# Glucose Detection Based on Light Reflection in Modulated Optical Fibers for Continuous Diabetes Monitoring

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***Abstract*— Diabetes mellitus is a chronic disease characterized by elevated blood glucose levels. Approximately 463 million adults worldwide have diabetes, and nearly half of them remain undiagnosed. Early diagnosis and treatment of diabetes are crucial to prevent serious complications. Continuous glucose monitoring (CGM) offers numerous advantages over traditional fingertip blood glucose measurements. CGM allows patients to track their glucose levels in real time, identify patterns, and adjust their diet and medication appropriately. This research presents a novel optical fiber-based glucose sensor utilizing the macrobending modulation technique. This method offers several advantages, including ease of use, low cost, and strong signal generation. The sensor exploits the refractive index difference between the glucose solution and the optical fiber. Variations in glucose concentration induce changes in the refractive index, which are converted into voltage signals. The sensor exhibits a sensitivity of 337 mV/decade and demonstrates a linear relationship between the voltage signal and glucose concentration within the range of 0-10 mM. The macro bending-modulated optical fiber sensor shows potential as a simple, cost-effective, and efficient CGM tool. Further research is necessary to enhance the sensor's sensitivity and stability and to evaluate its performance in biological samples.**

***Keywords*— diabetes, fiber optic, glucose, macrobending modulation, sensor**

## I. Introduction

Diabetes mellitus is a chronic disease resulting from the body's inability to produce insulin hormones or the ineffectiveness of insulin production. It is characterized by elevated blood glucose levels. The mortality rate attributed to diabetes in Indonesia increased by 58% in 2021 compared to 2011 [1]. Insulin deficiency can lead to several other disorders in the body, such as kidney failure, liver disorders, and heart disease if not appropriately managed [2]. Before the onset of diabetes, individuals typically go through a pre-diabetes stage. During this phase, there are indications of diabetes, yet they often go undetected. In reality, at this stage, patients can still be cured, but due to unawareness of diabetes symptoms, the condition remains uncontrolled and ultimately becomes difficult to manage [3]. Additionally, diabetes is one of the diseases that is challenging to cure; the focus is on controlling blood glucose levels.

Type 2 diabetes is the most common type of diabetes, accounting for more than 90% of all diabetes cases worldwide. In type 2 diabetes, hyperglycemia initially results from the body cells' inability to respond fully to insulin, a condition known as insulin resistance. With the onset of insulin resistance, hormones become less effective. Over time, inadequate insulin production may develop as a result of pancreatic beta cell failure to meet demand [1].

To control blood glucose levels, measurements are typically taken by pricking the patient's arm or finger to obtain a blood sample. Individuals with diabetes usually perform monitoring at least 4 times a day, with each test taking approximately 2 hours. However, skin punctures in diabetic patients can lead to infections due to the difficulty in self-healing wounded areas [2]. This method of blood sampling is less effective as a blood glucose monitoring effort, thus necessitating the development of alternative methods. Non-invasive methods involving sampling from urine, sweat, tears, and other samples have emerged as effective options currently under extensive development [4]–[6].

Several alternative non-invasive glucose sensors are currently under development, such as non-invasive biosensors utilizing enzymes and optical instruments with lasers. However, enzyme immobilization processes require special handling. Additionally, biosensor storage time and reproducibility pose significant challenges. Another type of sensor utilizing optical instruments is the Quantum Cascade Laser (QCL) and spectroscopy [7]. However, the configuration of instruments using this method is sufficiently complex, making it difficult to translate into portable sensor applications.

The utilization of optical fibers has been widely observed in the telecommunications industry. Its ability to transmit information at the speed of light makes it inherently attractive


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for exploring the potential applications of optical fibers in other fields [8]. Optical fibers are prime candidates for monitoring changes in the surrounding environment because they offer several advantages, such as ease of integration with other materials and components, resistance to electromagnetic interference, lightweight nature, resilience in extreme environments, and multifunctional detection capabilities for various physical and chemical changes. Several research efforts on biomolecule detection and disease diagnosis using optical fibers have been conducted, including the detection of food compositions [9], bacteria [10], and glucose [11].

To develop effective optical fiber sensors for diabetes detection, thorough analysis, and optimization methods are necessary to achieve high sensitivity and accuracy. When light propagates within optical fiber cables, it can escape from the fiber if the cable bends with a small enough radius of curvature. This phenomenon, known as macrobending loss, results in a decrease in optical power exiting the fiber end and being received by the light detector [12]–[14]. This research aims to develop a non-invasive method for detecting diabetes in a solution, with the further goal of creating a ready-to-use sensor for body fluids, particularly urine.

## II. Methods

### A. Preparing Glucose Solutions

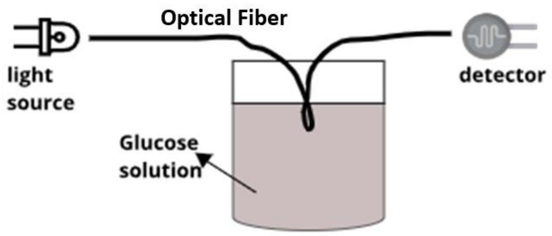


Fig. 1. Glucose solution and the placement of optical fibers in the solution.

The study focused on fluctuations in glucose levels to provide data for the research. Glucose levels were adjusted to mimic those typically seen in type 2 diabetes, ranging from 3 to 8 mmol/L. In this research, glucose concentrations varied from 2 to 8 mmol/L, increasing in increments of 2 mmol/L. The optical fiber was immersed in the solution, and changes in light intensity were detected, which are shown in Figure 1, and then displayed in a graph. This design choice aimed to facilitate further related research and to enable the development of instruments in resource-limited laboratory settings.

### B. Hardware Implementation

This glucose detection sensor model primarily consists of optical fibers. The sensor includes a light source, a 3mm, 3V light-emitting diode (LED), and a light detector, a light-dependent resistor (LDR), connected through optical fibers as the light-carrying medium. The light intensity received by the LDR varies depending on the angle of light entering the optical fiber. Two optical fibers are connected to the light source and detector (Figure 1 and Figure 2). The experimental setup for glucose detection using macrobending is shown in Figure 2.

The fiber optic is immersed in a glucose solution within a black box, which minimizes light noise. One end of the fiber optic is connected to the light source, while the other end is connected to the detector. This arrangement ensures that changes in light intensity due to glucose concentration variations are accurately detected with minimal interference from external light sources. Based on previous works, the curvature of the optical fiber is adjusted to have a diameter of 12 mm to maximize the effect of bending and achieve effective results [15]. An Arduino Uno R3 is used for signal reading and processing.

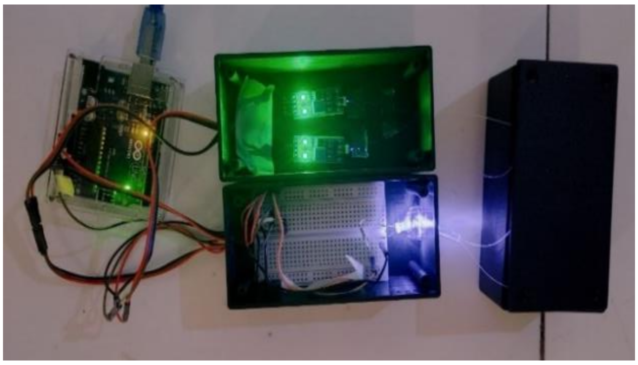

Fig. 2. Light travels through the reference and modulated fiber optic (macrobending) in the black box

### C. Data Acquisition

The Use of MATLAB Application for signal processing and data acquisition connected with Arduino. When analog input from Arduino is detected in MATLAB, the data can be directly displayed in the form of a graph. The first input from Arduino is a modulated optical fiber inserted into various glucose solutions. The second Arduino input is an optical fiber inserted only into distilled water, serving as reference data. The output displayed is the voltage on Arduino ranging from 1-5 volts. The graph shows differences in light intensity received by the LDR on different optical fibers.

## III. Results and Discussion

The macrobending technique leverages the bending-induced variations in light intensity as a measure of glucose concentration. While macrobending has been studied in other contexts, its application to glucose monitoring for diabetes management is innovative. When optical fibers are bent, a change in the angle of incidence of light occurs, disrupting light reflection and reducing light intensity. The reduction in light intensity is then interpreted as a change in a phenomenon to be detected, which can include the detection of changes in a solution (biosensors), deformation of an object (*structural health monitoring*), expansion of an object, movement of body organs (biomechanics), etc.

Light propagation in optical fibers is based on the principle of total internal reflection. Light undergoes total internal reflection when two conditions are met: the refractive index of the core must be higher than that of the cladding, and the angle of incidence must exceed the critical angle.. The magnitude of this critical angle depends on the core and cladding refractive indices. The analysis of the angle of incidence and angle of reflection can be obtained from Snell's law. The optimal macrobending radius will be calculated [16]–[18]. In this regard, the best linear trend of the refractive index detection response will be observed for its sensitivity. Sensitivity is then defined as:

$$S = \frac{d}{dn}[10log_{10}T(n)] \quad (1)$$


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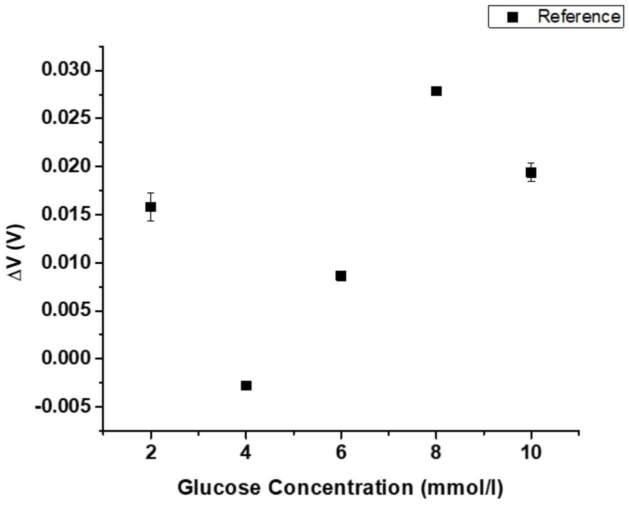
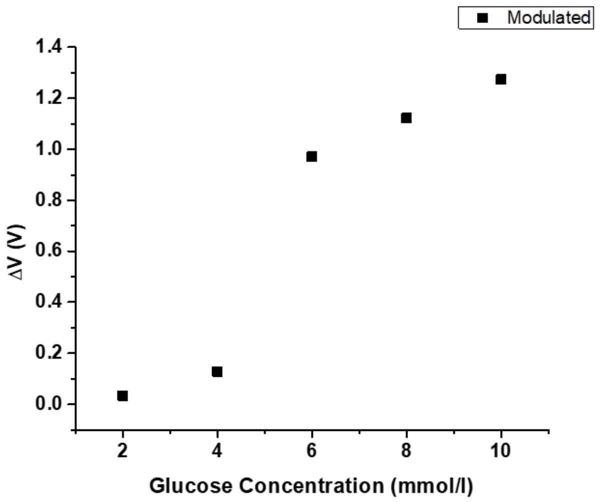
The sensor is calibrated by immersing the fiber in glucose solutions with known concentrations, establishing a relationship between voltage output and glucose concentration. Sensitivity (*S*) is defined as the change in output signal per unit change in glucose concentration, indicating the sensor's responsiveness to glucose variations.

According to the measurements, increased glucose concentration correlates with higher voltage readings detected by the light sensor. The relationship between solution concentration and power loss (voltage) can be explained as follows: the higher the concentration, the denser the medium, resulting in a lower light speed in the medium and a larger refractive index. The value of the voltage change is obtained from the difference in measurement values at a certain concentration compared to the voltage value in distilled water.




(a)




(b)

Fig. 3. a) Voltage changes with glucose concentration variations, b) Voltage measurement in distilled water (without glucose)

The measurement of voltage changes from each optical sensor is depicted in Figure 3. The sensor's sensitivity is calculated based on the linear equation in the final curve, namely the calibration curve (Figure 4). For measurements using optical fibers immersed in various glucose solutions, the sensitivity value obtained is 337mV/decade ± 2.30mV. This value indicates that the sensor detects changes of approximately 337mV for every change in glucose concentration (2mmol/l). This sensitivity is relatively high with an error of 2.30 mV. Repetition of measurements yields results with a small margin, indicating good repeatability of this sensor. However, the linearity of the sensor still needs to be improved.

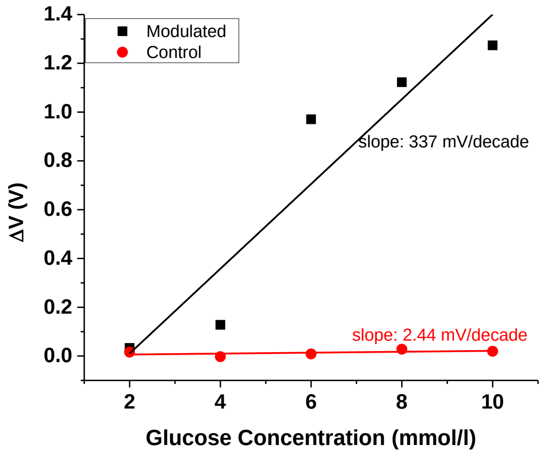



Fig. 4. Graph of voltage changes based on glucose variations

The sensor demonstrates a sensitivity of 337 mV/decade within the glucose concentration range of 2-10 mmol/l. This high sensitivity, coupled with a low standard error (2.3 mV), showcases the efficacy of the macrobending modulation technique in detecting small changes in glucose concentration, which is critical for continuous glucose monitoring. The integration of the Arduino platform with MATLAB for real-time data acquisition and analysis is highlighted. This setup allows for immediate processing and visualization of glucose concentration changes, enhancing the practicality of the sensor for continuous monitoring.

Unlike traditional blood glucose meters, the macrobending optical fiber sensor does not require blood samples, thereby reducing discomfort and infection risk. This sensor utilizes inexpensive materials, such as optical fibers, LEDs, and light-dependent resistors (LDR), along with standard electronic components like the Arduino platform, making it potentially more cost-effective than continuous glucose monitors (CGMs) and other advanced non-invasive sensors. The sensor demonstrates a sensitivity of 337 mV/decade, which is competitive with other non-invasive methods, enabling it to detect small changes in glucose concentration effectively. Additionally, the sensor design is versatile and can be adapted for various applications, including monitoring different body fluids such as urine and sweat.

The findings provide a foundational basis for further research into optimizing optical fiber sensors for biological samples. Future studies can build on this work to enhance sensitivity, stability, and specificity, as well as to validate the sensor's performance in clinical settings with real human samples. Although this study uses an invasive setup for initial testing, the findings suggest potential applications for non-invasive glucose monitoring for human urine by optimizing the sensor design. This could lead to more comfortable and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less risky monitoring solutions for diabetic patients. The results position the proposed sensor as a simpler and more feasible alternative to current non-invasive glucose monitoring technologies, such as enzyme-based biosensors and complex optical systems.

## IV. Conclusion

The voltage changes (loss signal) detected are due to imperfect reflection arising from the difference in refractive indices between the solution and the optical fiber. The difference in refractive indices of different glucose concentrations results in voltage changes. Optical fiber sensors can detect glucose changes within the range of 2-10 mmol/l effectively. The calibration curve demonstrates a sensor sensitivity of 337 mV/decade with a standard error of 2.3 mV. Further research is needed to improve the linearity of the sensor and to conduct trials with real human samples.


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