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Non Invading Method for Blood Glucose Measurement Using Photo Acoustic

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Abstract—**In this paper we present a idea of non invading blood glucose measurement by using photo acoustic method. Diabetes is one of the major disease due to which more than 246 million people suffer and this number is increasing at very higher side. Diabetes disease affects very important organs of the body. A person who has Diabetes needs regular measurement of blood glucose after some regular intervals to avoid further complications. Different methods have been used to measure blood glucose by non invading method. In this paper photo acoustic method to measure blood glucose for non-invading is explained. Sources which interfere the result of blood glucose readings by melanin content of skin tissue & skin profile. While changes in blood flow due to variation in blood pressure also be considered.**

Keywords-Photo acoustic, Diabetes, non invading glucose

I. INTRODUCTION

Diabetes is one of the major threats for human being in 21st century. More than 246 million people suffer from diabetes worldwide and this number is expected to rise to 380 million by 2025 [1]. The disease is increasing at alarming rate. In order to prevent complications, regular interval glucose measurement is necessary for therapeutic adjustments. Most of the regular glucose measurement methods are invading in nature. Invading methods cause pain, time consumption, high costs per measurement and also carry potential risk of spreading infectious diseases & these techniques are not suitable for continuous monitoring. All these factors lead to a necessity of non invading glucose measurement.

Non invading glucose monitoring techniques can be grouped as subcutaneous, dermal, epidermal and combined dermal and epidermal measurements. Other than blood ocular fluid, sweat and interstitial fluid have been considered for the determination of glucose concentration. Researchers have explored various test sites like, finger tips, cuticle, finger web, forearm and ear lobe, etc. Some more techniques include fluorescence technique, impedance spectroscopy, thermal emission spectroscopy, and electromagnetic sensing, etc. However, major limitation of these techniques is that they are highly sensitive to physical parameters of the skin and tissue like, skin pigmentation, redness, epidermal thickness, temperature, etc. [2] [3]. In optical techniques, near infrared absorption spectroscopy, near infra red (NIR) scattering technique, Raman spectroscopy, Polarimetry technique and photo acoustic spectroscopy are noteworthy. In near infrared absorption spectroscopy the weak spectral band of glucose overlaps with the stronger bands of water, hemoglobin, protein and fats. Thus multiple measurements need to be carried out using several wavelengths. Also physical properties of the skin cause interference with glucose measurements. In NIR scattering technique physiological effects unrelated to glucose concentration could produce variations in scattering coefficient. In Raman spectroscopy instability of laser wavelength and long acquisition time are major drawbacks. Polarimetry technique is very sensitive to scattering properties of tissue, as scattering depolarizes the signal [2]. Photo acoustic (PA) spectroscopy uses laser light for excitation of fluid under investigation, which in turn generates acoustic response and it can be sensed by suitable ultrasonic transducer [4]. Due to the superiority of this method it is used for development of non invading glucose monitoring system [5]. This paper presents a possible methodology and an apparatus to detect blood glucose in noninvadive manner using photo acoustic spectroscopy.

The organization of the paper is as follows. Section II describes the principle of glucose measurement using PA method. System description is presented in Section III along with the criteria of selection of wavelength and transducer. Results are furnished in Section IV. Section V finally concludes the paper.

II. PRINCIPLE OF GLUCOSE MESUREMENT

Conversion of light energy into acoustic energy by photo acoustic effect was reported in 1880 by Alexander Graham Bell. It remained neglected for almost a century. In 1971 Kreuzer used powerful laser light in photo acoustic spectroscopy to measure very low levels of pollutants in gases. Then in 1970s, Allen Rosencwaig and Allen Gersho provided theoretical basis for photo acoustic effect in solids, by developing R-G theory [4].

In PA method, the glucose in blood is excited by a short duration (order of nanoseconds) laser pulse. Light absorption causes microscopic localized heating in the medium resulting in volumetric expansion. During the absence of optical energy the heated volume returns to the normal state. If the optical

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source is excited periodically, due to continuous stress and strain in the medium, a pressure wave is generated which travels outward and can be picked up by a suitable transducer. Amplitude of this pressure signal is dependent on the concentration of glucose in the fluid [6].

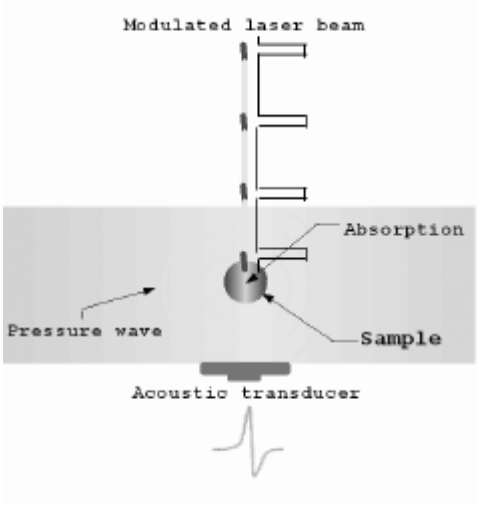

Figure 1. Photo acoustic signal generation mechanism.

It has an advantage that the detected signal is purely due to the absorption of the optical energy by the sample alone. The PA signal does not depend on sample size or shape. The photo acoustic spectrum as a function of laser light wavelength mimics the absorption spectrum in clear media.

When a laser beam having intensity E_i is incident on a tissue layer, its intensity decreases exponentially as a function of depth at a rate dependent on the attenuation coefficient, due to the absorption by the medium, in accordance with the Beer-Lambert Law. So, the intensity of light at a depth x can be given by

$$E(z) = \left(1 - R_f\right) E_i e^{-\mu_{eff} x} \quad (1)$$

Where, R_f is the coefficient of Fresnel reflection at the normal beam incidence and media and μ_{eff} is the effective absorption coefficient. Due to absorption of optical energy by the illuminated volume, the energy of photons is converted into heat.

$$A + h\mu \rightarrow A^*$$
$$A^* \rightarrow A + heat \quad (2)$$

This results in volumetric expansion of illuminated volume. Itthen comes back to its original shape and volume in absence of excitation, producing a pressure wave called Photo acoustic (PA) signal. Figure 1 shows the mechanism of PA generation. When the light penetration depth is much larger than the diameter of light beam, the PA source can be regarded as cylindrical in shape [7]. In this case, the amplitude of the PA pressure is given by [8].

$$|P| = \frac{E_\alpha \beta}{C_p \tau_L^{\frac{3}{2}}} \left(\frac{v}{r}\right)^{1/2} \quad (3)$$

where,
r = The distance between the PA source and the observation point.
α = 1 + light penetration depth
β = thermal expansion coefficient
C_p = specific heat
τ_L=optical pulse width
v = Acoustic velocity

$$E = \frac{E_\alpha}{\pi R^2}$$

$$E_\alpha = E_0(1 - e^{-\alpha l})$$

where,
R = radius of the optical beam
l = length of absorbing path
E_o = input pulse energy per pulse

The glucose concentration dependent terms are β, v, and C_p. It is found that with increase in glucose concentration β and v increase, but C_p decreases. However, reduction in C_p is much less as compared to combined increase in β and v [6]. So with increase in glucose concentration PA amplitude increases due to these factors and it is evident from equation (3).

III. System Description

In this section the blood glucose measuring system has been described. Initially a study has been carried out on selection of wavelength of light source is the most suitable for maximum absorption by glucose. Then the description of the system and test methodology have been detailed.

A. Selection of wavelength and transducer material

Absorption of light by tissue causes localized heating, which causes expansion and subsequent contraction, which gives rise to a PA signal. As composition of blood is quite complex and has various constituents, wavelength needs to be chosen judiciously. It can be seen that absorption by water, melanin, and oxy-haemoglobin is less in red and NIR region. This region extending from 600nm to 1300nm is known as optical window of biological tissue. Also, in this region the depth of penetration of light in tissue is several millimeters [9].

One more fact that needs to be considered is that, in wavelengths ranging from 1000nm to 1200nm absorptions for oxy-hemoglobin and deoxy-hemoglobin are different, whereas this difference is fairly small at around 900nm [9]. This may lead to errors as light absorption will change with the changes in amount of blood oxygenation. Considering the above phenomena tissue's optical window (wavelength around 900nm) is the most suitable for glucose detection. Although glucose has relatively lower absorption around this wavelength, but due to minimum attenuation of optical signal

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by other constituents, desired depth of penetration can be achieved with substantial energy available for absorption by the glucose. Excitation signal has nanosecond pulse duration and hence microphone cannot be used due to its limited bandwidth.

B. Block Level Description

Block level diagram of apparatus is shown in Fig. 4. System consists of a Laser Diode Module operating at 905nm and having provision for adjusting the pulse width and the pulse power. Laser Diode Module is controlled using microcontroller system.

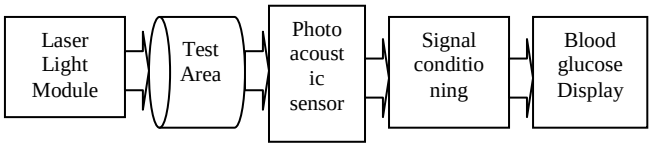

Figure 4. Block diagram of the system

Signal conditioning block allow changes in power and pulse width voltages of Laser Diode Module with respect to photo acoustic sensor block signal. It also automates the process of collecting the PA waveform data from the signal conditioning block at specified intervals.

Photo acoustic signal is sensed by ultrasonic transducer. Output of the transducer is amplified by Low Noise Amplifier (LNA) and further provided to signal conditioning section. To reduce effect of random noise and external EMI interference, PA signal is averaged over 1024 frames to achieve SNR above 40dB [10].

TABLE 1 SETTINGS USED FOR EXPERIMENT

Parameter	Value
Pulse power (vP1)	80 W
Pulse width (vTW)	100 ns
Pulse repetition frequency	90 Hz
Interval between two readings	2 min
Total Time	64 min

IV. CONCLUSION

The system for non invading glucose measurements using Photo acoustic technique, prototype model is under test process. Trial & error methods have been carried out using this setup and it is observed photo acoustic signal resembles on the power of the laser at the same time precaution is been taken to avoid any subsequent effect on skin or test area. Correcting factors, which will remove the errors due to test area repositioning and melanin content of the skin needs to be developed to improve accuracy of reading.

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