Non-invasive blood glucose monitoring using near infrared spectroscopy

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Sruthi Krishna
Amrita Vishwa Vidyapeetham

Non-Invasive Blood Glucose Monitoring Using Near Infrared Spectroscopy

Gayathri B, Sruthi K and K A Unnikrishna Menon

Abstract— **Diabetes has become a grave concern which can affect anyone irrespective of their age. To prevent the uneasiness of invasive glucose monitoring system, it is desirable to develop a low cost non-invasive blood glucose monitoring system. The present work proposes the feasibility of developing such a method for the continuous monitoring of blood glucose concentration using near infrared spectroscopy. Both linear regression and polynomial regression analysis are studied for developing an enhanced algorithm for estimation of glucose concentration using the scattering property of glucose molecules and the principle of photoplethysmography. Processing of data conversion is performed with MSP430G2553 microcontroller in the integrated development environment (IDE) of Code Composer Studio (CCS). Data analysis is carried out in MATLAB from which a relation between blood glucose concentration and photoplethysmograph is derived.**

Index Terms— **Photoplethysmography, non-invasive glucose monitoring, scattering, regression techniques.**

I. INTRODUCTION

In order to enhance the health care systems, several patient monitoring systems especially multiple parameter monitoring devices are evolving in the world [1] and diabetes is one among them. Just like real doctors and nurses, such health care tools with good communication skills can promote healthier lifestyles. Diabetes mellitus, more commonly referred to as diabetes, is a lifelong disease. The insulin hormone is responsible for controlling the blood sugar amount in our body. However, in a diabetic person, his body either doesn't produce enough insulin or the insulin produced doesn't work properly. As a consequence, blood sugar level rises up. This creates relentless complications which may degrade different body organs like eyes, kidneys, nerves, teeth and heart [2]. There are cases in which blood glucose level falls too low called hypoglycemia. Research says around 387 million persons are affected by diabetes [3]. Considering these hardships, it is crucial to treat and regulate glucose levels on time thus helping to determine how well our diabetes is being managed.

Blood sugar tests can be carried out in fasting or random conditions. Fasting state provides the most accurate results and is easier to interpret than random state tests. The prevalent diagnosing systems for blood sugar system are invasive in nature. This procedure is performed by drawing blood through puncturing the skin [4] with a needle and applying it to a chemically active test strip. Another procedure for diagnosing blood sugar is non-invasive method. Some of the existing non-invasive methods are near infrared (NIR) detection, ultrasound and dielectric spectroscopy which do not need any supply of blood for conducting the tests and calculating its result.

Section II describes the principle being used for the development of the proposed method. Section III gives the outline of system architecture and design. Inferences based on experimental procedures are depicted in section IV. Finally the work is summarized in section V.

II. METHODOLOGY

A. Photoplethysmography

The skin tissue consists of three layers of which only dermis layer consists of information about blood glucose [5]. Infra-red wavelength (780nm to 2500nm) is able to penetrate until the dermis layer, hence avoiding the need of any invasion procedures [6]. The transmitted IR light will be absorbed by different skin tissues, different molecules in the blood like melanin, keratin, fats, proteins, hormones etc. and the skin pigments. Variations in the volume of blood flow are detected by the PPG sensors optically. It records the changes in reflected light intensity from the dermis layer of skin [7].

A photoplethysmographic waveform consists of both direct current (DC) and alternating current (AC) components. The DC component of the PPG waveform corresponds to the transmitted or reflected optical signal from the tissue while the changes in blood volume that occurs between the systolic and diastolic phases of the cardiac cycle are indicated by the AC component [8]. In this work, reflection photoplethysmography is considered for determining glucose levels non-invasively. Here light passes through the epidermal layer and on reaching dermis layer light gets absorbed, scattered and reflected by the

Gayathri B is with Amrita Center for Wireless Networks and Applications (AmritaWNA), Amrita School of Engineering, Amritapuri, Amrita Vishwa Vidyapeetham, Amrita University India. (e-mail: gayathri.b.hari@gmail.com).

Sruthi K is with Amrita Center for Wireless Networks and Applications (AmritaWNA), Amrita School of Engineering, Amritapuri, Amrita Vishwa Vidyapeetham, Amrita University, India. (e-mail: sruthik@am.amrita.edu).

K A Unnikrishna Menon is with Amrita Center for Wireless Networks and Applications (AmritaWNA), Amrita School of Engineering, Amritapuri, Amrita Vishwa Vidyapeetham, Amrita University, India. (e-mail: kaumenon@am.amrita.edu).

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glucose molecules. The intensity of reflected light from the dermis layer was examined for predicting glucose levels.

B. Principle

When a beam of infra-red light is focused on to the fingertip, it gets absorbed, scattered and reflected by the glucose molecules present in the dermis layer. It is a medical fact that blood absorbs more light than its surrounding tissue [9]. The concentration of glucose molecules will be higher in blood and therefore scattering of light by the glucose molecules will be more in case of a diabetic patient. Thereby, much amount of light coming out through the fingertip. Thus the reflected intensity will get increased in diabetic patients and vice versa for non-diabetic persons.

The present proposed work is based on the above fact that blood glucose concentration is proportional to the intensity of reflected light.

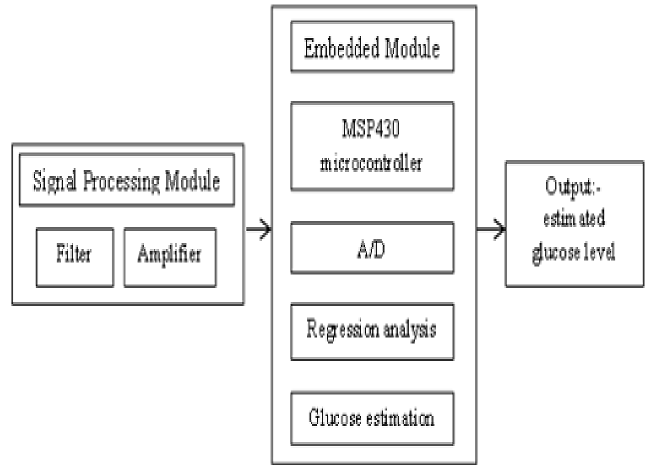

Fig. 1. System Architecture

III. SYSTEM ARCHITECTURE

The system architecture of the proposed system is depicted in Fig.1. The reflected light from the IR sensor is passed through a signal processing module for its processing and then to an embedded module where different operations are performed by the microcontroller. At the end, the estimated glucose values are displayed.

The hardware components of the proposed system include an IR sensor, a micro-controller, a high pass filter, an amplifier and a low pass filter. The developed algorithm has to be embedded into the respective micro-controller. The schematic diagram of hardware design is represented in Fig. 2.

An ultra-low power MSP430G2553 microcontroller is used here. INA128, an instrumentation amplifier is selected for amplification purpose expecting better accuracy and lesser noise. The cut off frequency of the high pass filter is selected after considering the average human heart rate. In certain cases it may vary from 42-120 beats/minute.

The experimental procedure is explained in this section. Initially, PPG signal is acquired from the IR sensor. Since the blood volume changes are associated with the alternating portion of the PPG signal, the output of the sensor is passed through a high pass filter with cut off frequency of 0.7Hz (while considering 42 b/m). This filtered signal is amplified by a low noise instrumentation amplifier with a gain 30. The amplified output is further passed through a low pass filter with a cut off frequency of 2.3Hz (while considering 120 b/m).

Finally, the output signal is fed to MSP430 microcontroller, where analog to digital (A/D) conversion of the signal is performed. An algorithm based on regression analysis is coded in CCS which is embedded in the microcontroller. Here the glucose values in blood are assessed and the result is displayed in the console; the PPG wave form is shown in Fig. 3.

Software requirements of the system

The mathematical modelling analysis is performed in MATLAB. Further the analog to digital conversion and UART transmission are implemented with the help of Code Composer Studio software which is the integrated development environment (IDE) identified for the microcontroller MSP430G2553. Non-invasive glucose value prediction was carried out in MATLAB.

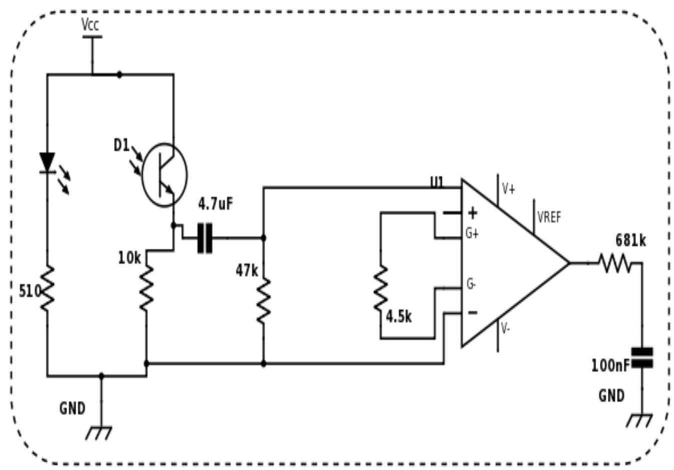

Fig. 2. Schematic diagram

Fig. 3. Photoplethysmograph waveform

IV. EXPERIMENT PROCEDURES AND RESULTS

A. Data Collection

For obtaining the non-invasive blood sugar concentration, the vital step is to derive a relation between blood sugar levels and the PPG. For this purpose, a pre-collected database is essential. 24 subjects in the age group of 20-30 years (including both male and female volunteers) participated in this trial. Invasive blood glucose readings and PPG voltage values were collected from all of them at two different stages viz., prandial and post prandial conditions (fasting and after taking food respectively). Maximum voltage peaks of PPG were taken, as there exists a functional relationship between the PPG signal and blood glucose level [10] i.e., the voltage intensity of PPG signal is proportional to the blood glucose concentration.

B. Data Analysis

Two slightly different regression analysis models were conducted with the two sets of data viz., prandial (fasting) and post prandial (after food intake) in MATLAB and tried to construct a system that could determine a method for prediction of blood glucose level for humans using non-invasive method of NIR spectroscopy.

C. Principle of Linear Regression Model

The general linear regression model is given by:

$$Y = mX + C \tag{1}$$

where Y is the blood glucose measure and X is the voltage of PPG signal. Glucose concentration was predicted from the correlation coefficient obtained in linear regression.

D. Principle of Polynomial Regression Model

The general polynomial regression model is given by:

$$Y = a_0 + a_1 x + a_2 x^2 + ... + a_n x^n \tag{2}$$

where Y is the blood glucose measure and x is the voltage of PPG signal. From the database collected and on performing poly fit analysis, a third degree polynomial of the form

$$Y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \tag{3}$$

was derived using which glucose concentration was predicted from the correlation coefficients a_0, a_1, a_2 and a_3 thus obtained.

E. Observations

To obtain the correlation coefficient between invasive blood glucose and PPG voltage levels, linear regressions as well as polynomial regression analysis were done in MATLAB with the pre-collected data samples. Fig. 4. and Fig. 5. show linear regression analysis for prandial condition and post-prandial conditions respectively; Fig. 6. and Fig. 7. shows polynomial regression analysis for prandial condition and post-prandial conditions respectively. In the case of linear fit, the coefficient for fasting condition was found to be 0.7 and that of post-prandial condition was 0.8. As the coefficient is closer to one it shows that there exists a strong relation between the X and Y components. For complete analysis of non-invasive glucose monitoring method, the random (where the patient can eat or drink before taking the test) glucose level measurements of different subjects has to be considered.

Statistical studies were executed on 24 subjects via regression analysis from which it was observed that the glucose level and voltage intensity are directly proportional in case of reflection photoplethysmography. This is very well understood from the results of regression techniques. For linear fit model, on attaining the correlation coefficient from regression of invasive glucose data sets, the slope and intercept values so obtained were substituted in equation (1) for the estimation of non-invasive glucose concentration. While for the poly fit model the correlation coefficients a_0, a_1, a_2 and a_3 along with the voltage intensity x from PPG are input into equation (3) for glucose concentration prediction.

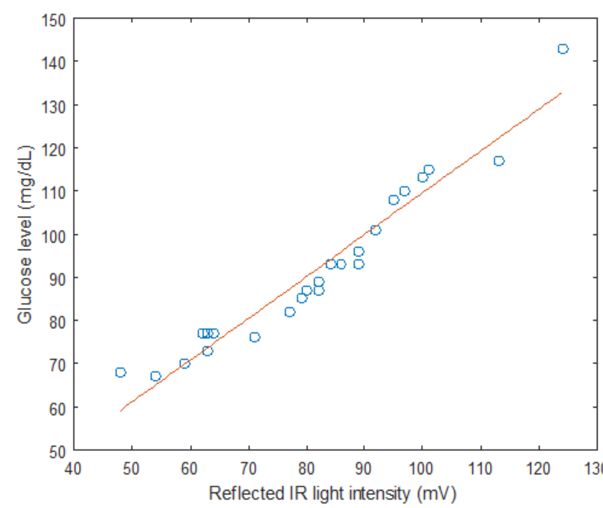

Fig. 4. Analysis of linear regression in prandial (fasting) condition

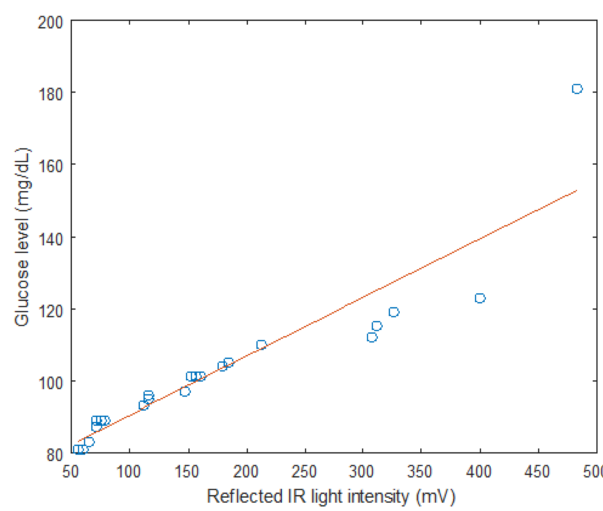

Fig. 5. Analysis of linear regression in post prandial condition

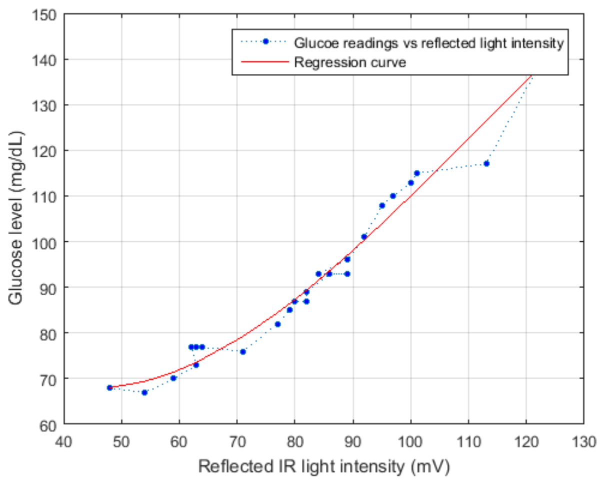

Fig. 6. Analysis of polynomial regression in prandial condition

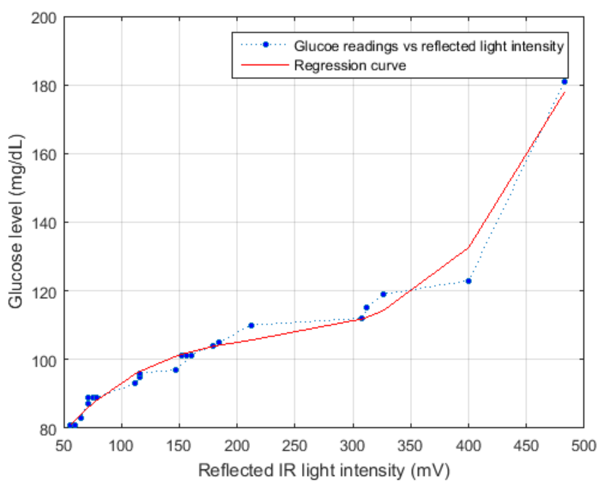

Fig. 7. Analysis of polynomial regression in post prandial condition

On comparing the predicted results of both the cases, it is observed that the predicted glucose concentration by linear fit non-invasive method shows an error of ±12 mg/dL while that of poly fit results an error of ±7 mg/dL. Thus from the linear regression analysis, we observe that a linear relation between invasive glucose values and PPG voltage intensities cannot be claimed. This initial study also shows that the polynomial regression method yields better result.

V. Conclusion

The software analysis carried out indicates the feasibility of developing a low cost non-invasive blood glucose monitoring system using PPG technique and near infrared spectroscopy. This will certainly attract rural population, since the qualms of blood sampling is totally avoided. It will be easier to handle such a system by common people as it doesn't need any technicians. This will help them to continuously monitor diabetes so as to receive proper treatments on time.

In this work, all the simulations are accomplished by adopting MATLAB.

To produce this as a totally implemented system, the circuit needs to be integrated with a display module as well as a wireless transmission module. Further, to make this system reliable and consistent similar to an invasive system, more measurements are to be carried out and thereby achieve improvement in the correlation coefficients and simulation results. This may be able to produce better results than the latter.

For easy handling purposes, the system can be integrated with smartphones. Also, a better accuracy level can be brought out either by including more number of real time data samples or by trying to accommodate another machine learning algorithm, say support vector regression, which can also enable the system to be self-learning.

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References

[1] Mohan, D, C.Santhosh Kumar "An efficient IKSVM based multi-parameter patient monitoring system", *International Journal of Applied Engineering Research, Research India Publications, Volume 10, Number 9,* p.22703-22710 (2015).

[2] Anjali Arunan, Rahul Krishnan Pathinarupothi, and Maneesha Vinodini Ramesh, "A Real-time Detection and Warning of Cardiovascular Disease LAHB for a Wearable Wireless ECG Device*", International Conference on Biomedical and Health Informatics (BHI),* 2016, pp.98-101.

[3] Dantu V, Vempati J, Srivilliputhur S. "Non-Invasive Blood Glucose Monitor Based on Spectroscopy Using a Smartphone", *36th Annual International Conference of the IEEE Engineering in Medicine Biology Society (EMBC)*, 2014, pp. 3695-3698.

[4] Swathi Ramasahayam, Sri Haindavi K, Bharat Kavala, Shubhajith Roy Chowdhury "Non Invasive Estimation of Blood Glucose using Near Infra red Spectroscopy and Double Regression Analysis", *IEEE International Conference on Sensing Technology*, 2013 , pp. 627-631

[5] K A Unnikrishna Menon, Deepak Hemachandran,T K Abhishek "A survey on non-invasive blood glucose monitoring using NIRSpectroscopy", *Communications and Signal Processing (ICCSP), 2013 International Conference,* April 2013, pp. 1069-1072.

[6] Shailaja P Vedpathak, Dr.B.B.Godbole *"Smart Ambulatory Blood Pressure Monitor: A Novel Approach"*, *International Research Journal of Engineering and Technology (IRJET),* Nov 2015, vol 02, issue 08.

[7] R. W. Waynant "Overview of Non-Invasive Fluid Glucose Measurement Using Optical Techniques to Maintain Glucose Control in Diabetes Mellitus", *A Publication Of The IEEE Lasers And Electro-Optics Society*, 1998, vol.12.

[8] Brince Paul, Melvin P Manuel, Zachariah C Alex "Design and Development of Non-Invasive Glucose Measurement System", *IEEE First International Symposium on Physics and Technology of Sensors* 2012.

[9] T. Tamura, Y. Maeda, M. Sekine and M. Yoshida, "Wearable Photoplethysmographic Sensors-Past and Present", *Electronics vol.3, no.2, pp.282-302,2014*

[10] Shailaja P Vedpathak, Dr.B.B.Godbole "Smart Ambulatory Blood Pressure Monitor: A Novel Approach." *International Research Journal of Engineering and Technology (IRJET),* 2015.