this experiment. As the concentration increases, the medium becomes denser, causing the speed of light in the medium to decrease and the refractive index to increase. Refractive index can be defined as the ratio of the speed of light in a vacuum to the speed of light in a given medium. The changes in output intensity are caused by variations in the refractive index of different glucose solutions.Previous studies have found that higher glucose concentrations result in larger refractive indices (Marzuki et al., 2018). Higher sugar concentrations lead to increased absorption of incident light, resulting in a decrease in light intensity. Changes in the refractive index will alter the effective refractive index and reduce the output intensity.

Figure 5. The relationship between intensity and glucose concentration



IV. CONCLUSION

This study has successfully identified the relationship between intensity and glucose concentration. Glucose solutions were varied into 6 different concentrations, including 5%, 10%, 15%, 20%, 25%, and 30%. The results of this study indicate that as the concentration of the solution increases, the output intensity decreases. Higher sugar concentrations result in greater absorption of incident light, leading to a decrease in light intensity. Changes in the refractive index will alter the effective refractive index and reduce the output intensity.

Conflict of interest

There is no conflict to disclose.

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