Voltage Intensity Based Non-Invasive Blood Glucose Monitoring

K A Unnikrishna Menon[1], Deepak Hemachandran[2], Abishek Thekkeyil Kunnath[3]
Amrita Center for Wireless Networks and Applications
Amrita Vishwa Vidyapeetham, Kerala, India
[1]kaumenon@am.amrita.edu, [2]deepakadiyodi@gmail.com, [3]abishektk@am.amrita.edu

***Abstract*—Diabetes is one among the supreme health challenges of the current century. Most common method for estimation of blood glucose concentration is using glucose meter. The process involves pricking the finger and extracting the blood along with chemical analysis being done with the help of disposable test strips. Non-invasive method for glucose estimation promotes regular testing, adequate control and reduction in health care cost. The proposed method makes use of a near infrared sensor for determination of blood glucose. Near-infrared (NIR) is sent through the fingertip, before and after blocking the blood flow by making use of a principle called occlusion. By analyzing the variation in voltages received after reflection in both the cases with the dataset, the current diabetic condition as well as the approximate glucose level of the individual is predicted. The results obtained are being validated with glucose meter readings and statistical analysis of the readings where done. Analysis shows that the bias as well as the standard deviation decreases as the glucose concentration increases. The obtained result is then communicated with a smart phone through Bluetooth for further communication with the doctor.**

Index Terms— Diabetes, Noninvasive, NIR, Intensity

I. INTRODUCTION

Diabetes is considered as one of the major contributors of premature illness and death among non-communicable diseases. According to the statistics about 100 million people live with diabetes worldwide and it is increasing day by day [1].

Number of diabetic patients is increasing at a greater pace; measures are to be made for controlling the diabetic patients. Measures for improvement include include self-management through disease preclusion and control.

Diabetes is a state where the human body does not produce the amount of insulin as required to regulate the normal blood glucose level [2]. So, normally all diabetic patients are emphasized to regulate their blood glucose levels through proper diet and by injecting insulin when needed. Diabetes in individuals leads to major complications including heart failure, blindness and amputation.

Efficacious method of treatment for diabetic patients is by measure blood glucose levels periodically on consistent intervals. At present the patients are making use of the piercing the skin and extracting the blood and doing chemical analysis using disposable test strips called a glucose meter.

So, developing a noninvasive way of measuring blood glucose would be much more user friendly from the end user. The main advantage of noninvasive methods is the aid from pain and malaise due to frequent finger pricks. Noninvasive determination of the glucose reduces all the above difficulties involved and hence reduces the healthcare cost. The method proposed, makes use of the difference in voltage measured in both the before and after occlusion condition of the received signal from the NIR sensor, to detect whether the patient is diabetic or not along with the approximate glucose level. Here the error percentage set using the mathematical analysis done using Clark's error grid analysis method is +/- 15mg/dl.

The remaining portion the paper is organized into different sections. In section II related works done in noninvasive field have been discussed, while section III discusses the theory of operation, section IV discusses the proposed system architecture and section V discusses about the proposed algorithm and VI the experimental results. Conclusions and future developments have been illustrated in section VII.

II. RELATED WORK

Current methods for measuring blood glucose include pricking the finger piercing the vein and collecting the blood. But the major problem with the existing method is that it is not proper for continuous monitoring of blood glucose level. The difficulties associated with this can be removed by making used of the proposed non-invasive way of measurement.

Gelao et. al describes an architecture based on dielectric spectroscopy for non-invasive, continuous blood glucose monitoring using a blood glucose sensor [3]. The electrical circuit, schematic and the PCB design were made. Using a dielectric constant for measurement, the frequency of both, amplitude and phase indicate the blood glucose level. Using dielectric spectroscopy through the change in tissue permittivity glucose level is measured.

Ashok et. al describes a method for assessment of blood glucose level of diabetic and non-diabetic patients using Trans illuminated laser beam. The laser used here is an atomic gas laser also called a He-Ne laser, operating at a 632.8 nm wavelength [4]. Here a single mode laser was used as a monochromatic light source to eliminate mode interference noise. Making use of this method it was able to monitor blood glucose level of the diabetic patient continuously and noninvasively. The result obtained shows that blood flow is directly proportional to blood glucose level.

Abdallah et. al describes different kinds of methods for detecting blood glucose. Elastic and inelastic (Raman) scattering as well as fluorescence and IR Spectroscopy measurements was discussed for the development of a solid noninvasive device for home monitoring [5]. Proposed method is making use of an optical multi-sensor, which measures the fluorescence and light scattering in the tissue optical window in and around a visible range through the finger.

Burmeister et. al describes collecting noninvasive human spectra by an experimental protocol that is designed to minimize correlation with blood glucose. In this paper, a series of first overtone transmission spectra is passed across the tongues of five humans who have diabetes [6]. Despite the high degree of scattering, it was observed that correlations were not related to temporal variances as the protocol separates glucose concentration and time.

Wang et. al describes a method based on metabolic heat conformation (MHC) and developed a prototype. In this method glucose level is estimated from the quantity of heat dissipation, local tissue blood flow rate and degree of blood oxygen saturation [7]. Clinical tests were conducted and correlation coefficient of the blood flow rate between this method and the Doppler blood flow meter were found to be equal to 0.914. This result is closer, yet still not acceptable for clinical use.

Amir et. al has developed a successful method acceptable for clinical use, which was used in our research. Amir et. al describes a noninvasive method for detecting blood glucose using the technology of occlusion spectroscopy, developed using a NBM device by Orsense Ltd. Here the technology is being presented and the efficiency of the device is evaluated [8]. In this experiment a light is passed through the finger and the amount of light present on the other side of the finger is measured as photons. The presence of glucose blocks the light from passing through the finger [9]. Therefore, the blood glucose can be measured as light intensity varies. Analyzing the transmission spectra shows that with a decrease in transmitted light intensity concentration, hematocrit increases.

III. Theory of Operation

In this research, the technology is based on the scattering property which has direct effect on glucose [10]. This includes passing an NIR through the finger and the amount of light present on the other side of the finger is measured. The presence of glucose blocks the light from passing through the finger. The blood glucose present can be measured by analyzing the variations present in the light intensity. A typical forearm skin tissue consists of three layers, i.e., epidermis, dermis, and subcutaneous tissue. The epidermis contains the stratum corneum and capillary vessels are not developed sufficiently in it, which does not contain useful information about blood glucose content. The subcutaneous tissue is mainly composed of fatty tissues. This tissue also does not provide any information about blood glucose content. Whereas on the other hand, there are well-developed capillary vessels in the dermis tissue and blood glucose is easily transferred to the dermis tissue due to its high permeability. Thus, the glucose content in the dermis is assumed to correlate with the blood glucose content in the same way as that in the interstitial fluid [11] [12]. As a result, with the growing concentration of glucose, fewer photons are absorbed and the light intensity increases [4]. The proposed method is based on the principle of absorbance transmittance photometry. Here the value of absorption, of light energy, is dependent on the number of molecules present in the absorbing material. Intensity of light leaving the matter is used as an indication of concentration of that particular matter [13].

IV. SYSTEM ARCHITECTURE

The proposed system setup consists of a reflective optical sensor, for transmission and reception of NIR rays with the fingertip as the body site. The proposed system architecture is shown in Fig 1. The optical sensor used is TCRT5000 operating at a wavelength of 980nm. NIR signals are passed through the fingertip with and without blocking the blood flow. The output is then fed to a microcontroller unit, to perform voltage variation analysis of the received signal, so as to monitor whether the obtained value is within threshold. Here intensity is inversely proportional to voltage. When the light intensity falling on the phototransistor increases, the conduction through the transistor will also increase as it will be in ON state. The output is taken across the collector of the phototransistor. As the conduction increases i.e., as intensity increases the output voltage across the collector decreases. This is due to the increase in voltage drop across the collector resistor.

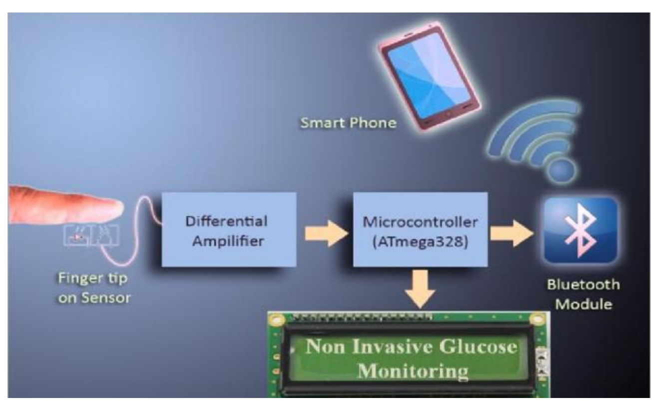

Fig. 1. Proposed System Architecture

The microcontroller used here is ATmega328. The reflected signal is first fed to ADC to perform an analog to digital conversion and then comparison based analysis.

The NIR sensor consists of a single module consisting of a transceiver unit. All the blood in a body represents a challenging matrix, especially when attempting to use noninvasive analytical measurements and infrared. The principal obstacles for measurements are: the strong attenuation of incident radiation by scattering processes and the strong absorbance properties of the solvent and major chemical constituents [13].

On receiving the signal from the amplifier ADC conversion of the received signal is performed and stored in the ADC buffer. The microcontroller unit used is ATmega328. The specifications of components used are given in Table 3.1 [14] - [16].Inside the microcontroller unit when the ADC buffer gets filled intensity variation analysis of the signal is performed. The analysis is performed by making use of the dataset made based on the long term machine learning analysis. In this machine learning process a lot of data has been acquired by analyzing the patients using the glucose meter as well as with the hardware set up. The obtained analysis results is displayed on an LCD as well as send to a smart phone using Bluetooth where the individual would be intimated about the diabetic status and health condition.

TABLE1. COMPONENT SPECIFICATIONS

Component	Specification	Dimension(L*W*H)mm	Operating Voltage(V)
NIR Sensor	Vishay-TCRT5000	10.2*5.8*7	3.3-5.0
Microcontroller	ATmega328	75*53.5*15	1.8-5.5
Bluetooth Module	HC-06	28*15*2.35	3.0-4.2

V. ALGORITHM

The algorithm discussed is for testing the basic capabilities of the proposed system. Here the data is read from 8th pin of microcontroller and stored in a variable'd'. Meanwhile algorithm also checks in which position the switch is placed. When it is put in correct position it reads the values and calculates the average sensor value and displays it until count<num_count. The read sensor value is converted into voltage values by multiplying with a factor of 0.0049 before it's displayed. Similar process is repeated by changing the position the tact switch. In this algorithm there are three conditions to be noted on i.e., which period of time the individual is taking the test. According to the condition set by the user corresponding flag would be set. For each condition the threshold glucose level is different. So according to the selected mode of operation the user is using the algorithm works.

Algorithm 1 Gluck-check Algorithm

```
1: START
2: Setup the pin mode, clear lcd, set Arrays diff_array, array_length and glucose_array
3: Read the mode
4: Take the reading before occlusion
5: if (sensorvalue > threshold, otherwise goto step3) then
6:     Compute the average sensorvalue w.r.t number of iteration
7:     print and Store reading in voltBO
8: end if
9: Take the reading after occlusion
10: if (sensorValue > threshold, otherwise goto step9) then
11:     Compute the average sensorvalue w.r.t number of iteration
12:     print and Store the reading in voltAO
13: end if
14: if (voltAO >= voltBO, goto step15 else goto step2) then
15:     sensorValue2 < − − voltBO − voltAO
16: end if
17: for all (i = 0 to array_length otherwise goto23) do
18:     if (sensorValue2 > diff_array[i] and sensorValue2 > diff_array[i +
        1], else goto step17) then
19:         glucose < − − glucose_array[i]
20:         goto step17
21:     end if
22: end for
23: if (Mode is Fasting goto step24 otherwise goto step30) then
24:     if (glucose > fasting_upper_threshold or glucose <
        fasting_lower_threshold, else goto step26) then
25:         Print "Diabetic!!!!!!"
26:         Print "Healthy!!!!!"
27:         goto step41
28:     end if
29: end if
30: if (Mode is POST Prandial goto step31 otherwise goto step37) then
31:     if (glucose > post_upper_threshold or glucose <
        post_lower_threshold, else goto step33) then
32:         Print "Diabetic!!!!!!"
33:         Print "Healthy!!!!!"
34:         goto step41
35:     end if
36: end if
37: if (glucose > random_upper_threshold or glucose <
    random_lower_threshold, else goto step39) then
38:     Print "Diabetic!!!!!!"
39:     Print "Healthy!!!!!"
40: end if
41: END
```

Fig. 2. Gluck-check Algorithm

After calculating the voltages in both the cases i.e, the two sensed averages it is then compared with the dataset values. In the dataset for each corresponding voltage obtained there is a glucose level. For each condition i.e.; fasting, pre-prandial and random different threshold values are also set. So after getting the glucose level value from the dataset it is compared with the threshold level

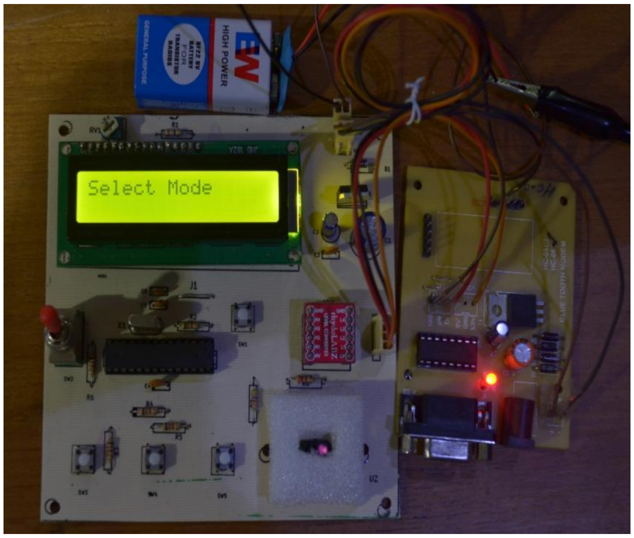

Fig 3. Hardware setup

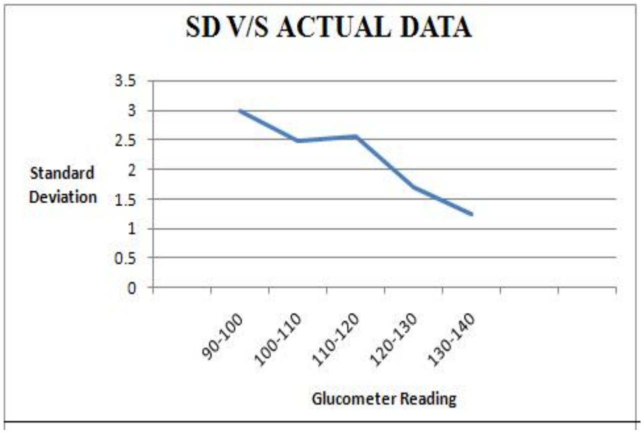

Fig 4. Standard Deviation v/s Actual Data Analysis

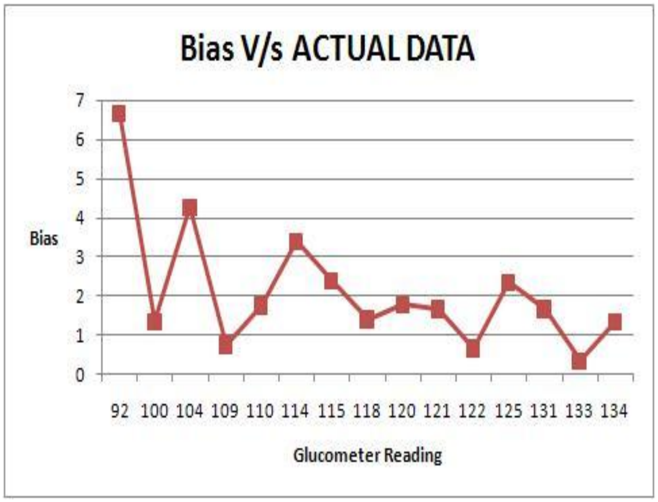

Fig 5. Bias v/s Actual Data Analysis

corresponding to the set flag. By this comparison and validation method, the obtained result would be displayed on an LCD and is further communicated with a smart phone using Bluetooth. Thus the user is able to analyze their current diabetic condition. The proposed Gluck-check algorithm is shown in Fig 2.

VI. EXPERIMENTAL RESULTS

The output of the designed analog front end circuit is tested and results were acquired. Voltage output obtained as a result of variation in signal intensity from NIR sensor is set as the input to the microcontroller. The PCB designed is shown in figure 3.

Here the analysis was performed under two phases; fasting and pre-prandial. First the finger tip is placed over the NIR sensor. The reflected received signal is send to microcontroller where the voltage conversion and difference is calculated and displayed in LCD. At the same time the glucose level obtained by database analysis is further communicated to a smart phone via Bluetooth. The power to switch ON the device is driven from a DC battery source; same power is used to power the Bluetooth device also. Since the Bluetooth works in 3V a level convertor is used. Three switches are used which helps the user to select in which phase the individual need to test. A reset button is also provided in case the device gets hang.

The pilot run of the device was successfully conducted at Amrita WNA and ashram devotees. Invasive method by collecting the blood and analyzing it was performed along with the device experimentation. The age limit of individuals who came forward to volunteer the service was in the range from 22-60. The results obtained by comparing both the testing methods found to be in close correlation. The difference between the readings obtained were >15mg/dl. Major assumptions taken into consideration are; there is no other light interference other than NIR.

When the device is powered ON the LCD would display as “Gluck-Check”, “WELCOME”,”READY FOR TEST”. Then it tells the user to select the mode they need to operate. According to the user selection input the device will tell the user to follow the instructions. Mean while the device would be collecting the values and calibrating the result by checking with the dataset. The Bluetooth of the smart phone is also switched on and paired with the device. While the user selects the input phase it gets displayed on the terminal of the android app also. Android app called blue term will display characters sent and received via a Bluetooth serial port connection. Whenever the full process is over the approximate glucose level along with the current diabetic condition would be displayed on the terminal.

Data analysis is performed using the readings obtained from 40 individuals as the case study. This was done to analyze the accuracy of the system developed. Glucose values were obtained at specific intervals using glucose meter along with the NI device. The data was collected among students from Amrita. From the analysis done the results obtained shows that as the glucose meter reading increases the standard deviation corresponding is decreasing. Similar is the case with the bias. The inference is that error percentage is more in case of low glucose readings and it decreases as the glucose meter reading increases. The analysis results are shown in Fig 4 and Fig 5.

VII. CONCLUSION AND FUTURE WORK

A lot of research work has been performed over the years to develop noninvasive measurements of glucose. Our research work provides an innovative idea to solve the existing problems, which patients are facing with the current glucose meter technique. A framework for non-invasive blood glucose measurement is been designed and tested successfully and results were validated. The results obtained from intensity variation analysis shows that there exists a correlation between the variation in intensity and glucose level. Also the presence of glucose in normal and diabetic patients is being analyzed using variation in intensity and the results were obtained successfully. In the future, research will be extended to increase the accuracy of the device for making it clinically available in near future.

ACKNOWLEDGMENT

We would like to express our immense gratitude to our beloved Chancellor Sri Mata Amritanandamayi Devi for providing a great motivation and inspiration for doing this research work.

REFERENCES

[1] Statistical Analysis [Online]. Available: http://www.who.int/mediacentre/factsheets/fs236/en/

[2] Diabetes[Online].Available:http://www.emedicinehealth.com/diabetes/article_em.htm.

[3] "Gennaro Gelao, Roberto Marani, Vito Carriero and Anna Gina Perri:"Design of a Dielectric Spectroscopy Sensor for Continuous and Non-Invasive Blood Glucose Monitoring", *International Journal of Advances in Engineering and Technology*, May 2012.

[4] V.Ashok, A.Nirmalkumar, and N.Jeyashanthi:" A Novel Method for Blood Glucose Measurement by Noninvasive Technique Using Laser", World Academy of Science, Engineering and Technology, 2011.

[5] O. Abdallah, A. Bolz, J. Hansmann, H. Walles, and T. Hirth*:" Design of a Compact Multi-Sensor System for Non-Invasive Glucose Monitoring Using Optical Spectroscopy*", International Conference on Electronics, Biomedical Engineering and its Applications (ICEBEA'2012), Jan. 7-8, 2012.

[6] Jason J Burmeister, Mark A Arnold and Gary W Small*:" Noninvasive Blood Glucose Measurements by Near-Infrared Transmission Spectroscopy across Human Tongues*", Diabetes Technology and Therapeutics, 2000.

[7] Fei Tang *, Xiaohao Wang, Dongsheng Wang and Junfeng Li*:" Non-Invasive Glucose Measurement by Use of Metabolic Heat Conformation Method*", Sensors 2008, 8, 3335-3344; DOI: 10.3390/s8053335, 2008.

[8] Prof..Mrs.A.A.Shinde, Dr.R.K.Prasad:"*Non Invasive Blood Glucose Measurement using NIR technique based on occlusion spectroscopy*", International Journal of Engineering Science and Technology (IJEST), Vol. 3, December 2011.

[9] O. Amir, D. Weinstein, S. Zilberman, M. lka Less, D. Perl-Treves, H. Primack, A. Weinstein, E. Gabis, B. Fikhte, and A. Karasik: "*Continuous Noninvasive Glucose Monitoring Technology Based on "Occlusion Spectroscopy",* Journal of Diabetes Science and Technology, July 2007.

[10] Scattering Property [Online]. Available: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2769638/

[11] S. N. Thennadil, J. L. Rennert, B. J. Wenzel, K. H. Hazen, T. L. Ruchti, and M. B. Block, "*Comparision of glucose concentration in interstitial fluid and capillary and venous blood during rapid change in blood glucose levels*," *Diabetes Technol. Ther.*, vol. 3, no. 3, pp. 357–365, 2001.

[12] J. P. Bantle and W. Thomas, "*Glucose measurement in patients with diabetes mellitus with dermal interstitual fluid*," *J. Lab. Clin. Med.*, vol. 130, no. 4, pp. 436–441, 1997.

[13] Absorbance transmittance photometry [Online]. Available: http://www.chem.purdue.edu/courses/chm224/Lab-Experiments/expt4_GENESYS_v2.pdf.

[14] TCRT5000 Optical Reflective Senor with Transistor Output [Online].Available:http://www.vishay.com/docs/83760/tcrt5000.pdf

[15] Bluetooth Module RN 42 [Online].Available: www.microchip.com/mymicrochip/filehandler.aspx*?*

[16] ATmega328 datasheet [Online].Available: www.atmel.com/Images/doc 8161.pdf.