A Comprehensive Research on a Non-Invasive Glucometer using Near-Infrared Spectroscopy

[1]Jinit R. Patel, [2]Prof. Yogita M. Parikh
[1]Student, [2]Assistant Professor
[1,2]Biomedical Engineering Department
[1,2]L D College of Engineering, Ahmedabad (Gujarat Technological Engineering)

***Abstract*— Diabetes mellitus more commonly referred to as diabetes has been an on-going problem around the world for several years. According to the World Health Organization, The number of individuals with diabetes rose from 108 million in 1980 to 422 million in 2014. The worldwide pervasiveness of diabetes among adults over 18 years rose from 4.7% in 1980 to 8.5% in 2014. [1] In 2016, an estimated 1.6 million deaths were directly caused by diabetes. Another 2.2 million deaths have been due to high blood glucose in 2012. Practically 50% of all passing inferable from high blood glucose happens before the age of 70 years. According to WHO diabetes was the seventh driving reason for death in 2016. A healthy diet, regular physical activity, maintaining stable body weight, and avoiding the use of tobacco are common ways to prevent or delay the onset of type 2 diabetes. Diabetes can be dealt with and its results dodged or postponed with diet, physical movement, drug and standard screening, and treatment for confusions. In this paper different strategies for glucose checking are evaluated and generally speaking accentuation is laid on the advancement of NIRS (close infrared spectroscopy) based non-intrusive glucose observing. The inspiration of this audit is to show the possibilities, impediments, and specialized difficulties for improvement of NIRS based non-intrusive blood glucose estimation framework. The Non-Invasive Blood Glucometer configuration containing two LEDs of a similar frequency with one going about as photograph producer and the different as the photodetector is proposed in. Three distinct tests (arm, finger, ear flap) were intended to quantify blood glucose utilizing a 940 nm NIR LED.**

***Index Terms*— Blood glucose monitoring, Non-invasive glucose monitoring, Near-Infrared Spectroscopy, Diabetes.**

I. INTRODUCTION

Blood glucose monitors are accustomed to measure the quantity of glucose within the blood, especially of patients with symptoms or a history of abnormally high or low blood glucose levels. Most commonly, they allow diabetic patients to administer appropriate insulin doses. The provision of home-use glucometers, as against clinical-use equipment, has greatly improved the quality of life of such individuals. In any case, such screens require a blood draw through finger pricks for each test, which causes torment and bother. Each test also requires a replacement test-strip, contributing to the recurring cost of such a tool. Even routine optimum insulin dosage requires persistent observation of blood glucose, and presently accessible glucometers don't address this prerequisite. Continuous monitors do exist, but they need to be implanted under the skin, causing trauma while being implanted, which they ought to get replaced hebdomadally. An alternate exists in non-invasive blood glucose monitors. This text introduces an architecture that uses Near Infrared (NIR) spectroscopy to figure out blood glucose levels supported transmittance spectroscopy on the ear lobe. Using multiple body parameters, like blood oxygen saturation, tissue thickness, and a linear regression-analysis based calibration system, an accurate and real-time architecture is proposed. An example implementation using full analog, digital, and mixed-signal capabilities of a programmable system-on-chip, the Atmega328 controller from Atmel, is given also.

II. BACKGROUND

Diabetes is the most recurrent disease nowadays in all societies and almost all age groups. It's a disease during which the body doesn't produce or properly use insulin. The cells in our body require glucose for growth that insulin is kind of crucial. When a person has diabetes, very little insulin is discharged. During this situation, plenty of glucose is obtainable within the bloodstream but the body is unable to use it. The subtypes of diabetes are Type-1 Diabetes, Type-2 Diabetes, and Gestational Diabetes. [2]

- ***Types of Diabetes:***
  - Type 1 diabetes: Is the structure where the pancreas doesn't produce insulin. Also formerly recognized as juvenile-onset diabetes or insulin dependent diabetes mellitus. Ten percent of sufferers have this structure. People with this structure must obtain a synthetic structure of insulin, either via a shot or from an insulin pump.
  - Type 2 diabetes: Here the pancreas does produce insulin, previously known as non-insulin-dependent diabetes mellitus or maturity-onset diabetes. However, it may not produce enough or the body might not use it accurately. This is known as insulin resistance. People with type 2 diabetes are required to take diabetes pills or insulin. In some cases it can be managed with exercise and a meal plan as well [2].
- ***General symptoms of diabetes:***

1. Increased thirst
2. Frequent urination
3. Loss of body weight
4. Frequent hunger
5. Slow healing infection
6. Blurred vision
7. Frequent vomiting

- ***Diagnose test***

1. Urine test
2. Fasting blood glucose level
3. Random blood glucose level
4. Oral glucose tolerance test
5. Glycosylated hemoglobin.
6. Diagnose Test

- ***Non-Invasive Glucose Monitoring: Technologies[4]***

1. Near-Infrared spectroscopic
2. Mid-infrared spectroscopy
3. Raman spectroscopy
4. Optical coherence tomography
5. Bioimpedance spectroscopy
6. Fluorescence spectroscopy

III. NEAR-INFRARED SPECTROSCOPY

Diabetic patients are advised to check their glucose level multiple times a day, but drawing blood is painful and there are chances of potential contamination. Convenience and decrease of torment can empower more successive tests and it gets simpler to control glucose level firmly. Near-infrared (NIR) spectroscopy is considered as a promising noninvasive glucose detection method since the NIR region contains the overtone and contains the hint and mix bands of glucose absorption. Unfortunately, glucose specificity is very low. The explicitness is the way well glucose is recognized without identifying firmly related substances. NIR peaks are broad and overlapped with other blood components. Water, fat, skin, and muscle account for the main absorption in organic tissue. In the IR, water is the most dominant absorbent material and measured spectra are dominated by the water spectrum. Glucose is liable for less than zero.1% of NIR absorption. Additionally, NIR spectra depend on not solely glucose absorption however conjointly light scattering properties of tissue. Soluble compounds, a variety of cell sizes, and inner inhomogeneous structures have an impact on scattering properties. The scattering property of a sample is set by the concentration of scatterers and by the distinction of the refractive indices between scatterers and medium. [4]

Multivariate statistical analysis consisting of the partial least squares regression (PLSR) has been used as an effective device for computing glucose concentration from measured spectra. Preprocessing of measured spectra and the selection of wavelength regions was reported to also be important issues.2, 3 Biological tissue is dominated by light scattering, which further complicates the problem. Not only glucose absorption but also scattering due to glucose molecules changes measured spectra. It has been reported that spectral changes caused by glucose are larger than those caused by absorption.4 It was proposed that a proper distance between the light source and detector could minimize the effect of medium scattering.5 One must think about which part of the body is used as a spot for light illumination and detection, and there have been studies comparing different parts of the human body as measurement sites. [5,6]

The design of noninvasive blood glucometer contains two LEDs of similar wavelength: one acting as a photo emitter and another as the photodetector is proposed in. Arm, finger, ear lobe probes were designed to measure blood glucose using 940 nm NIR LED. Glucose has low absorption peaks at wavelengths of 940 nm, 970 nm, 1040nm, 1085nm, 1109nm, 1150nm, 1197 nm, 1408nm, 1536nm, 1688nm, 1925 nm, 2100nm, 2261nm and 2326nm, But at 940nm, 1085nm and 1150nm wavelengths the attenuation of optical signals consisting of the blood like water, platelets, red blood cells, etc. is minimum, therefore an expected depth of penetration can be achieved and actual real concentration can be forecasted. NIR light communication has been determined through an ear lobe, finger web and finger cuticle, skin of the forearm, lip mucosa, oral mucosa, tongue, nasal septum, cheek, and arm. NIR diffuse reflectance measurements performed on the finger showed a correlation with BG but predictions were often not adequately precise to be clinically worthy. The method has serious limitations as it is caused by physicochemical parameters such as changes in skin hydration, body temperature, blood pressure, and concentrations of triglyceride and albumin. Moreover, it is subtle to environmental differences in temperature, humidity, atmospheric pressure, and carbon dioxide content. The estimation is likewise influenced by the thickness and thermal properties of the skin and the illness states such as hyperglycemia and hyperinsulinemia.

- ***Flowchart of System***

The flowchart of the system is shown in fig.1. Firstly the Ear Lobe Thickness is measured followed by blood oxygen measurements. After the NIR Light at lower wavelength is initialized, lower NIR wavelength attended signals are stored. Similarly, the middle and higher wavelength is initialized and stored. This received signal is amplified and filtered for noise by using first-order filtering to all NIR signals. An average is been calculated by doing average all variables over X time units. Input variables are then queued followed by applying the best fit linear regression model. Based on that final oxygen and glucose level is determined and it is displayed on LCD or other terminals.

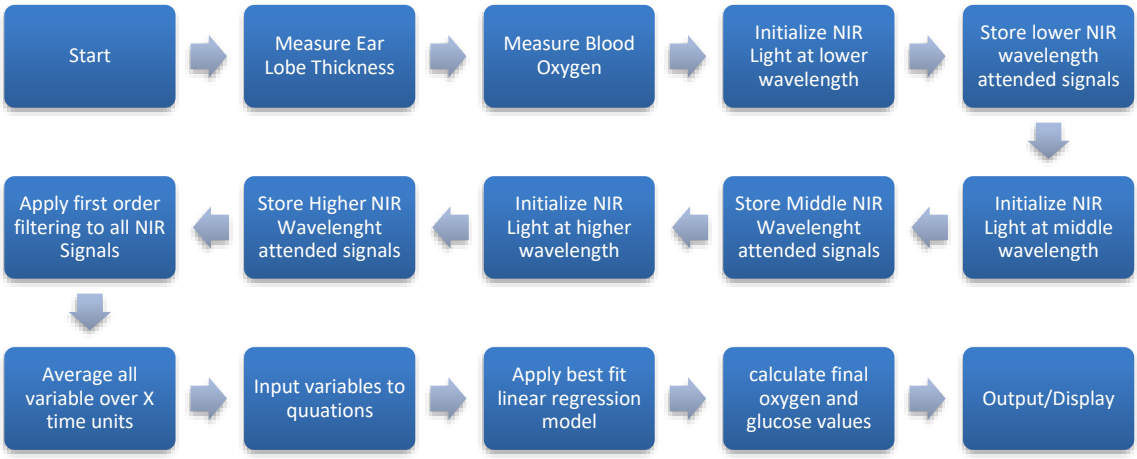

Figure 1: The complete flowchart of a system

- **Selection of *Wavelength***

There are some wavelengths at which glucose absorption is exceptionally large. These wavelengths are 935nm, 1040nm, 1085nm, 1109nm, 1150nm, 1365nm, 1450nm, and 1536nm. This band is transparent for water and consequently extremely helpful for examination on glucose wavelengths of 940nm, 1085nm, and 1150nm has been chosen for analysis. More than 1550nm penetration depth of human tissue is precisely larger but the absorption of light by water in the blood rises prominently. [7]

IV. HARDWARE DEVELOPMENT

The fundamental goal is to dissect infrared spectra through glucose human samples for blood glucose level measurement. Infrared light is passed through the fingertip. The attenuated light is acknowledged by the photodiode located at the opposing side of the IR emitter. The proposed work diagram is shown in Figure 2.

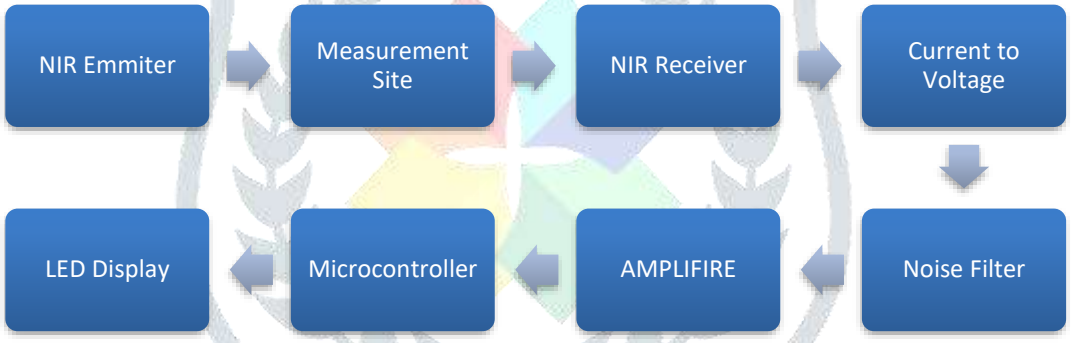

Figure 2: Diagram of Non-Invasive Glucose Concentration Measurement System

The proposed work is derived from the NIR optical technique. NIR emitter for 940nm, 1085nm, and 1150nm wavelength is suitable for measuring blood glucose concentration. The sensing unit consisting of a NIR receiver is positioned on either side of the fingertip. When the NIR light is penetrated through the fingertip in which it comes in contact with the glucose molecule, a part of NIR light gets absorbed depending on the glucose concentration in the blood and the remaining light is passed through the fingertip. The amount of blood glucose concentration is derived from the amount of NIR light passing through the fingertip.

The attenuated signal is detected by the photodetector, which is used for analog processing. The output current coming out from the photodetector is converted into a voltage signal and then it is filtered and amplified to remove noise and black current. This processed signal is fed into a microcontroller. The built-in ADC block is used to convert received analog signals into digital form. Second-order regression analysis is used to process the digital signal to predict the blood glucose value. A linear regression model is used for analysis, which is performed by utilizing the dataset.

V. TEST AND RESULT ANALYSIS

The output of the designed analog front end circuit is planned and results were obtained. The voltage yield obtained as a result of variety in signal intensity from the NIR sensor is observed. The age limit ranging from 20-80 were approached to volunteer this experimental research. Some Sample readings were not gained appropriately and were discarded for analysis. Test readings with gadget experimentation and real Lab testing result appear in Table 1.

Sr#	Age	Fasting		Non-Fasting	
		Glucose Concentration (mg/dL)	Output Voltage (mv)	Glucose Concentration (mg/dL)	Output Voltage (mv)
1	21	93	1555	105	1610
2	24	119	1616	133	1641
3	25	131	1705	148	1648
4	36	73	1575	92	1534
5	44	122	1640	176	1648
6	52	125	1620	160	1784
7	76	100	1560	118	1608
8	82	92	1513	98	1542

Table 1: Test Results

The curve fitting plot for regression analysis is shown in Figure 3, performed on collected samples.

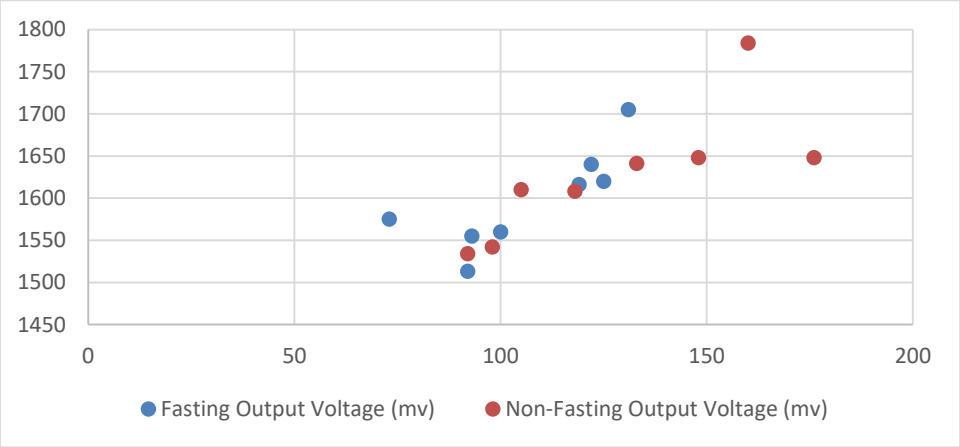

Figure 3: Curve fitting plot for regression analysis

VI. CONCLUSION

A simple front end for non-invasive glucose measurement is designed and tested successfully. The outcomes show that there exists a correlation between intensity level after transmission and glucose level in blood. The glucose level in both diabetic and non-diabetic persons is broke down using variation in intensity and results were acquired successfully. Additionally, this data can be sent to a specialist for additional investigation.

VII. ORCHID ID

Jinit Patel: https://orcid.org/0000-0002-6798-7845

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