Near Infrared LEDs based estimation of Glucose

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Abstract: *As all of us are aware that diabetes is a major cause of concern among affluent families, there is a need for an effective, non-invasive and portable method for glucose monitoring. The article describes a glucose sensing method leveraging light absorption in the near-infrared region. Here, we probe the sample using LEDs at fixed wavelengths at 2150, 2250 and 2350nm. The wavelengths are specifically chosen to lie in the close vicinity of glucose absorption peaks in the combination band. The absorption signatures detected are found to have a strong correlation with the glucose concentration. Linear fitting analysis are done on the readings at each wavelength and show a strong linear relationship at all wavelengths with best R^2 of 0.9857 at 2250nm. The reduction in the number of wavelengths is aimed at drastically reducing the memory, power and computing requirements as compared to traditional approaches thus leading to better portability.*

Keywords: Near Infrared, LED, Glucose estimation, power meter

1. Introduction

Diabetes is a health condition that crops up when the body is not able to process insulin properly[1]. This condition results in elevated sugar levels in the blood. In a recent report published by the International Diabetes Federation globally, there are 573 million adults (20-79 years old) who require regular blood glucose testing to control hyperglycemia. The alarming situation is that by 2045 this number is predicted to reach 783 million[2]. Hence it is critical that a person suffering from diabetes monitors his blood sugar levels regularly to prevent or manage the condition well. Regular blood glucose checks also help diabetic patients to maintain tight control over their sugar. This is done by changes in diet, oral medication, and administration of timely insulin injections[3]. If the blood sugar levels are not maintained in the normal range, it could result in some serious life-threatening ailments such as renal failure, strokes cardiovascular illness, eye conditions, and heart failure.

The standard methods are invasive in nature and painful as they involve the withdrawal of tiny amount of blood via a finger prick. The blood drop is then placed on a glucose strip inserted into a device that uses electrochemical method to measure the amount of sugar in the blood sample. Along with the associated recurrent cost involved with the glucose strip, there is a serious danger of infection at the pricking site. All of the above drawbacks of invasive method underline the need for a non invasive method.

Noninvasive method is capable of circumventing all the problems posed by invasive methods and is able to provide in-vivo blood glucose monitoring [4,5] Various techniques such as reverse iontophoresis[6], amperometric biosensor using enzymes[7], Raman Spectroscopy[8], and Near Infrared Spectroscopy (NIRs)[9,10], are investigated to develop a viable non invasive glucose estimation.

The most popular methods used to predict levels of glucose is absorption of near-infrared (NIR) radiation [11–16] due to the various salient features offered by it. Usually the wavelengths employed are the ones where glucose has absorption peaks and valleys in the wavelength range of 800-2500nm. As the glucose in the sample absorbs the passing light, we can predict the glucoses concentrations form the intensity of signal picked up by the NIR detector. NIR light has a deeper penetration in human tissue. As a result, NIR absorption spectroscopy has been regularly sought in biology and medical research [17, 18].

This paper describes a sensing method which employs light absorption in the near infrared spectral range. The sample is probed at fixed wavelengths in the spectral range of 2000 to 2500nm namely at 2150, 2250 and 2350nm. The wavelengths are chosen such that they lie in the vicinity of the glucose absorption peaks in the spectral region of 2000 to 2500 nm. The application of the above wavelengths improves the signal selectivity and detection accuracy as the absorption signal at these wavelengths highly correlated with the glucose concentration. It also aids in reduction of the overall cost of the devices due to the use of relatively cheap LED light sources as compared to the expensive spectrophotometers used in pathological instruments. The reduction of number of wavelengths to three warrants the requirement of less memory and computation resources.

2. Theory

Due to its relatively deep penetration in body tissues to several millimeters, NIR has been frequently used for tissue probing. The Beer-Lambert law gives the absorption by glucose (A)and is given by $A = -\log(I_0/I_i) = \alpha dc$ where I_i is the input optical power, I_o the output optical power, and α is the extinction coefficient, d the optical path length corresponding to the width of the sample holder, and c the glucose concentration. There is a linear relationship between absorption and the glucose concentration in the sample.

The presence of molecules with O-H, N-H, and C-H bonds in the human tissue results in the absorption of NIR light. During this process they excite the combination and overtone vibration of the bonds by absorbing NIR radiation. The fundamentals of the bond vibration lie in the mid-infrared region. The absorption of glucose lies in two distinct regions of NIR radiation namely the first overtone region and the combination band region which entails a spectral region of 1500 to 1800 nm and 2000 to 2500 nm respectively. Glucose has weak absorption signatures in aqueous solution hence it is very challenging to detect glucose concentration in the NIR region[19, 20].

3. Experimental method

3.1. Sample Preparation

The laboratory samples were prepared with glucose (D-glucose anhydrous, S D Fine-chem Ltd.) dissolved in distilled water (Fisher Scientific). To simulate absorption of the NIR radiation by glucose, the laboratory samples were made have glucose in the range of 0-3g/10ml. The absorption studies were carried out in 1mm quartz cuvette as a sample holder. The 1mm path length was found to be optimum for our study to mitigate the strong water absorption effects.

3.2. Design of the sensing method

The instrumentation consists of three probing NIR LEDs namely LED21-PR, LED22-PR, LED23-PR (IBSG Co. Ltd Company, Russia) with typical wavelengths at 2150, 2250 and 2350nm respectively. All the LEDs were made to emit a power of 1.2μW by varying the forward current in the range of 50-60mA. This was done to eliminate the errors due to variation in intensities of sources. The detection is done using optical power meter (Newport, 2936-R) interfaced with an InGaAs photodiode detector (Newport, 918D-IG-C1-OD3).The InGaAs detector is cooled with a thermo-electric cooler with a response in the 1200 nmto 2500 nm. The optical power meter gives readout of the detected radiation emitted by the LEDs. The above detector is calibrated against National Institute of Standards and Technology, USA standard. The Figure 1 illustrates the experimental setup. The sample is placed between the LEDs and photodiode of the optical power meter. The distance between the LEDs and the detector was 50mm. The emitted light is absorbed by the sample based on the Beer Lamberts law and then detected by the InGaAs detector.

4. Result and Discussion

In the investigation performed on the laboratory samples at the above specified concentration. The emitted power of all LEDs was standardized to 1.2 µW using the driver circuitry. The samples were placed in the cuvette and corresponding detected powers were recorded on the power meter. The initial optical power reduced drastically when only distill water is placed in the sample holder due to the high absorption of water in this spectral region. The detected optical power is tabulated in table 1 for the different glucose concentration contained in the laboratory samples. As the concentration of glucose is reduced from 3g/10ml to 0g/10ml a clear increase in detected power is observed for each of the probed wavelength. This indicates a linear correlation between glucose concentration and detected absorption.

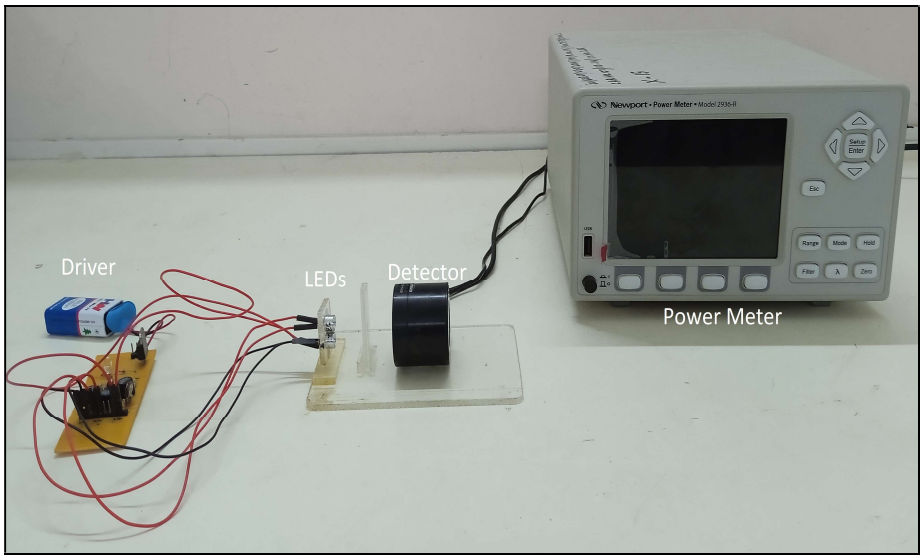

Figure 1. The experimental setup

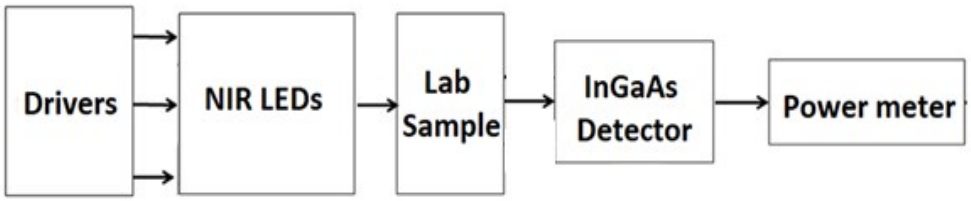

Figure 2. The detailed block diagram

The Figure 2 shows the block diagram of the designed sensing methodology. The experimental setup consists of three LEDs sources driven by a driver section. The radiation emitted by the sources reaches the detector after transmission through the sample. The Beer relationship is utilized to determine the attenuation of light by the sample. The optical power meter is set to apply an averaging of 10000 points on the detected signal. The entire experiment is performed in a dark room to eliminate the interference from the ambient light.

Table 1. The detected optical power for the different laboratory sample

	Wavelength in nm		
	2150	2250	2350
3g/10ml	33.30	47.26	45.01
1.5g/10ml	34.90	48.84	45.99
0.75g/ml	35.60	49.23	46.49
Distill water	35.70	49.92	46.39
	All above readings are optical power in nW		

Table 2. The detected absorption readings for different laboratory sample

	Wavelength in nm		
	2150	2250	2350
3g/10ml	0.0302	0.0238	0.0131
1.5g/10ml	0.0098	0.0095	0.0038
0.75g/ml	0.0012	0.0060	-0.0009
	All above readings are absorption according to Beer Lambert law		

Here the authors validate the data collected to measure glucose satisfactorily by conducting linear fitting analysis. This is done in order to validate if the absorption by glucose is linear to concentration according to Beer Lamberts Law. At each wavelength a linear fitting is done absorption reading tabulated in table II for each of the individual wavelengths. It is clear that there is a linear relationship concentration and absorption. This confirms that we are accurately measuring glucose. Coefficient of determination was used to evaluate the curve fitting quality, The expression used to calculate R^2 is

$$R^2 = 1 - \frac{\Sigma(y_1 \ \hat{y}_1}{\Sigma(y_i - \bar{y}} \qquad (1)$$

The actual data points to which the line is fitted are denoted by y_i, the estimated values by the equation of the line are $\hat{y}_i$ and $\bar{y}$ is the mean of the y_i.

The linear fitting for the absorption measurements at 2150nm is shown in Figure 3(a). The equation of the line fitted is y=0.0106x – 0.0035 with a R^2 for the fitted line of 0.9438. The concentration and absorption bears a linear relationship for glucose at 2150nm.

The linear fitting for the absorption measurements at the 2250nm is shown in Figure 3(b). The equation of the line fitted is y=0.078x – 0.0004 with a R^2 for the fitted line of 0.9857. The concentration and absorption bears a linear relationship for glucose at 2250nm.

The linear fitting for the absorption measurements at the 2350nm is shown in Figure 3(c). The equation of the line fitted is y=0.047x – 0.0022 with a R2 for the fitted line of 0.8980. The concentration and absorption bears a linear relationship for glucose at 2350nm.

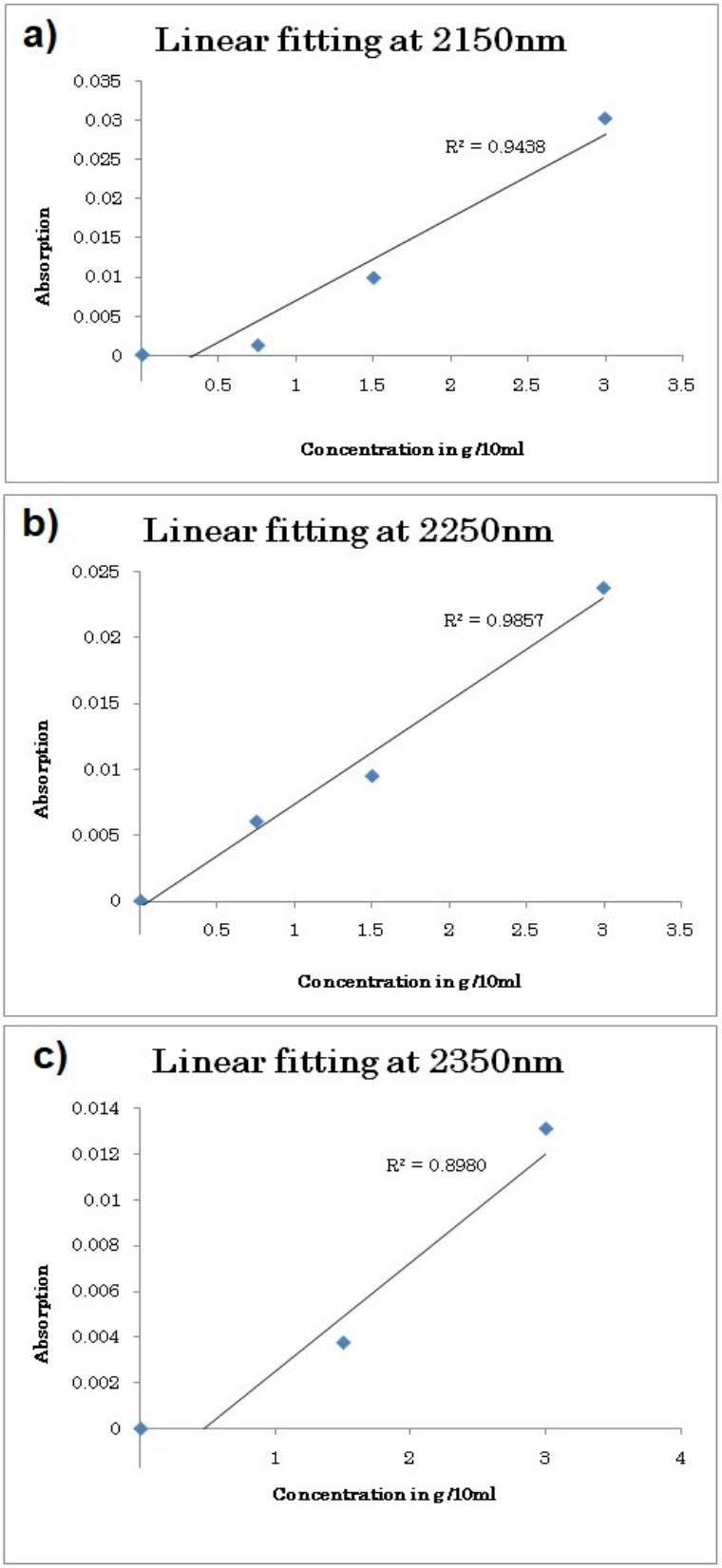

Figure 3. The linear fitting analysis done at (a) 2150nm (B) 2250nm and (c) 3150nm

Conclusion

In this paper, we developed a sensing methodology based on NIR absorption for a non-invasive, cost effective and portable glucose measurement. The results obtained have validated the hypothesis of using fixed wavelengths at glucose absorption peaks in the 2000 to 2500 nm spectral region of NIR. The linear fitting analysis conducted on the recorded absorption reading show good linear relationship at all wavelengths with best R^2 of 0.9857 at 2250nm. The reduction in wavelengths used for probing makes our method efficient in terms of memory, computing and power requirements. The signal to noise ratio of the systems can be improved if the emission power of the sources can be enhanced by use of high power NIR sources such as laser diodes.

Acknowledgments

This research work was supported by the Institutional Seed Money grant of Goa University.

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