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# Glucometry and Pulse Oximetry - Comparative Noninvasive Methods for Determining Blood Glucose

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**Abstract**

The paper aims to study non-invasive detection methods for blood glucose determination. Glucometry and pulse oximetry are two methods that are based on the absorption of light in tissues. Pulse oximetry measures blood oxygen saturation based on red (infrared) light, using a wavelength of 600-750 nm, and infrared light, using a wavelength of 850-1000 nm. For detecting blood glucose we will use the same method. Glucose can also be found in hemoglobin, according to the latest studies. Glycemia is a less well-known blood test than conventional blood glucose, but it is especially useful when there is a suspicion of diabetes or prediabetes or to monitor long-term, in the case of diabetics.

**Keywords:** glucose; near infrared; monitoring; glucometry; pulsoximetry

## I. INTRODUCTION

Parameters, such as heart rate, blood oxygen and glucose are few of the vitalities that need to be monitored for patients who need it. There are cases such as during surgery or in postoperative progression, when these vital signs need to be monitored continuously to ensure surgery on the patient. There are medical procedures that produce accurate results, but the only disadvantage is that they are invasive, so it comes with a pain factor. This non-invasive method is based on the operating principle of the pulse oximeter and combines the principle of the glucose meter called the OGH monitor that calculates the saturation of oxygen, glucose and heartbeat of an individual, without actually depending on parameters such as blood samples, urine samples. This monitoring is based on the principle of differential light absorption, which is considered the input parameter to produce three different parameters, such as the percentage of oxygen saturation, glucose and the heartbeat rate. If pulse oximetry is concerned with measuring oxygen saturation in the blood, by examining hemoglobin, which is the oxygen-bearing pigment of red blood cells that gives them red color and serves to transmit oxygen to tissues, glucometry measures a patient blood glucose level. The advantage of glycated hemoglobin analysis is that, unlike the classic blood glucose test that needs to be done on foods, it does not require fasting and can be done even when the patient is on a diet. The two modern methods are based on the absorption of light in the matter and on the flux and reflux of blood from the tissues. Changing the volume of blood in the tissues affects the amount of light, such as the amount of red or infrared light that will be transmitted through the tissue, which allows both methods to determine the amount of light that passes through the blood.

## II. THEORY

### *A. Pulse Oximetry*

Pulse oximetry is the monitoring and measurement of oxygen saturation in blood. This monitoring it is usually read in percentages (a normal reading is usually 97 percent). Pulse oximetry visualizes the concentration of O2 (O2 in the blood is bound to hemoglobin and only a small part dissolved in plasma). The operating principle of the pulse oximeter is based on spectrophotometry and Bees's law, measuring the changes in light absorption by two forms of hemoglobin: oxygenated and reduced. In pulse oximetry, two light sources are used: an invisible source in the infrared spectrum and a source in the visible spectrum, with the

wavelength for the red light. The light source and sensor are mounted in a couple that attaches to the pulp of the finger or ear lobe. As the background absorption of radiation by the venous blood, subcutaneous tissue and skin is practically constant, the only variable is the amount of Hb (pulsating wave) in the vascular bed. Saturation measurement is done at the tip of the pulse wave to isolate the arterial signal. A pulse meter is a noninvasive device used in the genome to monitor and measure oxygen saturation in the blood as well as the heartbeat. This device can be standalone or integrated into a patient monitoring system or portable tracker. [8]

Hemoglobin is the oxygen-bearing pigment of red blood cells that gives them red color and ensures the transmission of oxygen to tissues, in two forms. The first form is called oxidized hemoglobin (oxy), which is called HbO2, and the second form is low oxygen hemoglobin (deoxy), denoted Hb.

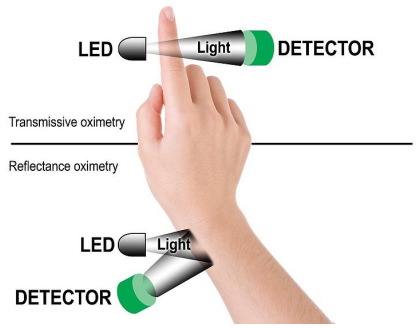


Fig. 1. **Reflectance light through finger [8]**

In this way, we can say that oxygen saturation in the blood, ie SpO2, is the ratio between oxy-hemoglobin and deoxy-hemoglobin. It is expressed as:

$$SpO2 = HbO2 / (Hb + HbO2) \quad (1)$$

The percentage of oxidized hemoglobin (HbO2) in the total hemoglobin in the blood represents the concentration of oxygen in the blood and gives important relationships on the functioning of the respiratory system. This parameter can be determined chemically by analyzing a blood sample obtained by puncture (invasive method) or approximated photoelectrically in infrared light at the nail bed level by Pulse Digital Oximetry (noninvasive method), which can be performed in max. 5 minutes). Digital pulse oximetry at rest gives information about the lung's ability to provide the body with sufficient oxygen in the absence

of effort: (SaO2 = 94 - 98%). Decreasing this parameter indicates a manifest respiratory failure (SaO2 below 94%). Related to hemoglobin, it is known that Hb absorbs more light and reflects less visible red light. On the other hand, HbO2 absorbs more and reflects less infrared light. [3] In order to measure both reflection and absorption we propose to illuminate both a red LED and an infrared LED on one side of the body and then compare their relative intensities. To achieve that we have two methods: (1) light measurement by tissue called transmissive oximetry and (2) measurement of light reflected by tissue called reflectance oximetry (Figure 1). [10]

When the heart beats, it pumps blood through his body. At each beat, the blood flows to the capillary and the volume increases. The volume of blood drops between the beats of the heart. Volume differences affect the amount of red or infrared light that crosses the tissue. [10] This fluctuation can be measured with a pulse oximeter. [8]

Typical pulse oximeters monitor SpO2 in a person's blood based on red light (using a wavelength of 600-750 nm) and infrared light (using a wavelength of 850-1000 nm) the absorption characteristics of HbO2 and Hb. This type of pulse oximeter illuminates the red and infrared lights alternately through a part of the body, such as a finger, towards a photodiode sensor. [1] The photodiode is normally used to receive unabsorbed light from each LED. This signal is then inverted using an operational reversing amplifier, or operational amplifier. The resulting signal represents the light that has been absorbed by the finger. [8]

SpO2 can be determined using the report value and a search table made up of empirical formulas. The pulse speed can be calculated based on the analog and digital converter (ADC) sample number of the pulse oximeter and the sampling speed.
An appearance table is an important part of a pulse oximeter.

### *B. Glucometry*

Diabetes is a condition of an organism in which it is unable to produce the amount of insulin sufficient to maintain the normal blood sugar level. Therefore, diabetic patients regulate their blood sugar levels through a proper diet as well as by injecting type 2 insulin. For effective diabetes treatment, patients must measure their blood glucose regularly. In pathology laboratories, glucose is measured by pointing the patient's finger with a needle to extract a small amount of blood sample. [6] Following the chemical reaction, we will have ferrous potassium cyanide. This will react with the metals on the electrode layer, producing an

electric current through electrodes. Non-invasive measurement methods have the advantage of pain-free measurement and also reduce healthcare costs. The noninvasive glucose measurement method such as IR spectroscopy has been popular for years, but the method with reliable results has not yet been established. In near-infrared spectroscopy (NIR) [9], glucose cells have the lowest absorption rate in the human body, because glucose is in the blood of the human body and light absorption signals can be measured within a depth range of 1 ~ 100 millimeters. The penetration wave decreases as the signal length increases. [14] This paper refers to the measurement of non-invasive glucose blood by using the NIR optical technique that can solve problems in invasive measurement, such as finger piercing, infection risk, etc. [10]

Changing the color of blood helps us to measure blood glucose levels. The prototype in this paper wants to address two problems:

• Determination of blood glucose by NIR method based on light absorption analysis by matter;

• Differences in light absorption through matter. In this case, the differences in light absorption through the three layers of the skin are taken into account: dermis, epidermis and hypoderma;

In order to demonstrate the presence of glucose in the blood we will develop a prototype device that interprets the values of light absorption through the different layers of tissues. Two NIR sensors will penetrate the layers, one of light absorption and the other of colorimetry measurement. Glucose monitoring values are calculated from the amount of light absorbed through the tissues to the blood capillaries. [10]

Due to the high concentration of the different constituents of the blood and tissues that light has to pass through the veins, the error standard can go up to 20%, and the spectral bandwidth can have big errors in this regard. To reduce the error related to monochromatic light absorption, we must remove from the calculation formula the standard deviation of absorption, which means the rate of light absorption through the skin layers plus other blood constituents such as water, platelets, lymphocytes, before actually reaching glucose. [10].

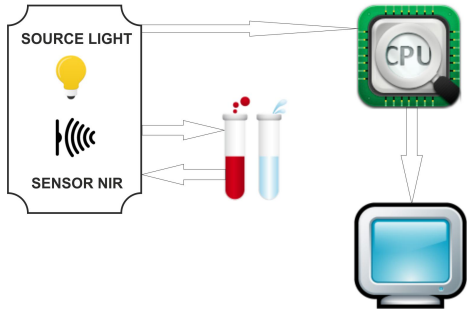


**Fig. 2 Diagram modul prototype**

When a ray of light interacts with the tissues of the human body, it is attenuated by scattering, but also by absorption by the tissues. Due to the differences in refraction between the extracellular fluid index and the cell membrane, light diffuses differently in tissues. The extracellular refractive index in the liquid varies with the glucose concentration since it is assumed that the cell membrane index remains relatively constant. The Beer-Lambert law plays a major role in the measurement of absorbance, which states that the absorption of light by any solution is proportional to the concentration of the solution and the length traveled by the light beam. Figure 3 illustrates the description of the optical effect of light passing through glucose molecules. [13] Less glucose leads to more light scattering, and impairs longer path lengths, as well as lower tissue uptake. More glucose molecules result in less light scattering, shorter optical path lengths, and therefore more tissue uptake. Due to more absorption in the glucose rich tissue, the reflected light has a lower intensity compared to the tissue with a lower glucose content.

## III. RESULTS

The concentration of glucose in the blood is determined by analyzing the variation of the signal intensity received after the reflection phenomenon. The results obtained from the designed system show the feasibility of using the non-invasive NIR-based method for blood glucose measurement. The system described is mainly useful for diabetic patients. The measurement accuracy of the proposed system can be improved by incorporating it with noise filtering techniques. [10] Light attenuation within the tissue depends on the coefficient known as the effective attenuation coefficient ($\mu_{eff}$):

$$\mu_{eff} = \sqrt{3\mu_a(\mu_a + \mu_s)} \quad [10] \qquad (3)$$

The absorption coefficient ($\mu_a$) is described as the probability of photon absorption inside the tissue on the path length unit and is given by:

$$\mu_{a=2.303} \in C \qquad (4)$$

, where, g defines the cosine mean of the scattering of angles which has a representative value of 0.91 and $\mu_s$ defines the scattering coefficient. With increasing glucose concentration, the wavelength of light decreases. [10]

Assuming that the refractive index in the blood cell remains constant (approximately 1,350-1,460), as the glucose concentration increases, its properties decrease. From the above equation, it can be concluded that $\mu_a$ also depends on glucose concentration, increasing glucose concentration increases the value of the absorption coefficient $\mu_a$ and hence the effective attenuation coefficient ($\mu_{eff}$) also increases, which leads to increase, in terms, of the attenuation level. From this it follows from the above equation, that in this way the increase of the attenuation decreases the intensity of the reflected light. [9]

The skin tissue of the human finger is made up of the epidermis, dermis and subcutaneous tissue layers. When the optical signal is sent perpendicular to the human tissue, the signal passes through the epidermis layer and is reflected in the dermis layer, following a parabola-shaped path, as shown in Figure 3.

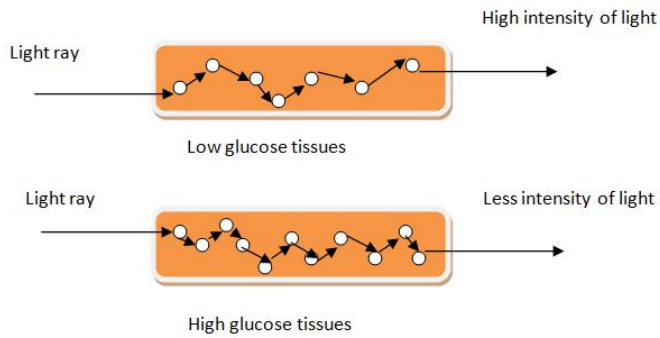


**Fig. 3. Light ray through tissues [15]**

Near infrared (NIR) has a wavelength of between 700 nm and 2500 nm, region in which infrared interacts with human tissue with low energy radiation. [9] The wavelength between 600 ~ 1300 nm is considered to be the penetration window known as the therapeutic window or the optical window. The range of wavelengths where light reaches its maximum penetration depth into tissue is called the near-infrared (NIR) window.

**TABLE I** STANDARD REFERENCES ABSORBANCE

| / | R-610 | S-680 | T-730 | U-760 | V-810 | W-860 |
|---|---|---|---|---|---|---|
| E1 | 7797.68 | 3150.99 | 874.13 | 416.04 | 387.01 | 291.97 |
| E2 | 7894.71 | 2573.4 | 897.28 | 424.99 | 305.84 | 296.62 |
| E3 | 8011.66 | 3247.07 | 901.92 | 427.98 | 388.00 | 298.95 |
| E4 | 7888.06 | 3186.12 | 882.23 | 419.0 | 389.98 | 294.29 |
| E5 | 7739.20 | 3184.05 | 874.13 | 415.04 | 392.95 | 290.80 |
| E6 | 7937.24 | 3175.79 | 882.23 | 420.02 | 391.96 | 295.46 |

Glucose has light absorption points at wavelengths of 940 nm, 970 nm, 1197 nm, 1408 nm, 1536 nm, 1688 nm, 1925 nm, 2100 nm, 2261 nm and 2326 nm. But at 940 nm, the wavelength attenuation by the optical signals of other blood constituents such as water, platelets, lymphocytes, etc. is minimal. At this wavelength of 940 nm, the actual blood glucose concentration can be determined.

As can be seen in Table I we have several samples that represent values of light absorption through tissues. The W-860 channel represents the wavelength of 860 nm. Here the absorption rate varies between the values 291 ~ 298. This channel would be closest to the wavelength of 940 nm. We know that a normal blood glucose on an empty stomach should be between 70-108. Between 120-180 it would be at the limit, between 215-250 the blood sugar is high and over 350+ would be dangerously high.

If we calculate $\varepsilon \in C$, where:

$\varepsilon$ = standard deviation

C = set of deviation factors (noise signal, optical signals of other blood constituents such as water, platelets, lymphocytes etc.)

We will therefore have the formula:

$$\gamma = \rho - \varepsilon \qquad (5)$$

where:

$\gamma$ = glucose value

$\rho$ = absorption rate

$\varepsilon$ = standard deviation

According to table I we would have the following results, if ε = 200 and we would calculate only the W-860 channel with the wavelength of 860 nm:

**TABLE II** VALUES GLUCOSE / SAMPLE

| W-860 | $\gamma = \rho - \varepsilon$ |
|---|---|
| E1 | 91.97 |
| E2 | 96.62 |
| E3 | 98.95 |
| E4 | 94.29 |
| E5 | 90.80 |
| E6 | 95.46 |

Where we would have a result after an arithmetic mean of: 94.68, the result of a patient who has glucose within the limits of normal values according to the standard of: 70 ~ 108.

## CONCLUSIONS

In this paper, a brief description of the near-infrared and noninvasive blood glucose measurement technique was made based on the pusloximetry technique. A good correlation is observed between the measurements of the glucometer and the system designed for measurements. The results also show the feasibility of using non-invasive NIR-based glucose as a measurement technique. [9] System performance can be increased by developing the proper conditioning of the signal in the circuit to eliminate interference caused by network signals, such as the noise signal or by the optical signals of other blood constituents such as water, platelets, lymphocytes, etc. Calculation of the standard deviation (ε), that is the absorption of light caused by the noise signal, the skin layers (dermis, epidermis, hypoderma), the optical signals of other blood constituents such as water, platelets, lymphocytes, a chapter to be addressed in the future to detail.

## ACKNOWLEDGEMENTS

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