ISSN 0974-3618 (Print)
0974-360X (Online)

www.rjptonline.org

RESEARCH ARTICLE

Non-Invasive Blood Glucose Monitoring using Visible Laser Light

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ABSTRACT:

Diabetes Mellitus is a widely spreading disease worldwide which claims millions of lives every year. Blood glucose monitor is vital for keeping daily track of blood glucose levels and helps in the routine management of diabetes. Current blood glucose monitoring methods mainly involve finger pricks which leads to pain, puncture of skin, inconvenience and causes prone to infections. The costs of disposable test strips and the unavailability of reliable non-invasive glucose monitors are also the challenges in blood glucose monitoring regimen. Recently introduced minimally invasive blood glucose monitors have limited lifespan, unstable accuracy and require invasive methods for regular calibration. Therefore, there is a need to develop a reliable non-invasive blood glucose monitor that addresses the existing challenges. In this project work, we focused on the development of non-invasive blood glucose monitor using visible laser light of 650nm wavelength. In the initial stage, in vitro, experimental measurements were performed using laser based non-invasive blood glucose monitor module to ensure the sensitivity of the system to glucose concentrations. Then, fasting and postprandial in vivo measurements were conducted using the laser based non-invasive blood glucose monitor module integrated with LabVIEW data acquisition system in the form of voltage output. The in vivo voltage output results were compared with Accu-check glucose monitor measurements which have shown good linearity. Finally, laser based non-invasive blood glucose monitor prototype was developed. This work involved 11 volunteer subjects and 18 different measurements for in vivo blood glucose measurement. The in vitro measurement results have shown an overall linearity of 96% while in vivo results had an overall linearity of 94.1% compared with Accu-check active blood glucose monitor measurements. The results are promising and show the potential use of 650nm visible laser light for blood glucose monitoring.

KEYWORDS: Glucose, blood glucose, voltage, non-invasive, laser light, glucose monitor

INTRODUCTION:

Diabetes is a widely spreading disease which causes several secondary complications and claims millions of lives every year [1,2]. According to the World Health Organization (WHO) estimation in 2016, the number of people with diabetes has increased from 108 million in 1980 to 422 million in 2014 worldwide [3].

The prevalence of diabetes among adults over 18 years has risen from 4.7% in 1980 to 8.5% in 2014 worldwide. WHO data indicated that about 1.6 million of deaths in 2015 were directly related to diabetes. The International Diabetic Federation (IDF) data approximated the global number of people with diabetes between the age of 20-79 years to be 425 million in 2017 [4]. This number will rise to 629 million by 2045. It was indicated that about 49.7% of people with diabetes remain undiagnosed [5]. IDF data also stated that 79% of people with diabetes live in low-income and middle-income countries. IDF indicated that about 16.2% of births are affected by gestational diabetes. Four million global deaths were

Received on 13.10.2018 Modified on 05.11.2018
Accepted on 28.11.2018
Research J. Pharm. and Tech 2019; 12(2):831-840.
DOI: 10.5958/0974-360X.2019.00144.6

attributable to diabetes in 2017 and 12% of global healthcare expenditure worth USD727 billion was spent on diabetes.

Current available invasive blood glucose monitors require finger prick which causes pain, inconvenience, discomfort, distress and prone to infections. The costs of disposable test strips in invasive techniques and unavailability of clinically dependable non-invasive blood glucose monitors are also the challenges of blood glucose monitoring. Recently introduced minimally invasive glucose monitors have limited lifespan, unstable accuracy and require invasive methods for regular calibration. Hence, the design of reliable non-invasive blood glucose monitor is needed. Several techniques have been attempted to develop non-invasive blood glucose monitors since last few decades. The optical methods which include; fluorescence spectroscopy [6,7], near-infrared spectroscopy [8], photoacoustic spectroscopy [9,10], optical coherence tomography [11,12], polarimetry [13], and Raman spectroscopy [14,15] techniques have been widely studied. Their limitations are; poor signal to noise ratio, lack of accuracy, poor linearity and sensitivity, susceptibility to environmental variations and tissue compositions. Other methods such as electromagnetic [16], reverse iontophoresis [16,17], bioimpedance spectroscopy [18,19] and ultrasound [16] glucose sensing techniques are also studied extensively. These methods are sensitive to environmental changes, the composition of tissues, and affected by the physiological time lag of blood glucose. Recent blood glucose monitoring techniques are widely discussed in [20] with their merits and limitations.

In this project work, we have proposed a non-invasive blood glucose monitor based on visible laser light (LAB-NIBGM). It was demonstrated that visible red laser light of 650nm wavelength has better penetration, signal to noise ratio and improved accuracy over near-infrared spectroscopy of 950nm [21]. But, high power laser of 1.5W was used which might cause potential hazards to skin and eye. Our goal is to develop a non-invasive blood glucose monitor based on low power visible laser light. Both in vitro and in vivo measurements were performed in this work. Finally, we have developed laser based non-invasive blood glucose monitor prototype.

MATERIAL AND METHODS:

The working principle:

The bond holding the molecular structure of glucose with **C-H-O** has the potential to interact with incident laser light. The aqueous glucose solution irradiated with the light has an ability to vary the optical properties of the incoming light source. When an incident laser light is allowed to pass through a medium of aqueous glucose solution, it refracts or transmits. The degree of laser light refraction depends on the concentration of glucose aqueous solution. The variations in refractive angle and the refractive index of the light passing through the glucose solution depend on glucose concentration. The glucose aqueous solution changes the speed of laser light that passes through it. This slows down its speed and changes the direction of laser light. The higher the concentration of glucose aqueous solution, the more the bending of light. This bending of light whose degree depends on the concentration of glucose is essential to estimate glucose concentration. When the light source is passed through aqueous glucose solution, the light refracts towards normal line AB as shown on Figure 1. The refractive angle (θ_g) of glucose changes with variations in glucose concentration. Snell's law states that an angle of refraction is inversely proportional to the concentration of glucose. As glucose concentration increases, the refracted light photons AC' fall on photodiode decreasing an angle of refraction for glucose solution. The decrease in θ_g increases the refractive index (n_g) for glucose solution. The relationship between refractive properties of laser light and glucose concentration is described by Snell's law.

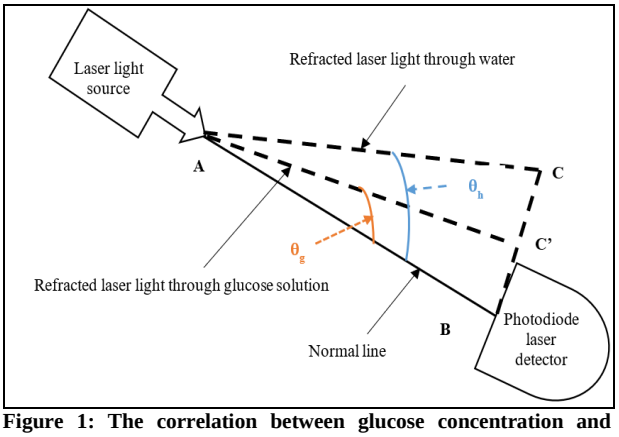

Figure 1: The correlation between glucose concentration and refractive parameters

$$n_h \sin\theta_h = n_g \sin\theta_g \quad (1)$$

$$n_g = \frac{(n_h \sin(\theta_h))}{\sin(\theta_g)} \quad (2)$$

Where, n_h =1.333 refractive index of water

θ_h=refractive angle of water

n_g=refractive index of glucose aqueous solution

θ_g= refractive angle of glucose aqueous solution

The θ_g and θ_h are calculated from the triangles ΔABC' and ΔABC respectively. The normal line AB has a fixed distance of 75mm. The lines BC and BC' represent the

laser circular spot for water and glucose solution respectively. Laser circular spot is the radius of laser light dot that passes through glucose solution. The refractive angle depends on the radius of the laser circular spot. The refractive angle θ_g is a parameter that varies with changes in glucose concentration. $\theta_{g\ and}$ θ_h are determined using equations 3 and equation 4.

$$\theta_g = \tan^{-1}\left(\frac{BC'}{AB}\right) \quad (3)$$

$$\theta_h = \tan^{-1}\left(\frac{BC}{AB}\right) \quad (4)$$

Where BC'=Radius of laser circular spot for aqueous glucose solution
BC=Radius of laser circular spot for the water
AB=Normal line at a fixed distance
The intensity of light passing through the photodiode depends on an angle of refraction and concentration of glucose. This helps to determine the levels of glucose concentration. The in vivo blood glucose concentration is only determined from the voltage output.

Photodiode current and voltage output relationship:
The photodiode detects and converts the incoming radiant energy into equivalent electrical current. The intensity of transmitted laser light depends on the concentration of glucose levels. When the concentration of glucose is higher, more laser photons strike the photodiode surface which increases an output light intensity and the photodiode current output The relationship between the intensity of light and photodiode current can be derived from the quantum efficiency and radiant energy [22–24]. Quantum efficiency is the fraction of incident photon flux that contributes to the photocurrent in the photodiode as given by equation 5.

$$\eta = \frac{I_{pd}}{q}\left(\frac{h\upsilon}{P_{optical}}\right) \quad (5)$$

Where η=Quantum efficiency
I_{pd}=Photodiode current
q=Charge of electron ($1.60217662 \times 10^{-19}$ Columbus)
h=Plank's constant (6.626176×10^{-34} Joule-seconds)
υ=Frequency of photons
$P_{optical}$=Radiant energy in watts

The photodiode current output can be derived from equation 5. Equation 6 shows that the photodiode current output is directly proportional to an incident radiant energy. Other parameters remain constant at constant temperature.

$$I_{pd} = q\eta\left(\frac{P_{optical}}{h\upsilon}\right) = q\eta P_{optical}\left(\frac{\lambda}{hc}\right) \quad (6)$$

λ =wavelength of incident light
c=speed of light in vacuum

This current is detected and converted into voltage output using trans-impedance amplifier (TIA). The trans-impedance amplifier detects the incoming radiant energy and converts it into equivalent voltage output. The voltage output can be calculated using TIA equivalent circuit on Figure 2.

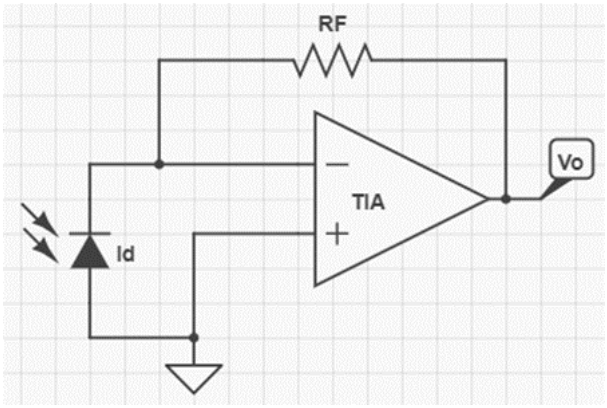

Figure 2: Trans-impedance amplifier circuit

$$Vo = I_d R_F \quad (7)$$

The voltage output (Vo) given by equation 7 shows the direct relationship with photodiode current output. RF is the feedback resistor used as gain of TIA. The current (Id) depends on the intensity of transmitted light and glucose concentration. The photodiode current output increases with glucose concentration as more photons fall on photodiode due to bending of incident light. This, in turn, increases the photodiode voltage output that helps to estimate the levels of blood glucose concentration.

***In vitro* experimental measurement setup:**
The aqueous glucose concentration was prepared by dissolving Glucose-D in distilled water in the range of 50mg/dl from 0mg/dl-450mg/dl. The uninterruptible laser light of 650nm wavelength was passed through cuvette that holds the concentration of aqueous glucose solution. The glucose solution sample holder is placed at a fixed distance from the laser source. The in vitro measurement setup was arranged as shown on Figure 3 below. First, the laser light that passes through glucose solution is allowed to fall on the screen to measure the radius of the laser spot. The change in radius of laser circular spot with varying glucose concentration is measured using a digital caliper. The refractive angle and refractive index are then calculated using Snell's law. In the second case, the laser light that passes through the sample holder strikes the surface of the photodiode. The photodiode detects and converts light

energy into electrical energy based on the intensity of the transmitted light. The intensity of transmitted laser light through photodiode is calculated using Arduino board in the form of voltage output as the concentration of aqueous glucose solution changes. The intensity of transmitted laser light is displayed on the Arduino serial monitor in the form of voltage output. The voltage was also measured with a digital multimeter to ensure the accuracy of the reading. This voltage was used to estimate the concentration of glucose in aqueous solution.

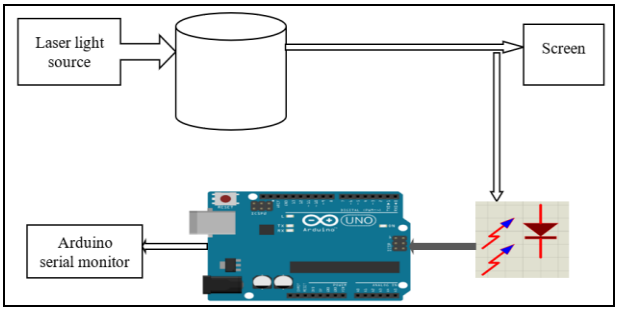

Figure 3: An in vitro measurement setup

In vivo experimental measurement setup:

An in vivo setup measurement involved an insertion of human forefinger into finger hose of proposed non-invasive blood glucose monitor module. The procedure was performed by taking voltage measurements for different subjects before and two hours after a meal. The voltage measurements were acquired using LabVIEW setup integrated with the proposed non-invasive device. The measurement results for each subject were taken ten times to ensure the precision and accuracy of the measurements. After each voltage measurements is taken, the glucose levels of each subject are measured using an Accu-check active glucose monitor. The measured voltage and glucose levels are then compared to estimate the glucose concentration levels in the blood. The laser light source was passed through human forefinger as shown in the diagram on Figure 4. The finger hose was designed to block external ambient light. The voltage output was measured with using non-invasive blood glucose monitor module integrated with LabVIEW data acquisition system. The blood glucose level was measured using Accu-check active invasive glucose monitor. Both measurements were performed consecutively for fasting and postprandial which helped us to estimate the relationship between voltage output and glucose levels in the blood. This is then implemented for the development of final non-invasive blood glucose monitor prototype.

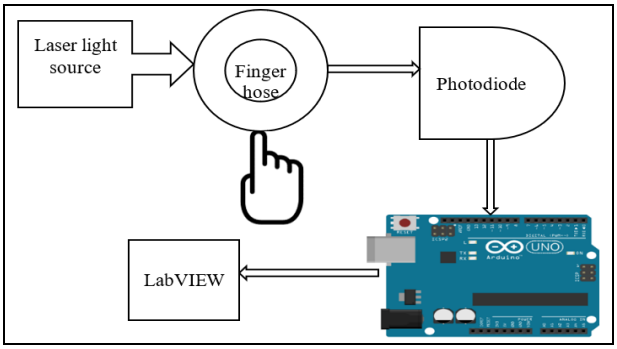

Figure 4: Block diagram for in vivo voltage output measurement setup

In vitro hardware implementation:

The aqueous solution was prepared by dissolving Glucose-D in distilled water of 100ml sample holder. The laser light is then projected through a glucose solution sample holder. The distance between the point where laser light hits the sample holder and falls on screen is 75mm which is equivalent to the length of the normal line. To measure the radius of the laser circular spot, the laser transmitter was arranged in a way to fall on the screen after it passes through glucose aqueous solution. The radius of transmitted laser spot was measured using a digital caliper. It was measured from the transmitted laser light that hits the surface of a screen. The in vitro voltage output from photodiode was also measured. In this setup, the photodiode was placed between the laser transmitter and a sample holder. The distance between the laser transmitter and photodiode was 12.5mm. Then, the voltage output of photodiode was connected to Arduino Uno analog input. This helps to display the voltage output on the Arduino serial monitor. The voltage was also measured using a digital multimeter to ensure whether the readings are correct. Figure 5 illustrates in vitro voltage output measurement setup. The LAB-NIBGM module was enclosed to block external ambient light.

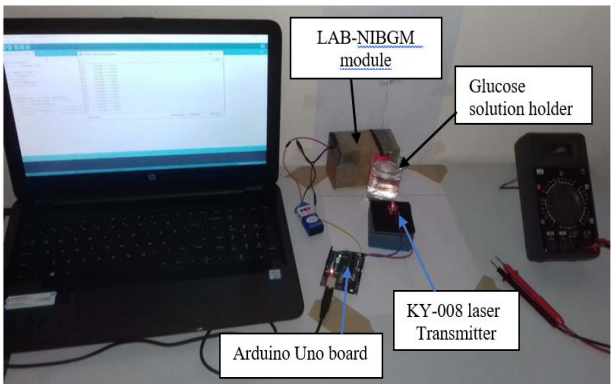

Figure 5: In vitro voltage output measurement setup

***In vivo* hardware implementation:**

The in vivo measurement setup is illustrated on Figure 6. The non-invasive glucose monitor measurement module has three main parts. The laser transmitter, photodiode and finger placement hose. The laser transmitter generates a continuous laser source of 650nm wavelength with 5mW power. This light is allowed to pass through human forefinger inserted into the finger hose. The transmitted light falls on the surface of the photodiode beneath the human finger. The whole part of the module is covered to block ambient light that could cause interference and changes in the measurement. The photodiode detects and converts the intensity of transmitted laser light into equivalent electrical current. An integrated on-chip trans-impedance amplifier (OPT101 TIA) amplifies and converts this current into a voltage output. The values of the voltage output signal are then displayed on the LabVIEW data acquisition system.

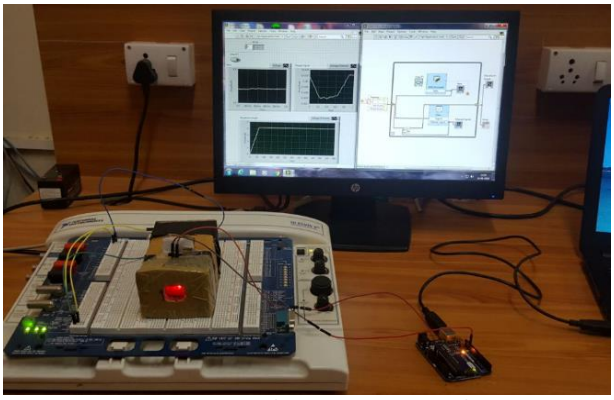

Figure 6: Practical setup for measurement of voltage using LabVIEW

The measurement setup for each volunteer subject is performed as shown on Figure 7. The subject is allowed to sit still and insert the forefinger into the finger hose. The laser transmitter generates uninterruptible low power laser of 5mW which passes through the finger. The photodiode detects and converts an intensity of transmitted light into the equivalent current output. The OPT101 TIA amplifies the current and converts it into a voltage output. The voltage output is proportional to the concentration of glucose levels in the blood. Fourteen measurements were performed for seven subjects before and two hours after the meal while four random measurements were taken from four volunteer subjects. The voltage output was measured ten times for each subject to ensure an accuracy. The blood glucose levels of each subject involved in this experiment were measured using an Accu-check active invasive glucose monitor. The measured voltage output with LAB-NIBGM and glucose levels using invasive glucose monitor were compared to construct an algorithm to estimate glucose concentration.

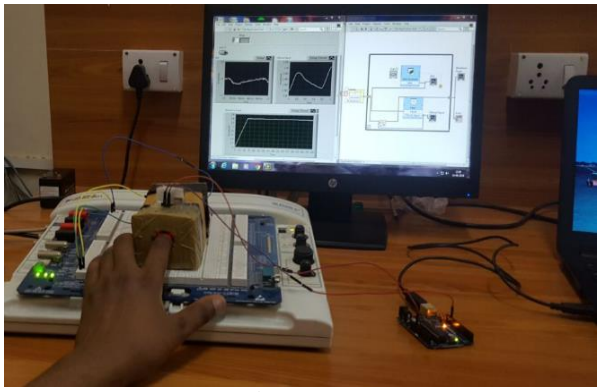

Figure 7: An in vivo setup for voltage measurement with human finger

Non-invasive blood glucose monitor prototype:

The developed visible laser based non-invasive blood glucose monitor (LAB-NIBGM) prototype is shown on Figure 8. The main components are; glucose sensor module, Arduino Uno board, power supply, and voltage buffer. The glucose sensor module consists of KY-008, OPT101 and finger hose. KY-008 is the visible red laser source that transmits laser light of 5mW power at 650nm wavelength. OPT101 is an integrated monolithic photodiode with on-chip trans-impedance amplifier which detects the transmitted laser light, amplifies and converts the current into a voltage output. The finger hose is designed in a way to block external ambient light interferences. Arduino Uno board has ATmega328P microcontroller that calculates blood glucose concentration based on the voltage output from the photodiode and displays the result on 16x2 crystal LCD display. The power supply contains a 12VDC power adaptor, DC power jack, power switch, and LM7805 voltage regulator. DC voltage buffer has two LM358 operational amplifiers which are used to remove DC offsets from voltage output. The buzzer is used to provide an alert when blood glucose level falls in abnormal range.

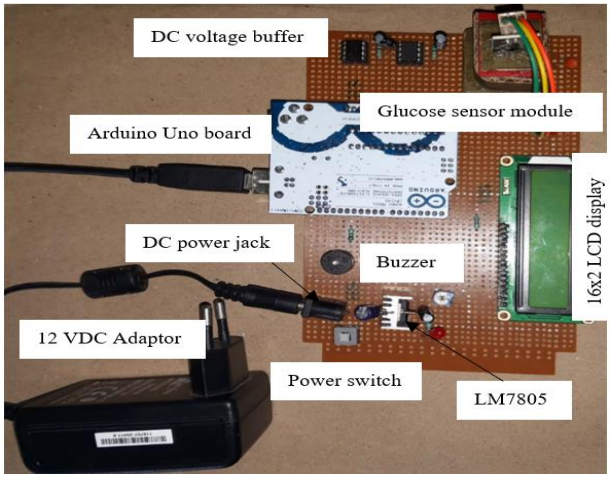

Figure 8: Non-invasive blood glucose monitor prototype

RESULTS AND DISCUSSIONS:

In vitro measurement results:

The in vitro measurements were performed by preparing the aqueous solution of Glucose-D concentration in distilled water. The separate experimental setups were used to measure the laser refraction properties and voltage output. The visible red laser light is allowed to pass through glucose solution where it falls on the screen for measuring the refractive properties of visible laser light. The screen is prepared to measure the circular spot of laser and refraction characteristics. The laser circular spot and refraction properties of laser light depend on the concentration of Glucose-D in aqueous solution. An overall principle and parameter calculations are governed by Snell's law. To measure the voltage output due to a change in glucose concentration, the photodiode was kept behind the sample holder. The photodiode detects the transmitted light and converts into equivalent voltage output displayed on Arduino serial monitor. Table 1 illustrates the summary of in vitro measured parameters.

Radius of circular spot:

The diameter and radius of the circular spot were measured from transmitted laser light through glucose solution. The laser circular spot is the diameter of laser dot that passes through the solution and falls on the screen. Due to an interaction of laser light with Glucose-D molecules, the incident light refracts and bends as it passes through the aqueous solution. This bending of light reduces the radius of the laser circular spot. The angle of refraction and refractive index are calculated based on this parameter. The laser spot radius decrease is shown on Figure 9.

Angle of refraction:

The angle of light refracted for the transmitted visible red laser of 650nm through Glucose-D in sample solution was determined based on the radius of the laser spot and the length of the normal line. The normal line has the fixed distance of 75 millimeters from where the laser hits the sample holder cuvette. As the concentration of glucose in the solution increases, the speed of light through a solution medium decreases. When the speed of light is lowered due to higher glucose concentration, more light photons bend towards the normal line. This bending results in decreasing of the refractive angle between the transmitted light and normal line. Therefore, the angle of refraction decreases as glucose concentration increases. Figure 10 shows that the angle of refraction decreases linearly with an increase in glucose concentration.

Table 1: Summary of in vitro measured values against variations with glucose concentration

Glucose-d concentration in mg/dl	Laser spot diameter in millimeters	Laser spot radius in millimeters	Refractive angle in degrees	Refractive index	Voltage output in volts
0	3	1.5	1.14576	1.333	2.63
50	2.5	1.25	0.95484	1.59950	2.70
100	2.25	1.125	0.85937	1.77718	2.74
150	2.0	1.0	0.76389	1.99929	2.77
200	1.85	0.925	0.70661	2.16135	2.80
250	1.72	0.86	0.65696	2.32469	2.88
300	1.60	0.8	0.61113	2.49902	2.93
350	1.47	0.735	0.56148	2.71999	2.80
400	1.34	0.67	0.51183	2.98384	2.98
450	1.22	0.61	0.46599	3.27384	3.303

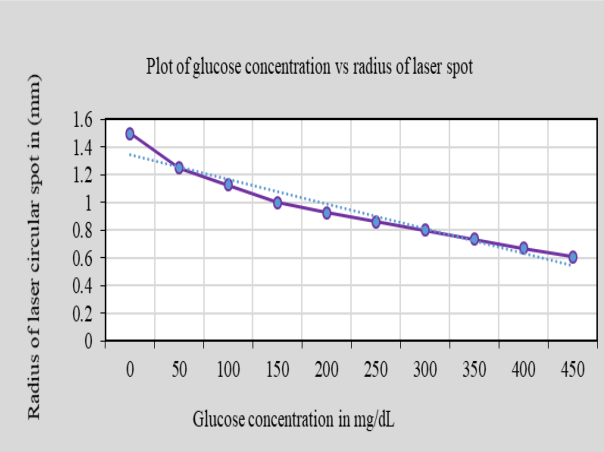

Figure 9: The measured radius of the laser spot with increasing glucose concentration

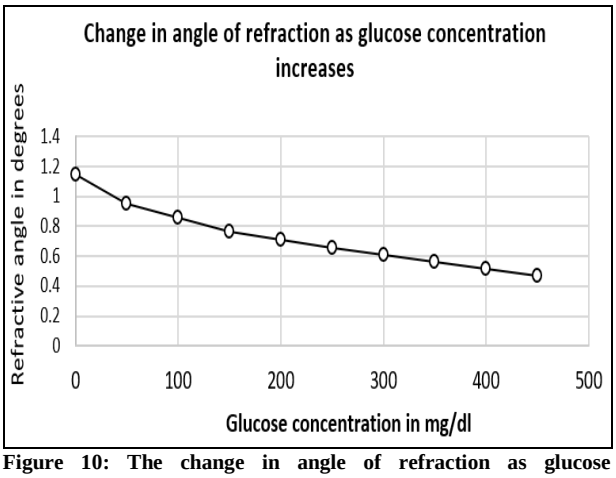

Figure 10: The change in angle of refraction as glucose concentration increases

Refractive indices:
The index of refraction was determined using the Snell's law. The refraction index and angle of refraction are inversely proportional. This in turn indicates the direct relationship between the index of laser light refraction and concentration of glucose solution. The variations of refraction characteristic with a concentration of glucose help to determine and estimate the levels of glucose in the solutions. As shown on the graph on Figure 11 the indices of refraction increase linearly with an increase in glucose concentration.

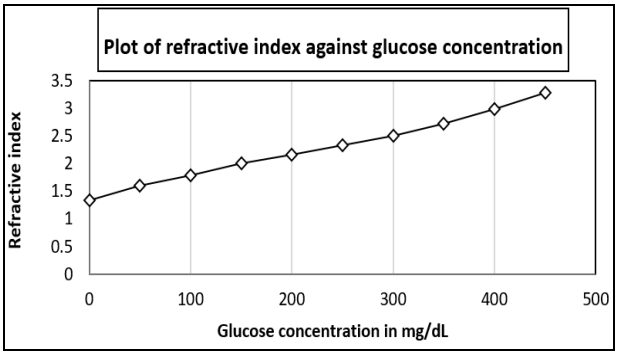

Figure 11: The change in refractive index with an increase in glucose concentration

Refractive angle and refractive indices relationship:
The relationship between angles of refraction and refractive indices with a change in glucose concentration was evaluated as shown on Figure 12. The angle of refraction decreases with an increase in glucose concentration while the refraction index increases. The measured values for both parameters had good linearity with a change in the concentration of aqueous glucose solution.

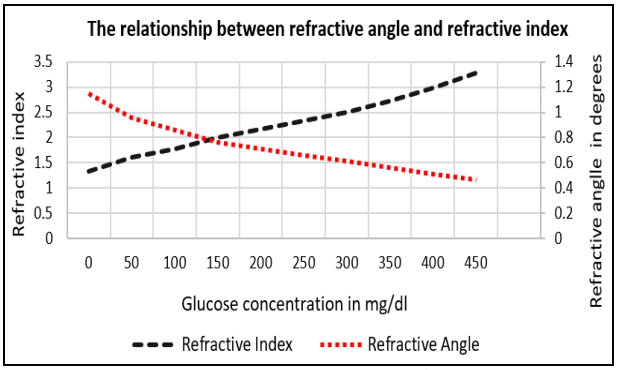

Figure 12: The relationship between refractive index and refraction angle with a change in glucose concentration

Linearity of *In vitro* measurement results:
We have evaluated the linearity of each measured parameters with varying levels of glucose concentration as shown in Figure 13. The in vitro measurement results for non-invasive blood glucose monitoring experimental setup have shown good linearity with glucose concentration. In vitro measurement results have shown an overall linearity of 96 % with glucose concentration. This indicates that our designed LAB-NIBGM device has good correlation with glucose concentration.

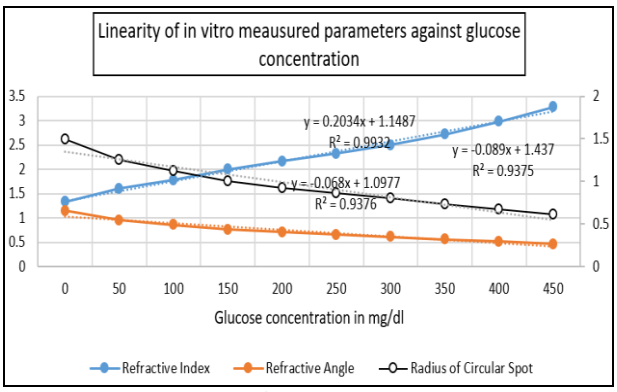

Figure 13: The linearity of in vitro measurement results with varying glucose concentration

***In vitro* voltage output measurement results:**
The voltage output was measured for the concentration of the Glucose-D aqueous solution. The laser light is irradiated through the glucose solution holder where the transmitted light falls on the surface of the photodiode. The voltage output from the photodiode was displayed on Arduino serial monitor and measurements were taken using a digital multimeter to ensure the accuracy of values. The results for voltage output are illustrated on the Figure 14. The output voltage increases with increase in the concentration of glucose solution. This is due to more bending of the visible red laser as the concentration of glucose increases that results in more light photons to strike the surface of the photodiode. The rise in voltage output with glucose concentration shows good linearity and sensitivity with a change in a glucose solution.

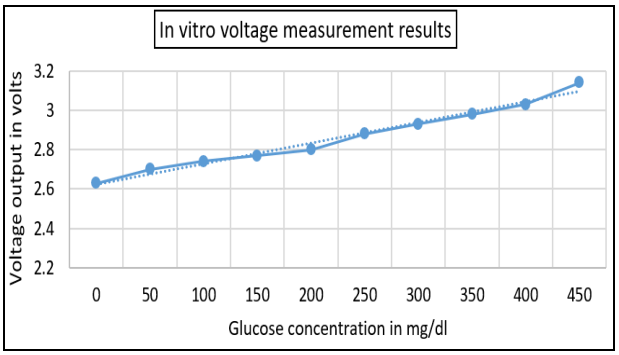

Figure 14: The in vitro voltage output measurement results for Glucose-D concentration

***In vivo* measurement results:**
We have implemented our LAB-NIBGM and performed in vivo measurements. The voltage output measurement was taken ten times for each subject before a meal and

two hours after food. The measured voltage output was compared with blood glucose levels measured with invasive Accu-check active blood glucose monitor. Table 2 summarizes in vivo blood glucose level measurements by invasive Accu-check active glucose monitor against voltage measurements using the LAB-NIBG module. The measurements involved seven volunteer subjects before breakfast in the morning and postprandial two hours after lunch. Human blood glucose rises after food and doctors prescribe glucose monitoring two hours after a meal [25]. Then, the glucose level starts falling until it reaches to a normal blood sugar level which takes four to five hours [21].

Table 2: Fasting and postprandial non-invasive voltage measurement against invasive blood glucose level measurement

Subjects	Before meal		Two hours after a meal	
	Voltage in volts	Glucose level in mg/dl	Voltage in volts	Glucose level in mg/dl
1	1.2175	84	1.858	115
2	1.3257	89	1.6804	95
3	1.3657	91	2.0428	120
4	1.2235	85	1.6971	100
5	1.3726	91	1.8522	114
6	1.8629	116	2.1534	128
7	1.7531	109	1.9716	118

Voltage output measurement results:

As illustrated on the graph of Figure 15, the variations in the voltage output for subject 1 and 3 is higher than other subjects' measurements. These subjects were allowed to take soft drinks and tea with sugar during lunch. The measured voltage output results increase after a meal for all subjects. The reason is due to digestion of meal contents and glucose intake in the blood which causes in rise of blood glucose levels. This increased the levels of blood glucose as soft drinks contain more carbohydrate percentage. Thus, our designed non-invasive blood glucose monitoring device is promising for non-invasive estimation of glucose concentration in the blood.

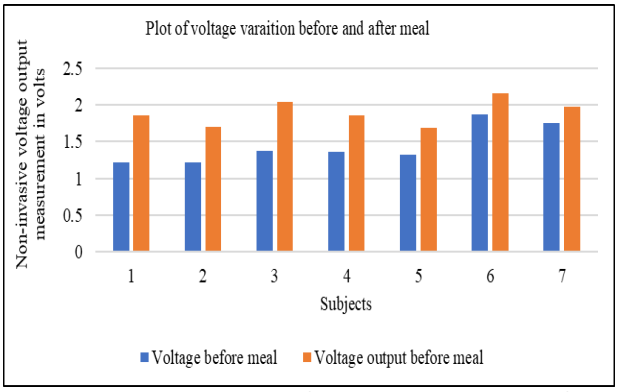

Figure 15: The voltage output before a meal and two hours after a meal on healthy subjects

Blood glucose levels measurement results:

The blood glucose level was measured for seven volunteer subjects using Accu-check active glucose monitor after performing voltage output measurement. The random blood glucose measurement was taken on four subjects to ensure the capability and sensitivity of the proposed device. As it is clearly shown on Figure 16, the blood glucose level rises after a meal. The glucose levels for subject 1 and 3 increase at a higher rate similar to that of designed LAB-NIBGM voltage output measurements which indicates the designed non-invasive glucose monitor has good correlation with invasive glucose monitor.

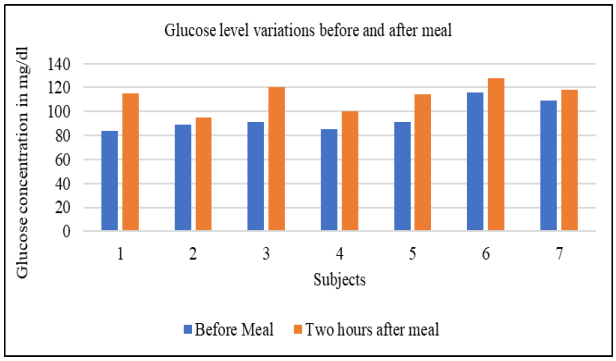

Figure 16: The Accu-Check blood glucose measurement before and after a meal

Table 3, summarizes the blood glucose levels and voltage output measured using Accu-check and LAB-NIBGM respectively. Eleven volunteer subjects participated in these experimental measurements. Eighteen separate measurements were taken from eleven healthy subjects for both voltage output and glucose levels. The consecutive results were taken and plotted to investigate their mathematical relationships. The linearity of values measured was also compared.

Table 3: In vivo measurements of LAB-NIBGM voltage output and Accu-check active invasive blood glucose levels

Serial number	Voltages measurements in (volts)	Blood glucose levels in (mg/dl)
1	1.2175	84
2	1.3257	89
3	1.3657	91
4	1.2235	85
5	1.3726	91
6	1.8629	116
7	1.7531	109
8	1.1727	79
9	1.4258	93
10	1.6543	95
11	1.4277	93
12	1.858	115
13	1.6804	95
14	2.0428	120
15	1.6971	100
16	1.8522	114
17	2.1534	128
18	1.9716	118

The plot of blood glucose levels measured using Accu-check glucose monitor and voltage output measured with the designed non-invasive glucose are illustrated on Figure 17.

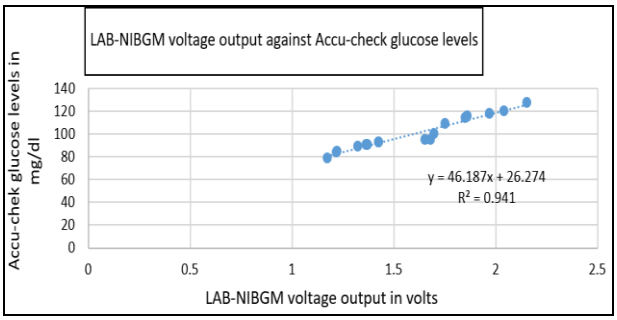

Figure 17: The mathematical relationship between voltage output and levels of blood glucose concentration

Equation 8 provides the mathematical relationship between blood glucose levels and voltage output derived from the plot shown on Figure 17.

$$Y = 46.187X + 26.274 \quad (8)$$

Where, Y represents the levels of blood glucose concentration in mg/dl and X represents the voltage output in volts. This equation was implemented in developing the final hardware prototype for non-invasive blood glucose monitor. It was employed as mathematical algorithm in the Arduino Uno program software to estimate the blood glucose levels. The designed device has shown an overall linearity of 94.1 % between in vivo voltage output and blood glucose measurement by Accu-check.

CONCLUSION AND FUTURE SCOPE:

In the present work, we have developed simple, compact and portable non-invasive blood glucose monitor using visible red laser light. We have designed and developed a non-invasive blood glucose monitor that operates on 5V DC power supply. Both in vitro and in vivo measurements were performed using the designed LAB-NIBGM. Our device has shown an overall linearity of 96% in vitro measurement results. The in vivo tests were performed on 11 volunteer subjects between ages of 19-45 years for fasting and postprandial blood glucose measurements. Total of 18 in vivo blood glucose level measurements were conducted. The non-invasive in vivo results were compared with invasive Accu-check active glucose monitor measurements. In vivo voltage output results have shown an overall linearity of 94.1% compared with invasive blood glucose measurements. The results show the potential feasibility of visible red laser of 650nm wavelength for the development of non-invasive blood glucose monitor. In the future, the performance of this proposed method can be improved by integrating visible laser light with multi-sensing systems. The mathematical algorithm for the correlation between glucose concentration and an output signal can be improved by performing more in vivo measurements on more number of volunteer subjects.

ACKNOWLEDGMENT:

We would like to thank Mr. Venkateshwara Rao, Head of the Biomedical Engineering Department, University College of Engineering (A), Osmania University, India for his technical and constructive support during this project work.

CONFLICTS OF INTEREST:

The authors have no conflicts of interest to declare.

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