Relationship between Human Glucose Level and Optical De/Polarization Information in 600 nm–800 nm Wavelength Region

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Abstract— Patients have to check their blood glucose level at least four times a day. If regular measurement is not made, hypoglycemia and hyperglycemia occurrence possibility increases. When measurements are not made regularly it is preparing the ground for organ damage in long term and life risk in short term. Nowadays many people with diabetes need to measure blood glucose levels by drilling their fingers, squeezing blood droplets on test strips and treating the results with portable glucometers. This method seriously disrupts patient's comfort. So, there is a growing need for a new generation of glucose-level monitoring systems. For this reasons' this study focused on non-invasive methods based on optical de-polarization rate relation with glucose level. By using optics-photonics information modeled biological tissue (skin layers and blood) is illuminated by circularly polarized light, and elliptically polarized light at the other side of tissue (transmitted light) is obtained.

1. INTRODUCTION

Diabetes mellitus (DM) is a lifelong chronic disorder caused by the inability of the pancreas to produce enough insulin or not effectively use of the insulin produced by the pancreas. Regular measurement is an essential in order to avoid hypoglycemia or hyperglycemia, and diabetics need to check their blood glucose level frequently. There are three categories of blood glucose level measurement methods which are typically invasive, minimally invasive and noninvasive. In invasive methods, the integrity of the body is disrupted (by finger punching) and some blood is taken out of the body with the needle and the blood glucose level is determined. This method is painful and seriously disrupts patient's comfort, and it is expensive due to need of change of needles for each measurement. In non-invasive methods, blood glucose levels are determined by direct contact from the body surface or at a certain distance without allowing the damage of body, pain and no risk of infection. These types of methods have potential to increase patient's comfort and to reduce costs.

In the past few decades, there are lots of research groups and commercial companies have focused on non-invasive glucose level measurement methods. But there is still no commercial product in the market, and the proposed theoretical studies in the literature are mostly in phase one [1]. Studies which are using commonly in literature based on optical techniques [2]. Such as MIR (middle infrared) spectroscopy [3, 4]; NIR (near infrared) spectroscopy [5]; Raman spectroscopy [6]; transdermal method [7]; electromagnetic method [8]; dielectrical method [9]; bio-impedance technique [10]; flourescence technique, photoacoustic method [11]; optical cohorence tomography [12] and polarization measurements [13].

This study focuses on determining glucose level in human blood model by means of polarimetric methods. Depolarization from circular polarization to elliptical polarization allows us to calculate the degree of depolarization and to determine the trend of increase or decrease of level of blood glucose ratio. Blood and skin layers are also included into the model as a component to be taken into account. Designed biological tissue is illuminated by circularly polarized light in 600 nm–800 nm wavelength region, and elliptically polarized light at the other side of tissue is obtained. The change of state of polarization called de-polarization rate is analyzed in order to obtain an empirical model.

2. THEORITICAL BACKGROUND FOR DE/POLARIZATION

When a polarized light wave is sent to an optically active sample, the polarized light undergoes number of changes. These changes called name de-polarization. Equipment used to measure polarization called polarimeters is used to measure the angle of rotation of the light, and this measurement allows us to determine the concentration of molecules.

Figure 1 shows the structure of a typical polarimeter. When polarized light goes through optically active substance initial polarization state of it changes in terms of an angle. These

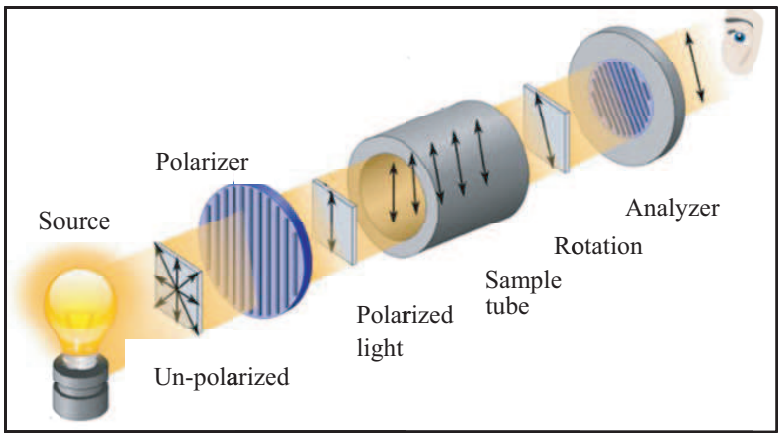


Figure 1: Typical polarimetric system.

angular changes indicate that amount of optical activity. This allows us to determine the molecular size, concentration and purity of the optically active substances.

Most of the biological tissues have an anisotropic structure. The main reason for the formation of this anisotropy is that the substances constituting the different sub-structure and they have different refractive index values. The fact that tissues have different refractive indices gives them important property called birefringence which is the most important factor that distorts the polarization information. It is known that de-polarization information occurs as a phase delay at the output of tissue. Tuchin reported that 90% of the phase delay within the tissue having several hundred micrometers depth is a result of birefringence [14].

Figure 2 illustrates the propagation of light in glucose and non-glucose media. It can be observed that, as the glucose level increases, both the scattering probability and the optical path followed by light decrease, and consequently the absorption event drops in tissue. Because of the weaker absorption, the resulting light intensity gets higher. Much more light intensity means that the polarization information contained in the light is retained [15]. This reason that, if the glucose level is high enough, the depolarization level will be weak within the tissue and the initial polarization information is kept quite similar to original one at the output.

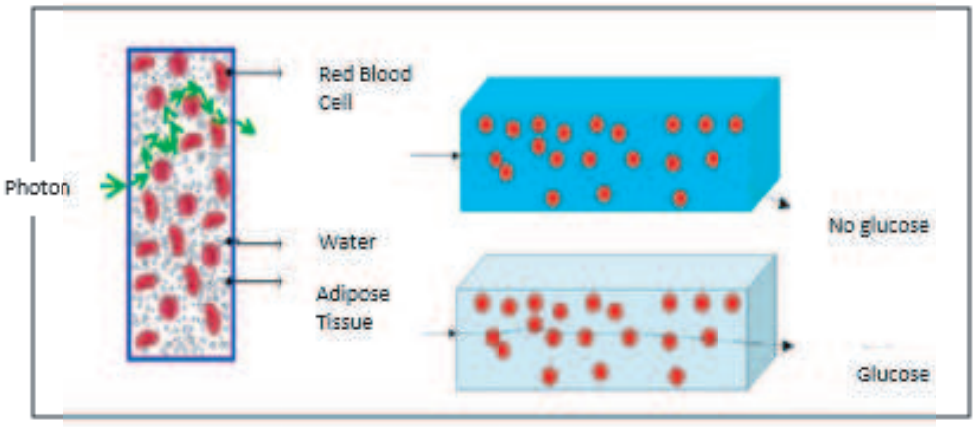


Figure 2: Photon behavior in biological tissue.

3. MODELLING AND DESIGN

In order to calculate the degree of polarization distortion, the models representing the biological tissues are created in optical design software as a first step. For creation of all models of human blood and skin, data from the literature is used. During the creation of models, the flow rate, viscosity and temperature changes of the blood are neglected and the parameters of a healthy person are used. In simulation software, polarization distortion measurements are performed on the light transmitted through the tissue. To perform this, program's polarization analysis functions

and Stokes parameters are used. Created model is illuminated by circularly polarized light wave, and elliptically polarized light wave is obtained at the output.

The optical design program considers polarization ellipse which have only the E_x and E_y components and neglecting E_z component. The polarization ellipse used in the optical design program is given in Figure 3. In Table 1, the explanations of the coefficients in Figure 3 and their corresponding coefficients.

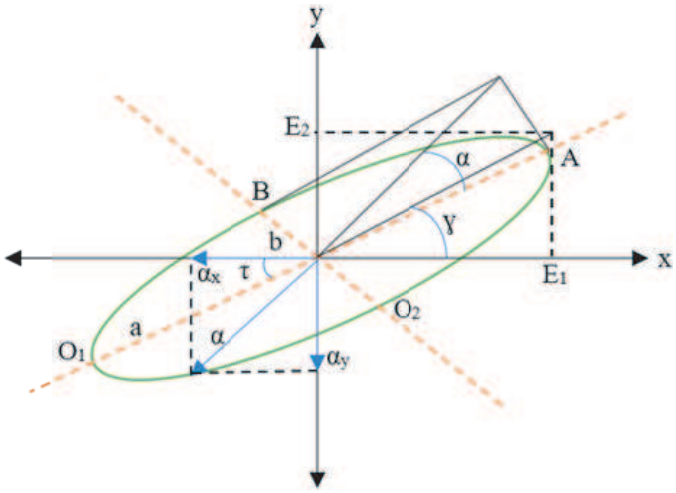


Figure 3: Polarization ellipse in optical design program.

Table 1: Values for the use of polarization ellipse in the optical design program.

Coef.	**Explanation**	**Optical Design Program**	**Formula**
a	Semi Major Axis	EM	AO1/2
b	Semi Minor Axis	E_m	BO2/2
τ	Angle of Major Axis: Angle of the ellipse major axis with x axis.	A_p Orientation Angle	(0°–180°)
$E1, E2$	Electrical Field Components	E_{xr}, E_{yr} (Real components electrical field)	
α	Ellipticity Coefficient	Program does not calculate directly	$\alpha = \arctan(b/a)$
γ	Angle of Polarization	Program does not calculate directly	$\gamma = \arctan(E_2/E_1)$
δ	Phase Delay	P_{xy}	

The degree of elliptic polarization is calculated by using (1) and (2). The degree of de-polarization amount of the photon from circular polarization to elliptical polarization varies depending on molecular concentration of particles forming the optically active substance. For any de-polarization event in optically active substances, the γ value in (1) and the δ value in (2) are the best coefficients to express polarization state [16].

$$\gamma = \frac{1}{2}\cos^{-1}(\cos[2\alpha] \cdot \cos[2\tau]) \tag{1}$$

$$\delta = \tan^{-1}\left[\frac{\tan(2\alpha)}{\sin(2\tau)}\right] \tag{2}$$

600–800 nm wavelength region is expected as an operating wavelength region for optical sensing of blood glucose level. Reasons of this expectation and selection are summarized as below;

1. Absorption and scattering coefficients from the blood molecules and plasma are low in the 600–800 nm region; and anisotropy factor is in the range of 0.98 and 1.

2. Hemoglobin is %40 –%50 of the total amount of blood, and absorption based on it is significantly low.

3. Reduction of refractive index values in this region due to hemoglobin, and lesser refractive index mismatch with other molecules such as glucose. Overlapping of the refractive indices of *oxy* and *deoxy* hemoglobin is seen above 600 nm.

4. 50–60% of the blood is made up from the plasma, and $\sim$ 90% of plasma is composed of water, and water-induced absorption and scattering events are low in this region.

5. Low absorption rate of epidermis layer [17].

4. RESULTS

In the next, with the help of optical design program analysis' features the information of polarization distortion in the light transmitted through the tissue at different glucose ratios in 600–800 nm region is examined. (1) and (2) are used for calculating polarization degrees. Different glucose ratios and wavelengths are entered and the degree of polarization at the tissue output is examined. The optical coefficients of the skin and blood which are previously obtained and modeled are used as in the optical design program. Five subplots are shown in Figure 4. In Figure 4, one may find the variation of polarization degree with respect to varying glucose level at five different wavelengths. Treated wavelengths are 600 nm, 650 nm, 700 nm, 750 nm and 800 nm. Instead the glucose level above 120 mg/dl is accepted as high for normal patients, this value is extendible up to 200 mg/dl especially for Type-1 diabetics. That's why, this extend region is investigated for offering mathematical model. It can be observed from these plots that 600 nm, 650 nm and 700 nm wavelengths are very close to each other rather than 750 nm and 800 nm. For the glucose level between 80 mg/dl and 120 mg/dl, there seems a linear relation [17].

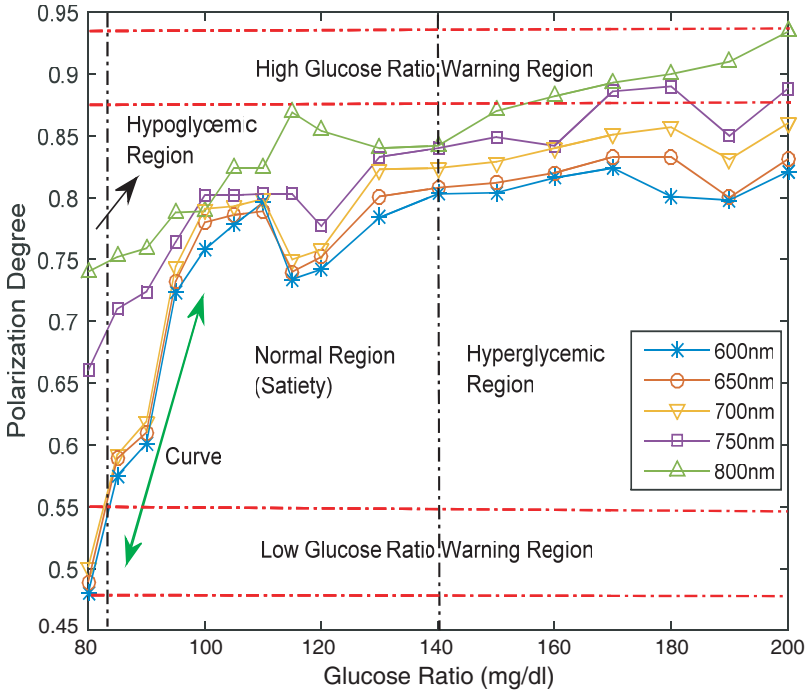


Figure 4: Changes in the degree of polarization for different wavelength with respect to different glucose level (80–200 mg/dl) (Hypoglycemic, normal and hyperglycemic region also shown).

5. CONCLUSIONS

In this study, a potential operating wavelength window is proposed for determining glucose level in human blood model by means of polarimetric methods. Limits of this window are determined as 600 nm and 700 nm. In order to determine this window, all components with their possible values are taken into account such as hemoglobin, melamine, skin and plasma. Other components and organic molecules are not taken into account, since they potentially have limited contributions. But for further academic studies and realization stage of proposed equipment, these components may need to be studied.

In the near future, as continuity of this study, proposed technique and methods will tried to be implemented and realized. Realized optical design will be integrated with an electronic driver that uses and analyzes data by means of offered mathematical model. We also would like to study on other possible working window for possibly cheaper solutions.

REFERENCES

1. Purvinis, G., B. D. Cameron, and D. M. Altrogge, "Noninvasive polarimetric-based glucose monitoring: An in vivo study," *Journal of Diabetes Science and Technology*, Vol. V, No. 2, 1–10, 2011.
2. Khalil, O. S., "Spectroscopic and clinical aspects of noninvasive glucose measurements," *Clinical Chemistry*, Vol. II, No. 45, 165–177, 1999.
3. Klonoff, D., "Noninvasive blood glucose monitoring," *Diabetes Care*, Vol. III, No. 20, 433–437, 1997.
4. Vaddiraju, S., D. Burgess, I. Tomazos, F. Jain, and F. Papadimitrakopoulos, "Technologies for continuous glucose monitoring: Current problems and future promises," *Journal of Diabetes Science and Technology*, Vol. VI, No. 4, 1540–1562, 2010.
5. Liu, J., R. Liu, and K. Xu, "Accuracy of noninvasive glucose sensing based on near-infrared spectroscopy," *Applied Spectroscopy*, Vol. XI, No. 69, 1313–1318, 2015.
6. Khalil, O. S., "Non-invasive glucose measurement technologies: An update from 1999 to the dawn of the new millennium," *Diabetes Technology & Therapeutics*, Vol. V, No. 6, 660–697, 2004.
7. Leal, L., C. Leon, D. Assad, and M. Chapa, "State of the art and new perspectives in non-invasive glucose sensors," *Revista Mexicana De Ingenieria Biomedica*, Vol. XXXIII, No. 1, 41–52, 2012.
8. Gabriel, S., R. Lau, and C. Gabriel, "Dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz," *Phys. Med. Biol.*, No. 41, 2251–2269, 1996.
9. Topsakal, E., T. Karacolak, and E. Moreland, "Glucose-dependent dielectric properties of blood plasma," No. IEEE, 978-1-4244-6051-9/11, 2011.
10. Caduff, A., M. Talary, L. Heinemann, and Y. Feldman, "Non-invasive glucose monitoring in patients with diabetes: A novel system based on impedance spectroscopy," *Biosensors & Bioelectronics*, 1–8, 2007.
11. MacKenzie, A., H. Ashton, S. Spiers, Y. Shen, S. Freeborn, J. Hannigan, J. Lindberg, and P. Rae, "Advances in photoacoustic noninvasive glucose testing," *Clinical Chemistry*, Vol. IX, No. 45, 1587–1595, 1999.
12. Kuranov, V., V. Sapozhnikova, D. Prough, I. Cicenaite, and R. Esenaliev, "Prediction capability of optical coherence tomography for blood glucose concentration monitoring," *Journal of Diabetes Science and Technology*, Vol. IV, No. 1, 470–477, 2007.
13. Heinemann, L. and G. Schmelzeisen-Redeker, "Non-invasive continuous glucose monitoring in type I diabetic patients with optical glucose sensors," *Diabetologia*, No. 41, 848–854, 1998.
14. Tuchin, V., *Tissue Optics: Light Scattering Methods and Instruments for Medical Diagnosis*, 2nd Edition, 866, SPIE Press, United States, 2007.
15. Yadava, J., A. Rania, V. Singha, and B. Murarib, "Prospects and limitations of non invasive blood glucose monitoring using near-infrared spectroscopy," *Biomedical Signal Processing and Control*, Vol. XVIII, 214–227, 2015.
16. Hum, S. V., *Wave Polarization, ECE422: Radio and Microwave Wireless Systems, Course Notes*, 2010.
17. Menguc, E., *Modeling of Glucose Level in Living Biological Tissues by Using Optical Depolarization Relationship*, Institude of Natural Sciences, Akdeniz University, Antalya, 2018.