ISSN: 2278 – 8875

*International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*
*Vol. 2, Issue 1, January 2013*

# Blood Glucose Monitoring Using Non Invasive Optical Method: Design Limitations and Challenges

Anuj Srivastava[1], Md Koushik Chowdhury[2], Dr. Shiru Sharma[3], Dr. Neeraj Sharma[4]

Research Scholar, School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh, India[1]

Research Scholar, School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh, India[2]

Assistant Professor, School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh, India[3]

Associate Professor, School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh, India[4]

**Abstract:** This paper intends to discuss the important points related with the design and development of the noninvasive blood glucose monitoring medical device. The advent of a pain free noninvasive technology would improve the patient's compliance for regular blood glucose monitoring. Subsequently the diabetic patient's life will improve considerably. The feeble signals produced by the glucose molecules provide the main difficulty in its optical detection. The weak sensitivity, specificity, water molecular spectral overlapping related to the glucose molecules needed to focus for the optimal advancement in this field. Moreover, the skin tissue based scattering, reflection pattern, transmittance plays the major role for the application of the noninvasive based optical techniques. This manuscript critically analyses the difficulties and short comes during the near infrared and mid infrared technique based noninvasive blood glucose monitoring processes. Some vital points are targeted and their optimal solution related issues are identified and discussed here.

**Keywords:** Noninvasive, Blood Glucose, Scattering, Reflection, Transmittance, Near Infrared and Mid Infrared techniques.

## I. INTRODUCTION

Diabetes mellitus refers to a physiological metabolic disorder in which elevated blood sugar levels prevails in uncontrolled manner. Usually millions of peoples in the USA and worldwide have been suffering from this metabolic disorder [1-4]. At present various types of commercialized invasive glucometer is available in the market for monitoring blood sugar levels [1,2]. Various symptoms like increased hunger, thirst and urination often indicates the high sugar levels. Diabetes mellitus is subdivided in to two major types known as Type 1 and Type 2 diabetes mellitus [1-4]. In Type 1 diabetes or juvenile diabetes, the beta cells of the pancreas were destroyed due to certain pathological conditions. This phenomenon results in absolute insulin scarcity. Insulin scarcity fails the normal blood glucose regulations. Type 1 diabetes is often genetically inherited [1-4]. Almost 50-60% of the young diabetic population belong the category of Type 1 Diabetes [1-3]. Resistance to insulin production triggers the symptoms known as Type 2 Diabetes. Sedentary lifestyle often leads to Type 2 Diabetes [2, 3, 4]. Generally, the populations belonging to the high physical activity, energetic lifestyle, with no-smoking habits are less prone to diabetic related difficulties [1-4].

At present with advent of invasive glucometer, the individuals can monitor their respective blood glucose levels at home. The invasive blood glucometer monitoring process is painful and costly. Tight blood glucose regulation is needed for effective blood sugar management. The painful and cost related factor often hinders the continuous blood glucose monitoring [2,3,4]. The noninvasive pain free approach would come up with clinically effective blood glucose monitoring [1-4].

This paper is structured as follows: Section I provides brief introduction about the diabetic predominance world-wide. Section II describes the methods involved in the noninvasive detection of blood glucose. Section III depicts the design based limits and its challenges. Section IV describes the mathematical model utilized for the blood glucose measurements. Section V illustrates the optical based absorption techniques. Section VI demonstrates the instrumentation scheme for the noninvasive glucometer. Section VII provides the conclusion of the paper and references were given later on.

## II. OPTICAL TECHNOLOGY BASED NON INVASIVE BLOOD GLUCOSE DETECTION METHODS

Optical technology based sensors were utilized in the biomedical field for various diagnostic purposes. These methods needed blood and tissues samples for their respective characterizations. Various optical methods have been engaged for non invasive blood glucose detections. They are as follows:

The **Infrared Spectroscopy** utilizes both the absorption & scattering phenomenon of the light when directed over the sample tissues for analytical purposes. The light and sample tissue interactions produce molecular specific vibrational information of the absorption and scattering phenomenon in the infrared spectral domain [5-7].

The **Raman Spectroscopy** utilizes the scattering phenomenon of the light. When a monochromatic beam of a laser light is irradiated over the sample tissue, the scattering phenomenon is produced due to the molecular vibrations and oscillations. The degrees of scattering for specific molecules (glucose) are purely dependent on its concentrations levels [8-10].

The **Fluorescent spectroscopy** utilizes the fluorescence produced from the sample tissue when illuminated by the light of specific wavelength. The glucose solution emits fluorescence in the spectral domain of 340 to 400nm when illuminated by the ultraviolet laser beam of 308nm. Here the intensity of fluorescence is proportionate to the glucose concentrations in the solution [2].

The **Thermal Spectroscopy** utilizes the emission of infrared light as compared to the glucose absorption. The extent of infrared emission matches the quantity of the glucose present in the target area of the body part [2].

The **Photo acoustic technology** utilizes the laser light for the body fluid excitations and it acoustic response is determined for the blood glucose level detections [2].

The **Optical Coherence Tomography (OCT)** utilizes the super luminescent light, an interferometer associated with the reference arm and the sample arm and the photo detector. When the incident light beam is backscattered from the tissue complex, the change in the sample arm reflecting light wavelength and the reference arm reflecting light wavelength is compared. The delay correlation between them is determined for the blood glucose level predictions [2,11].

The **Ocular Spectroscopy** utilizes the specially designed hydrogel based eye contact lenses. The lens used change color depending up on the glucose concentrations. These color change serves as the tool for blood glucose detections from the tears of the diabetic subjects concerned [12,13].

With the rise in the diabetic population, the noninvasive approach for the blood glucose measurement has been the demanding need of the medical sciences [1-4]. Blood glucose determination without pain and finger piercing method has added to the noninvasive glucometer popularity [2-4]. This research paper discusses the design issues and countermeasures required for the effective noninvasive infrared spectra based glucometers.

## III. DESIGN LIMITATIONS & CHALLENGES

In optical technology based noninvasive blood glucose measurement, the living tissue is utilized. The living tissue by virtue of being living is subjected to various, continuous change in the physiological conditions. Moreover, the glucose molecule specific signal is very feeble and mostly overlapped by the water molecules. The actual difficulties and short comes occurs during the infrared light based measurements are as follows:

**(a) Instrumental difficulties in the acquisition of the precise absorption spectra:** Very small quantity of glucose is present in the tissue and blood matrix, causing its difficult detections. Spectral signals acquisitions under goes difficulty due to low glucose signals [2-4,14,15]. The infrared spectroscopy based measurement for in vivo conditions are influenced by numerous and dynamic reasons like machine drift, time drift, noise from the background medium, extend of signal to noise ratios, room temperatures, subject medical conditions, sweating of the skin layers, light absorption, reflection, scattering induced phenomenon, etc [14,15].

**(b) Calibration model: its features and robustness:** The calibration model for noninvasive blood glucose detection is designed based on various statistical and experimental tools [2-4,14,15]. The model building key factors includes: blood pulsatile nature of flow, room temperature, climate based humidity, variable pulse rate, osmolarity of the glucose molecules and the body fluids, heart rate, subject emotional status, skin pigmentations, etc [2-4,14]. Again, these factors may cause serious impaired results. The degree of factorial effectiveness over blood glucose level fluctuations must be considered carefully [14,15].

**(c)The spectroscopy instrument and human interfacing:** The spectroscopic findings vary from subject to subject depending on the temperature conditions, motion artifacts, skin dryness, angle of contact, body positions, nature of the measuring sites, etc. To remove all these hurdles in the signal acquisition process, unique algorithmic or mechanical schemes are to be engaged for filtering out such unwanted signals. These approaches will help in designing human friendly spectroscopy machines for the noninvasive blood glucose detections [2-4, 14,15].

**(d) Measuring the light photon travelling scheme:** The light passing through the biological tissue subjected to the absorption and scattering phenomenon. All these factors deviates the light from following the shortest straight path [2-4,14]. All the light photons that are received at the detectors are those bunches of photons which had travelled through different optical path lengths of varied optical characteristics. Therefore to determine the area specific glucose concentrations, the shortest straight light route must be identified [2-4, 14,15]. The signal to noise ratio plays an important role here [2-4, 14,15].

**(e) Effect of the surrounding medium with different frame of the time periods:** All the physiological process of human body keeps on changing depending up on metabolic rate, emotional status, etc. These ever changing factors create problems for the accurate blood glucose determinations in the real time scenario [2-4, 14,15]. To overcome this difficulty a suitable and universally acceptable measurement approach is desired [2-4, 14,15].

## IV. BLOOD GLUCOSE MEASUREMENT USING MATHEMATICAL MODELING

The Near infrared and Mid infrared spectroscopy detects blood glucose through indirect determinations. The multivariate approaches have been utilized to correlate the input and output of the sample concentrations, which is dependent over these key factors:

a) Stable and good signal to noise ratios for precise and steady measurements.
b) The output of the spectroscopy methods is dependent on the instrumental condition, sample quality and reaction kinetics, etc [2-4, 7, 14,15].

## V. OPTICAL ABSORPTION TECHNIQUES

The Lambert-Beer law accounts for the light intensity change on the sample light path by a specific wave number (v), of the wavelength, where the Absorption is denoted as (A). This incident is represented as follows:

$$\mathbf{A\ (v) = -log\ I\ (v) / I_0\ (v)} \qquad \textbf{(1)}$$

Where $\mathbf{(I_0)}$ referred as light intensity of the medium, (**I**) expressed for the amount of light intensity at the specific wave number **(v)** [16-21]. For glucose molecule identification, usually the optical absorption spectroscopy in the near and mid infrared is applied. The figure 1 and 2 depicts the absorption spectra for the aqueous glucose solution in the Near (NIR) and Mid (MIR) infrared spectral domain. The water based absorption pattern has been omitted [7].

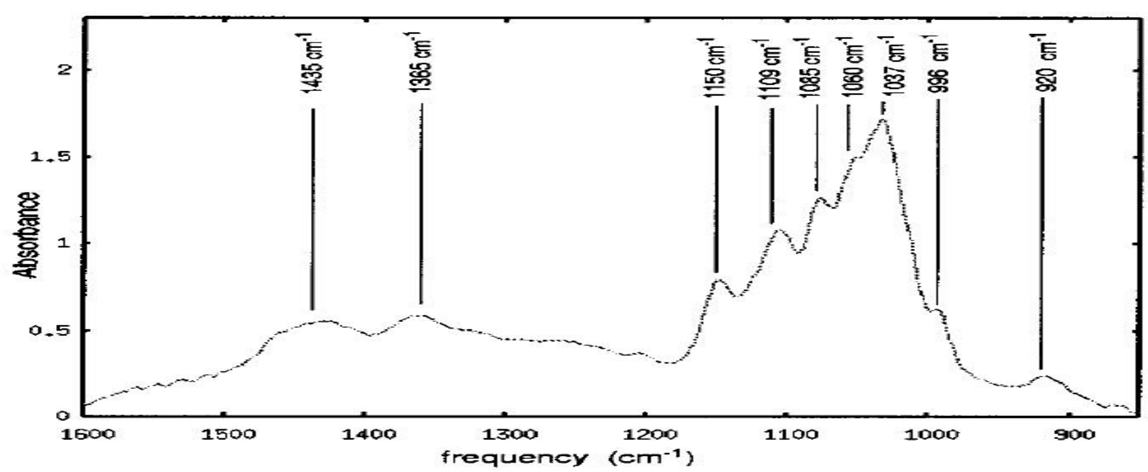


**Figure-1.** The figure represents the glucose molecule based optical absorption spectral pattern at the MIR (Mid Infra Red) region extending from 1600 to 900 $cm^{-1}$. Adapted from the Reference [7]

ISSN: 2278 – 8875

*International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*
*Vol. 2, Issue 1, January 2013*

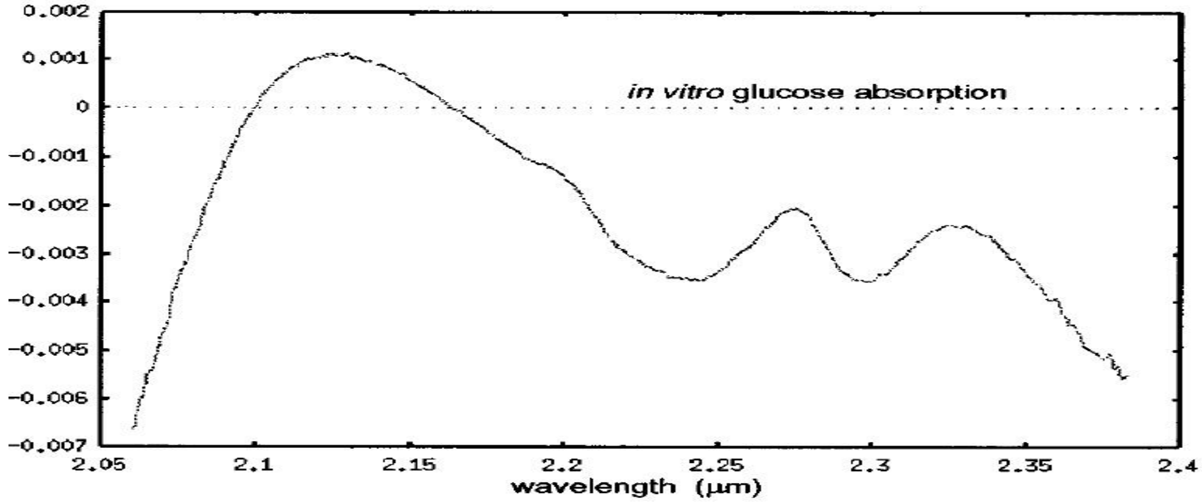


**Figure-2**. The figure represents the glucose molecule based optical absorption spectral pattern at the NIR (Near Infra Red) region extending from 5000 to 4000 $cm^{-1}$. Adapted from the Reference [7]

## VI. GENERALIZED INSTRUMENTATION SCHEME FOR NON INVASIVE GLUCOMETER

The block diagram illustrates the noninvasive blood glucose sensing system. Light source includes a 940nm LED (Light Emitting Diode). This infrared light is used as input signal propagates through the sample/finger holder unit. During the propagating phase, the IR light interacts with the molecules present in the medium. The resultant output signal is detected by the array of infrared sensitive detectors. After that, the signal is digitized and amplified. The digital output signal is processed in microchip by the specially designed algorithm to detect the blood glucose levels. The blood glucose level is then displayed electronically through the digital monitor.

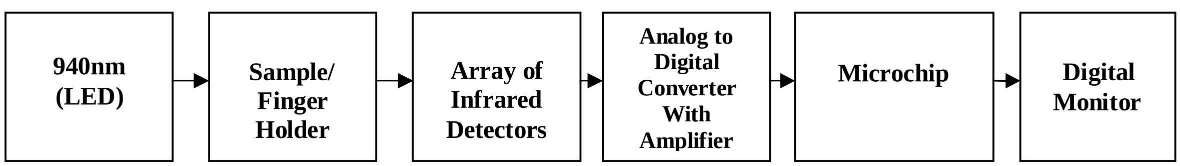


Figure 3. Depicts the Noninvasive blood glucose sensing system.

## VII.CONCLUSION

The alarming increase rate of the diabetic population has been the great matter of concern now a day. The clinically effective noninvasive technology will be helpful in active control over the blood glucose levels regulations [22-24]. This paper shows the critical and necessary issues related to noninvasive technology developments. The new noninvasive glucometer with accurate blood glucose detection capabilities will dominate the commercialized glucometer market in near future. Technologically we are at beginning phase for the noninvasive blood glucose detection techniques. The result oriented teamwork of various group of scientist is needed for productive results in this area.

## ACKNOWLEDGMENT

The authors were grateful to the Coordinator, Officials and Lab staff of the School of Biomedical Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi, for their active support in completing this research work.

ISSN: 2278 – 8875

*International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*
*Vol. 2, Issue 1, January 2013*

## REFERENCES

**[1**] Wild S, Roglic G, Green A, Sicree R, King H. Global prevalence of diabetes: estimates for the year 2000 and projections for 2030. Diabetes Care. 2004;27(5):1047-53.

**[2]** A. Tura, A. Maran and G. Pacini, "Non-invasive glucose monitoring: Assessment of technologies and devices according to quantitative criteria", Diabetes Research and Clinical Practice, vol. 77, 2007, pp. 16-40.

**[3]** O.S. Khalil, Non-invasive glucose measurement technologies: an update from 1999 to the dawn of the new millennium, Diabetes Technol. Ther. 6 (2004) 660–697.

**[4]** Daneman, Denis. "Type 1 diabetes."The Lancet 367, no. 9513 (March 2006):846-858.

**[5]** S.F. Malin, T.L. Ruchti, T.B. Blank, S.N. Thennadil, S.L. Monfre, Noninvasive prediction of glucose by near-infrared diffuse reflectance spectroscopy, Clin. Chem. 45 (1999) 1651–1658.

**[6]** L. Brancaleon, M.P. Bamberg, T. Sakamaki, N. Kollias, Attenuated total reflection-Fourier transform infrared spectroscopy as a possible method to investigate biophysical parameters of stratum corneum in vivo, J. Invest. Dermatol. 116 (2001) 380–386.

**[7]** Roger J. McNichols, Gerard L.Cote, Optical glucose sensing in biological fluids: an overview. Journal of Biomedical Optics, 5(1), 5-16(January 2000).

**[8]** E.B. Hanlon, R. Manoharan, T.W. Koo, K.E. Shafer, J.T. Motz, M. Fitzmaurice, et al., Prospects for in vivo Raman spectroscopy, Phys. Med. Biol. 45 (2000) R1–R59.

**[9]** A. Owyoung, E. Jones, Stimulated Raman spectroscopy using low-power cw lasers, Opt. Lett. 1 (1977) 152–154.

**[10]** R.V. Tarr, P.G. Steffes, The non-invasive measure of d-glucose in the ocular aqueous humor using stimulated Raman spectroscopy (http://www.ieee.org/organizations/pubs/newsletters/leos/apr98/dgloucose.html).

**[11]** K.V. Larin, M.S. Eledrisi, M. Motamedi, R.O. Esenaliev, Noninvasive blood glucose monitoring with optical coherence tomography:a pilot study in human subjects, Diab. Care 25 (2002) 2263–2267.

**[12]** A. Domschke, W.F. March, S. Kabilan, C. Lowe, Initial clinical testing of a holographic non-invasive contact lens glucose sensor, Diabetes Technol. Ther. 8 (2006) 89–93.

**[13]** R. Rawer, W. Stork, K.D. Muller-Glaser, Polarimetric methods for measurement of intra ocular glucose concentration, Biomed. Tech. (Berl.) 47 (Suppl. 1) (2002) 186–188.

**[14]** Kexin Xu, Ruikang K.Wang, 'Challenges and Countermeasures in NIR Noninvasive Blood Glucose Monitoring'.

Valery V. Tuchin (editor.), Handbook of Optical Sensing of Glucose in Biological Fluids and Tissues, CRC Press, Taylor & Francis Group,6000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487-2742.pp.no.281-317.

**[15]**Wei-Chuan Shih, Kate . Bechtel, Michael . Feld, Mark A. Arnold And Gary W. Small, 'Introduction To Spectroscopy For Noninvasive Glucose sensing', Edited by David D. Cunningham and Julie A. Stenken, In Vivo Glucose Sensing, 2010 John Wiley & Sons, Inc. pp.no:331-356.

**[16]** S. Radel , M. Brandstetter, B.Lendl, 'Observation of particles manipulated by ultrasound in close proximity to a cone-shaped infrared spectroscopy probe', Ultrasonics 50 (2010), pp.240–246.

**[17]** W. Terence Coakley, 'Ultrasonic separations in analytical biotechnology', Trends in Biotechnology (1997), pp. 506-511.

**[18]** L.V. King, 'On the acoustic radiation pressure on spheres', Proceedings of the Royal Society of London (1934), pp.212–240. A147.

**[19]** K. Yosioka, Y. Kawasima, 'Acoustic radiation pressure on a compressible sphere', Acustica 5 (1955), pp.167–173.

**[20]** F. Petersson, A. Nilsson, C. Holm, H. Jonsson and T. Laurella, 'Separation of lipids from blood utilizing ultrasonic standing waves in microfluidic channels', The Analyst, The Royal Society of Chemistry,(2004),129,pp.938-943. doi: 10.1039/b409139f.

**[21]** Ter Haar, G. and S.J. Wyard, Blood cell banding in ultrasonic standing wave fields: A physical analysis. Ultrasound in Medicine and Biology, 1978. 4(2): p. 111-123.

**[22]** W. L. Clarke, L. A. Gonder-Frederick,W. Carter, and S. L. Pohl, "Evaluating clinical accuracy of systems for self-monitoring of blood glucose,"*Diabetes Care*, vol. 10, no. 5, pp. 622–628, 1987.

**[23]** A. Maran et al. "Continuous Subcutaneous Glucose Monitoring in Diabetic Patients" Diabetes Care, Volume 25, Number 2, February 2002.

**[24]** B.P. Kovatchev et al. "Evaluating the Accuracy of Continuous Glucose Monitoring Sensors" Diabetes Care, Volume 27, Number 8, August 2004.

## BIOGRAPHY

**1. Anuj Srivastava** is a Research Scholar at School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh. India. His research interests are in the field of Bio-instrumentation Design and Developments.

ISSN: 2278 – 8875

*International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*
*Vol. 2, Issue 1, January 2013*

**2. Md Koushik Chowdhury** is a Research Scholar at School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh. India. His research interests are in the field of Bioinstrumentation, Non invasive medical devices.

**3. Dr.Shiru Sharma** is Assistant professor at School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh. Her specialization area is Biological Control System Analysis.

**4. Dr.Neeraj Sharma** is Associate professor at School of Biomedical Engineering, IIT-(BHU), Varanasi, Uttar Pradesh. His specialization area is Bioinstrumentation, Biomedical Signal and Image Processing.