Enhanced Non-Invasive Blood Glucose Monitoring System Employing Wearable Optical Technology

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Abstract

Diabetes presents significant health risks globally, necessitating precise blood glucose monitoring to prevent serious repercussions including blindness, renal illness, kidney failure, heart disease, and even death from hyperglycemia or hypoglycemia, it is imperative to maintain normal blood glucose levels. However, regular blood glucose monitoring can be difficult for diabetics, and current non-invasive techniques sometimes do not assess blood sugar levels accurately or directly. In order to solve this problem, this study suggests a wearable optical system that is affordable and low-complexity. In this study, a wearable optical system has been proposed which can address the challenges in the accuracy and convenience in existing methods. This system used an Arduino Nano as a central control unit and a laser-transmitted module for blood glucose measurement. Light Dependent Resistors (LDRs) is used to detect and measure the intensity of laser light passing through the skin and impressed by blood glucose levels. The results are displayed on Organic Light Emitting Diode (OLED). During one weak trial, the system achieved average error present of 7.6% and 3.9% for before and after meal blood glucose concentration. The aim of this study is to enhance the lifestyle of diabetic patients by providing user-friendly technology for convenient blood glucose monitoring. It focuses on the potential benefits of non-invasive approaches and concentrates on the importance of the proposed wearable optical system in improving healthcare outcomes.

Keywords: Monitoring System; Blood Glucose measurement; Diabetes; Arduino

1. Introduction

Use optical measurement techniques is already widespread in the medical and industrial domains, and these techniques provide number of advantages that can be useful for glucose sensors. Consequently, the development of glucose sensors has generated a lot of interest in optical approaches [1] [2]. Diabetes is a chronic disease that occurs when the body's insulin fails to maintain blood sugar levels. Based on the statistics of the World Health Organization, there are hundreds of millions of people with diabetes types (1) and (2) in the world, and this disease is considered one of the most important causes of death in many parts of the earth [3]. 382 million individuals worldwide have diabetes in 2014, and this number has the possibility to reach 592 million by the year 2035[1]. Recent studies show that the Continuous Glucose Monitor (CGM) can be improved to control blood glucose levels [4].

In this research The NIR optical technology becomes new approach to use laser to non-invasively measure blood sugar levels that has a region of wave length between (630 - 690 nm), it transmits the signal that will be received

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by a photoconductive detector which will be read by means of reflectance spectroscopy measurements and Arduino Nano has been used as a central control unit. Recently, modern medical technology applied in the field of medical and health care and the possibility of using wearable devices by patients has become an important and attractive technology by researchers in our daily lives [5][6]. These wearable technologies have the potential to revolutionize diabetes management by providing individuals with continuous, non-invasive glucose monitoring capabilities, enhancing their quality of life and reducing the burden of this chronic condition.

In light of the escalating global diabetes epidemic and the potential for optical technology to revolutionize glucose monitoring, this research delves into the development of a novel glucose sensor utilizing NIR optical technology and controlled by Arduino Nano. This technology not only promises greater convenience for patients but also holds the potential to improve the precision and reliability of glucose level measurements. In doing so, it aims to contribute to the ongoing efforts to address the challenges posed by diabetes on a global scale.

2. Literature Review

Many systems were implemented to help diabetic patients in all types, using various electronic components for measurement the blood glucose concentration. These technologies were presented as follows:

Shengping, et al. (2016), mentioned one of the methods for sensitive and non- invasive blood glucose measurement by using the effects of circulating glucose and Faraday magneto-optical. The device used in detection and control was composed of Programmable System-on Chip (PSoC), system initialization, interrupt, signal acquisition, Faraday coil control, display and transmission. The current comes from Faraday coil measures the concentration of glucose in blood. The advantages of this technique are the ability for determining the blood glucose level with different concentrations and we may extend this to vivo non-invasive and real-time blood glucose detection [7].

Sruthi, et al. (2016), presented another method which proposed patient monitoring system that consists of several wearable sensors work remotely to continuously know blood glucose concentration using non-invasive techniques, then process the data in real time using microcontroller and send it to the healthcare centre wirelessly, which based on Photo-Plethysmography (PPG) technology that relies on optical technologies. The advantages of this method are low cost, small size, low weight, high efficiency and accuracy [8].

Jayoung, et al. (2018), mentioned another system, which developed for non-invasive skin electrochemical monitoring that based on two bio-fluids such as sweat and interstitial fluid. This system can be represented as a wearable platform such as: (wrist-watch or small tattoo) that having wireless electronics to complete the system, and can provide real time and continuous blood glucose measurement also it can give the patient self-monitoring and provide a good way to control diabetes and the possibility of measuring blood sugar. One of the important challenges of the successful implementation of this system is the possibility to combine accurate real-time glucose reading with good stability of reading [9].

Bassant, et al (2019), proposed new technique of non-invasive glucose measurement depending on oral fluids like sweat and tears. All of these methods can be spectroscopic, ultrasonic, optical, electrical, electrochemical or thermal. Relation of iontophoresis to electrochemical-enzymatic glucose is very important to know the blood glucose concentration. The advantages of these methods are low cost, flexibility, good compatibility with human cells and skin but the disadvantages of using tears may cause eye irritation [10].

Wu, et al. (2020), introduced a novel approach for non-invasive blood glucose monitoring utilizing advanced wearable technology. They developed a smartwatch-like device equipped with near-infrared spectroscopy (NIRS) sensors. NIRS technology permits the measurement of glucose levels by analysing the absorption and reflection of near infrared light by blood vessels lying under the skin. This wearable device continuously tracks glucose levels and provides users with real-time data. Non-invasiveness, convenience, and potential for seamless integration into daily life represent the main advantages of this method. However, ensuring the accuracy and reliability of NIRS-based measurements, especially under varying physiological conditions remains great challenges [11].

Gupta, et al. (2021), presented a non-invasive blood glucose monitoring system using advanced artificial indolence and machine learning algorithms. This system depends on using the smartphone app with portable spectrophotometer sensor, which captures the spectral data of the skin. This data processed by the smartphone app p using AI to determine blood glucose levels. The advantages of this method are its accessibility, cost-effectiveness, and potential for continuous monitoring. The accuracy of glucose estimation based on AI depends on the quality and quantity of training data, and further research is needed to improve the algorithms for different conditions [12].

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Li, et al. (2022), introduced a cutting-edge technology for non-invasive blood glucose monitoring based on graphene-based biosensors. They developed a wearable patch that incorporates graphene-based sensors capable of detecting glucose levels through the skin's sweat. The patch is connected to a smartphone app via Bluetooth, allowing users to monitor their glucose levels in real time. The advantages of this technology include high sensitivity, rapid response and minimal discomfort, also reducing the need for frequent blood sampling is a very important advantage in this method. Nevertheless, in order to use this technology in widespread adoption the challenges of sensor calibration and long-term reliability need to be addressed [13].

Cheng, et al. (2023), presented a new method for measurement of non-invasive blood glucose depending on microwave technology. the proposed system emits low power microwave signals towards the human skins using a wearable device with microwave sensors, then the reflected signals has been analysed to estimate the blood glucose levels. The system provides many advantages including rapid measurement, minimal discomfort, and potential for continuous monitoring. In addition to the fact that microwave-based, systems do not interference with the environmental factors such as light and changes in temperature [14].

Kumar, et al. (2023), proposed a non-invasive blood glucose monitoring system based on nanotechnology and microfluidics. In this study a microchip that uses microfluidic channels to extract and analyse tiny volumes of interstitial fluid has been developed. The microchip includes nanoscale sensors using to accurately detect glucose levels. Minimal pain, quick results and ability to monitor glucose continuously are the advantages of this system in addition that the small size of the microchip make it suitable for wearable devices. However, this approach also suffers from some challenges such as optimizing sensor sensitivity and ensuring the biocompatibility of materials used in the microchip [15].

3. Theoretical and Experimental Work

3.1. Methods of Measuring the Level of Glucose in Blood

Depending on the method of detection, there are three categories for measuring blood glucose levels diagnosis, invasive, minimally invasive (MI), and non-invasive (NI).

3.1.1. Invasive Blood Glucose Method:

In invasive blood glucose, measurement methods, samples used to measure blood glucose levels may be whole blood, plasma, or serum. However, it is recommended to use plasma or serum because sometimes readings taken from blood are not enough accurate. This method is more commonly used, but needs sample of the patient's blood and calculation the amount of glucose for accurate measurement [16][17].

3.1.2. Minimally-Invasive (MI) Blood Glucose Method:

The focus of the minimally invasive (MI) blood glucose measurement method is to find ways to determine glucose concentration without invasive procedures that invade privacy, cause discomfort, or pose hazards. MI techniques involve extracting body fluids such as tears or interstitial fluid to quantify glucose concentration using an enzyme reaction. There are several MI devices, but they are expected to be replaced by non-invasive (NI) methods. This is because MI technology still requires accessing internal fluids and carries potential risks of infection [18]. However, ongoing research into MI techniques has led to the development of potential substitute methods, particularly those based on reverse iontophoresis and fluorescence [19].

3.1.3. Non-Invasive (NI) Blood Glucose Method:

The trend in personal diagnostic equipment is moving towards wearable technology, which requires non-invasive approaches that are secure, simple to use, light, and affordable. Non-invasive (NI) blood glucose measurement methods allow measurement without the need for invasive tools inside the body. These methods involve sending light into the body and measuring the response of body fluids [2].

Researchers have been investigated the development of non-invasive continuous glucose monitoring (CGM) devices to improve the comfort of diabetes patients who need regularly monitor of the blood glucose levels. Studies have been conducted on measurements of breath, sweat, and saliva. However, in many cases, the glucose levels or other correlating tests are either very low, poorly associated with blood glucose levels, or have slower dynamics [20]. There are many sensors, which can be used in this method; one suggestion is to use a sensor similar to a contact lens on the eye to obtain continuous readings from tear fluid. However, tear fluid has significantly lower glucose levels than blood, and the glucose levels in both fluids do not appear to be well correlated throughout the day [21].

Among various non-invasive modalities, methods that measure glucose levels on the skin have attracted great interest. Numerous technologies have been researched, including reverse iontophoresis, ultrasound, impedance spectroscopy, and various optical techniques [22]. Optical methods have gained popularity for non-invasive blood

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glucose measurement, with the depth of light penetration into the skin varying depending on its wavelength [2]. Figure 1 shows description of methods used to check blood glucose [12].

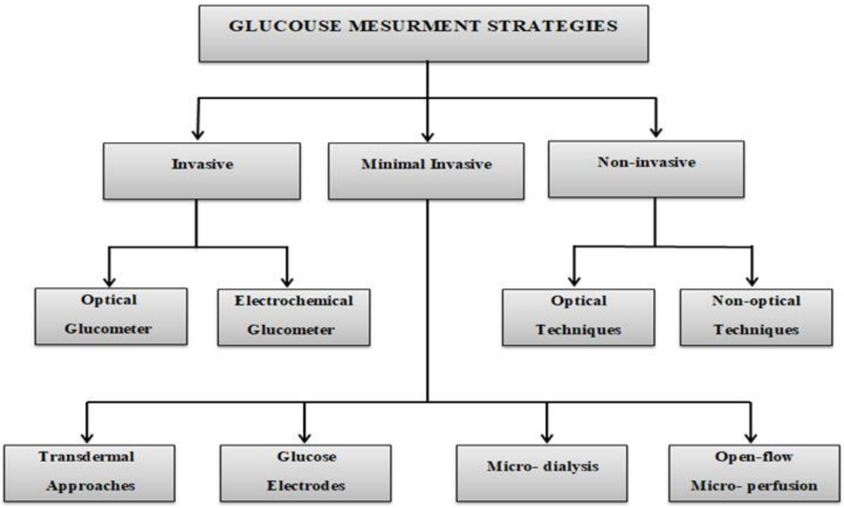

Figure 1. Description of methods used to check blood glucose

3.2. Theoretical Calculation

Beer Lamberts Law [23] explains the connection between a substance's characteristics and how light is attenuated by it. It can be defined as "The amount of light absorbed is directly proportional to the length of the path as well as the concentration of the chemical". The main idea is that incident light is attenuated when it passes through any chemical solution. Light reduction is achieved either by increasing the distance inside the solution or by concentration. Equation (1) shows description of "Beer's Law"

$$A = \varepsilon \, b \, C \quad (1)$$

Where: A represents the amount of light absorbed, ε is the coefficient of molar absorption in units (mol-1 cm-1), b is the length of the optical path within the crossed sample measured in centimeters, c represents the concentration of the compound in the solution measured in molarities. Error percentage of readings can be calculated using equation (2)

$$error\ persentage = \frac{experimental\ value - theoretical\ value}{theoretical\ value} \times 100\% \quad (2)$$

3.3. Proposed System

3.3.1. Main Parts of System

Figure 2 shows the block diagram of the hardware system which consists of input unit, control unit, output unit and power supply.

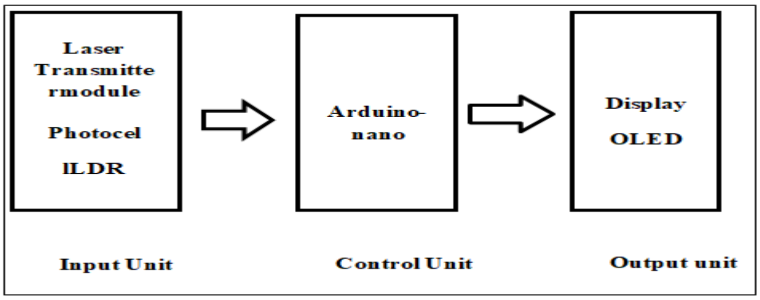

Figure 2. Block diagram of hardware parts

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• Arduino Nano: The Arduino Nano consider as the central control unit of the system. It operates at a voltage of 5V and draws 40 mA DC current on its I/O pins. The microcontroller used is the ATmega328P, which belongs to the 8-bit AVR family. It has 32 KB of flash memory and supports communication protocols such as IIC, SPI, and USART [24].

• Laser Transmitter Module: The laser transmitter module utilized in the system is classified as a class 2M, indicating low-intensity laser emission suitable for medical applications. It consists of a diode that emits a red laser with a wavelength of 650 nm. The module also includes a photo-resister and three head pins. The module operating voltage and current are 5 V and more than 40 mA respectively and the output power is 5 mW [25].

• Light-Dependent Resistor (LDR): LDR is employed in the system in order to detect the presence and measure the intensity of light, LDRs, also known as photo-resistors, are specifically designed to exhibit changes in resistance as a response to variations in light levels. Unlike other types of resistors commonly used in electronic systems, LDRs are highly sensitive to light and enable accurate light detection [26].

• Organic Light-Emitting Diode (OLED): The system includes an OLED screen used for displaying the measured results. The OLED screen operates at a supply voltage of 3.3V and consumes low operating current. It is a monochrome display with a resolution of 96×16 pixels. The displayed information is programmed and transmitted from the Arduino to the OLED screen. The monochrome display appears as light blue. The arrangement of all these components can be seen in Figure 3. [27] [28].

The proposed system integrates these components to create a functional blood glucose measurement device. The Arduino Nano works as the control unit, receiving data from the laser transmitter module and LDR. The LDR detects the intensity of the laser beam transmitted through the skin, which is affected by the glucose levels in the blood. The Arduino processes this information and displays the results on the OLED screen. By utilizing these components, the system aims to provide a reliable and user-friendly approach for non-invasive blood glucose measurement.

Elevated levels of blood glucose can lead to changes in the viscosity of blood, transforming it from a fluid with low thickness to a denser and more adhesive state. This increased density affects the transmission of laser light through the earlobe to the optical resistance. The Arduino Nano measures the optical resistance, which exhibits a decrease in resistance when exposed to light. The results are then displayed on the screen as both a percentage and resistance reading. Additionally, the device is equipped with a rechargeable lithium-ion battery and an operational button for user interaction. Figure (4) shows the electronic circuit of proposed system.

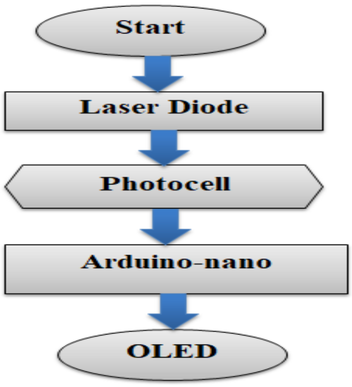

Figure 3. Flowchart of the proposed system

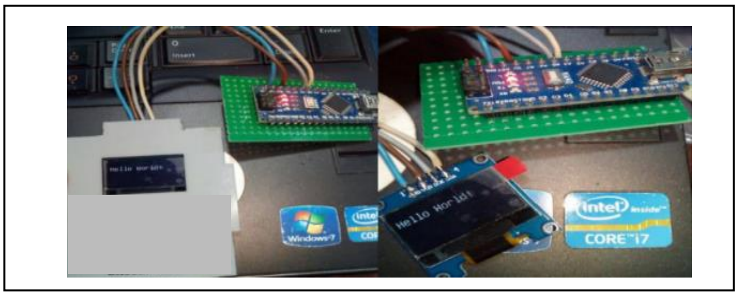

Figure 4. Electronic circuit of proposed system

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3.3.2. Experiment Procedure

1. Charge the battery then turn on the device by the on/off switch.
2. Make sure the battery is full charged by checking the screen readings (98%,100%).
3. Put the black piece of the device that contains the laser on the test participant ear (make sure that the earlobe is located at the middle space of the laser and detector) as shown in Figure 5 after that collect the reading for every participant.
4. Compare the reading with a reading in glucose meter taken to every participant.

Figure 5. Use of proposed system

5. Results and Discussion

The study involved non-diabetic females with an average age of 43 years, and it encompassed the measurement of blood glucose levels before and after fasting using both the traditional diabetes device and the proposed laser device. The collected readings from the laser device were then compared to those obtained from the World Health Organization-approved traditional device, as presented in Table 1.

From analyzing the results, several noteworthy observations can be made:

1. Before Eating: The lowest blood glucose reading recorded by the glucometer was 101 mg/dL, whereas the lowest reading obtained from the laser device was 972 mV. In contrast, the highest reading of the glucometer was 119 mg/dL, while the highest reading of the laser device was 933 mV. These findings are visually depicted in Figure 6(A).

2. After Eating: the lowest blood glucose reading attained by the glucometer was 114 mg/dL, whereas the corresponding reading obtained from the laser device was 915 mV. Conversely, the highest reading of the glucometer was 247 mg/dL, whereas the highest reading of the laser device was 843 mV. These results are illustrated in Figure 6(B).

When comparing the results between the traditional device and our method, an inverse relationship between the reading of blood glucose that obtained from presented study and the measurement of millivolt values is achieved. This relationship indicates that when the sugar concentration in the blood increases, the millivolt absorption by the blood condenses. In the result, the blood resistance increases proportionally with the sugar concentration.

The percentage of error in reading achieved from traditional device and our system is very important in assessing the accuracy and reliability. In the proposed method the percentage of error before eating (B.E) was 7.6%, while after eating (A.E) was 3.9%, which give valuable insights into the precision of measurements and the possible accuracy of the proposed system. The lower value of error percentage refers that the proposed system measurement gives a closer approximation to the true blood glucose values. From the error, percentages also show that the proposed system measurement provides lower error percentage than traditional device, which supports that the system is reliable and suitable for accurate blood glucose monitoring.

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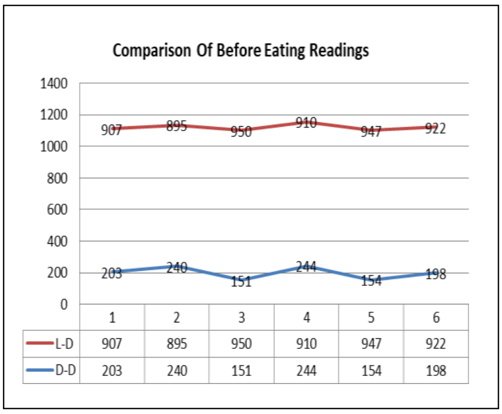
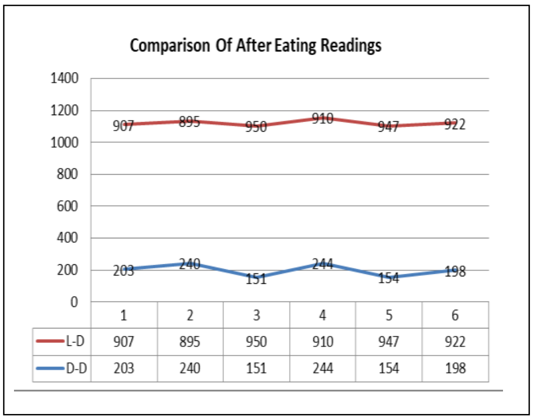
Table 1: Reading of blood glucose concentration

	Readings BeforeEating (B.E.)		Readings AfterEating (A.E)		Percentage of Error (%)	
	Glucometer Reading (mg/dl)	LaserDevice (mv)	Glucometer Reading (mg/dl)	Laser Device (mv)	B.E	A.E.
Saturday	104	949	203	872	8.1	3.3
Sunday	119	933	114	915	6.8	7.0
Monday	111	944	240	858	7.5	2.6
Tuesday	103	954	151	895	8.2	4.9
Wednesday	108	923	229	866	7.5	2.7
Thursday	115	938	247	843	7.1	2.4
Friday	101	972	159	902	8.6	4.6
Mean of Percentage of Error For one week (%)					**7.6**	**3.9**





(A) **(B)**

Figure 6. Readings of Diabetes Device (D-D) and Arduino Nano based laser device (L-D) (A) Before Eating and (B) After Eating

6. Conclusion

This study includes using of Arduino Nano based laser device for non-invasive blood glucose measurement with comparison with traditional glucometer. The results obtained showed that the proposed system provided millivolt reading that is correlated inversely with the blood sugar levels. Higher sugar levels resulted in lower millivolt readings, indicating blood resistance increasing. These results refer to the possibility of using the proposed system as a non-invasive method to monitor the blood glucose.

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