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NIR Based Non-Invasive Blood Glucose Measurement

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Abstract

Objectives: This paper describes the method of measurement of glucose concentration in the human blood non-invasively using the near infrared optical technique. **Methods/Analysis**: In recent medical practice, the concentration of glucose in blood is measured using an invasive techniques which generally involves puncturing finger. In generic few ml of blood whereas in recent practice less than a drop of blood is taken out and passed through the standard chemical tests to measure glucose concentration. These methods are expensive as well as painful. The frequent finger puncturing causes calluses on the skin and also increases the risk of spreading infectious diseases. **Findings**: So, the development of a non-invasive blood glucose measurement system will be boon to the diabetic patients. This paper describes the method of blood sugar measurement in the human blood non-invasively using the painless near infrared based optical technique. The designed system consists of LED emitting signals of 940 nm wavelength. These optical signals are sent through the fingertip and reflected signals are detected by phototransistor placed beside the LED. The glucose concentration in the blood is determined by analyzing the variation in the intensity of received signal obtained after reflection. The results obtained from the designed system shows the feasibility of using NIR based non-invasive method for the measurement of blood glucose. **Applications/Improvements:** The described system is majorly useful for diabetic patients. The measurement accuracy of the proposed system can be improved by incorporating it with noise filtering techniques.

Keywords: Blood Glucose, Diabetes, Near Infrared, Non-Invasive

1. Introduction

Diabetes is a type a metabolic diseases in which the blood glucose (blood sugar) level in human body increases drastically from its normal level. The increase in sugar level is either due to inadequate production of insulin in blood cells or can be because of improper response of body cells to the insulin or can be because of both the reasons. diabetes can lead to major complications like heart failure and blindness in the human body[1]. Hence regular monitoring of glucose level is important. The World Health Organization (WHO) estimated that the number of people with diabetes is more than 200 million.

Diabetes is a state of a body where it not able to produce the quantity of insulin sufficiently required to maintain normal level of blood glucose. So, diabetic patients regulate their blood glucose levels through proper diet as well as by injecting insulin[2]. For the effective treatment of diabetes, patients have to measure the level of blood glucose periodically[3-5]. At present, diabetic persons are using invasive figure pricking instrument knows as glucose meter to know the concentration of blood glucose.

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In the pathology laboratories, glucose is been measured by puncturing the patient's finger using a lancet to take out a small quantity of blood sample[6-10]. Then the sample of blood will be placed on the strip and is inserted into the blood glucose meter. Inside a glucometer, a series of chemical reactions will take place and as a result of chemical reaction Potassium Ferro cyanide is produced and it reacts with the metals on electrode layer and causes the electric current to flow through the electrodes. More the concentration of glucose in the blood, more the Potassium Ferro cyanide production and more the current through the electrode. This strength of current is used to predict the glucose level present in the blood[3].

Development of a non-invasive glucose measurement technique would be a boom for a diabetic patient. The major advantage of noninvasive measurement methods is the relief from pain and comfort due to no finger puncturing. The non-invasive methods of glucose monitoring reduces the difficulties involved in glucose measurement and hence reduces the cost of healthcare. The noninvasive method for glucose measurement like IR spectroscopy is popular from years, but method with a reliable results has not been established yet.

From a last decade or two, lot of research work is going on for the non-invasive blood glucose measurement. The researchers are using various optical methods for the non-invasive measurements which includs near-infrared, photo acoustic spectroscopy, Raman's spectroscopy[11], polarization technique and light scattering techniques[3,12,13], Trans illuminated laser beam is used to measure glucose concentration by[14]. As described by Tang[15], metabolic heat conformation technique can be also used for blood glucose measurement.

In the Near Infrared (NIR) Spectroscopy[16], glucose cells will produce the weakest NIR absorption signals in the human body as glucose is one of the biological component present inside the human body. In measuring the glucose level, the NIR spectroscopy enables the penetration of signals inside the tissue within the range of 1 to 100 millimeters depth. Penetration depth decreases as the signal wavelength value increases[17,18]. Recently few authors incorporated neural network techniques in the non-invasive blood glucose measurement[19, 20].

This paper is all about the measurement of blood glucose non-invasively by using NIR optical technique which overcomes the problems in invasive measurement like finger puncturing, risk of infection, etc.

The full paper is organized as follows: Section II describes the Principle behind the blood glucose measurement, Section III deals with the system design that includes light wavelength selection, system hardware and experimental analysis. Section IV shows the experimental results of the designed system and Section V concludes the paper.

2. Principle of Blood Glucose Measurement

When a light ray interact with human body tissues, it is attenuated by scattering as well as by absorption by the tissues. Due to the mismatch between the refraction index of extracellular fluid and the cell membrane, light scattering occurs in tissues. Refraction index of extracellular fluid varies with the glucose concentration whereas the cellular membrane index is assumed to be remain relatively constant[20]. Beer-Lambert Law plays a major role in absorbance measurement which states that absorbance of light through any solution is in proportion with the concentration of the solution and the length path travelled by light ray[21].

Figure 1 shows the description of effect of glucose molecules on the light path[16, 18]. Less glucose leads to more scattering, more path length and hence less absorption whereas more glucose tissues result in less scattering, less optical path length and hence more absorption by the tissues. Due to more absorption in high glucose tissue reflected light is having less intensity compared to tissue with less glucose content.

Light transport theory describes light attenuation as[1]

$$I = I_0 e^{-\mu_{eff} L} \quad (1)$$

where, I is the reflected light intensity, I_0 is the incident light intensity and L is the length of optical path inside the tissue. Attenuation of light inside the tissue

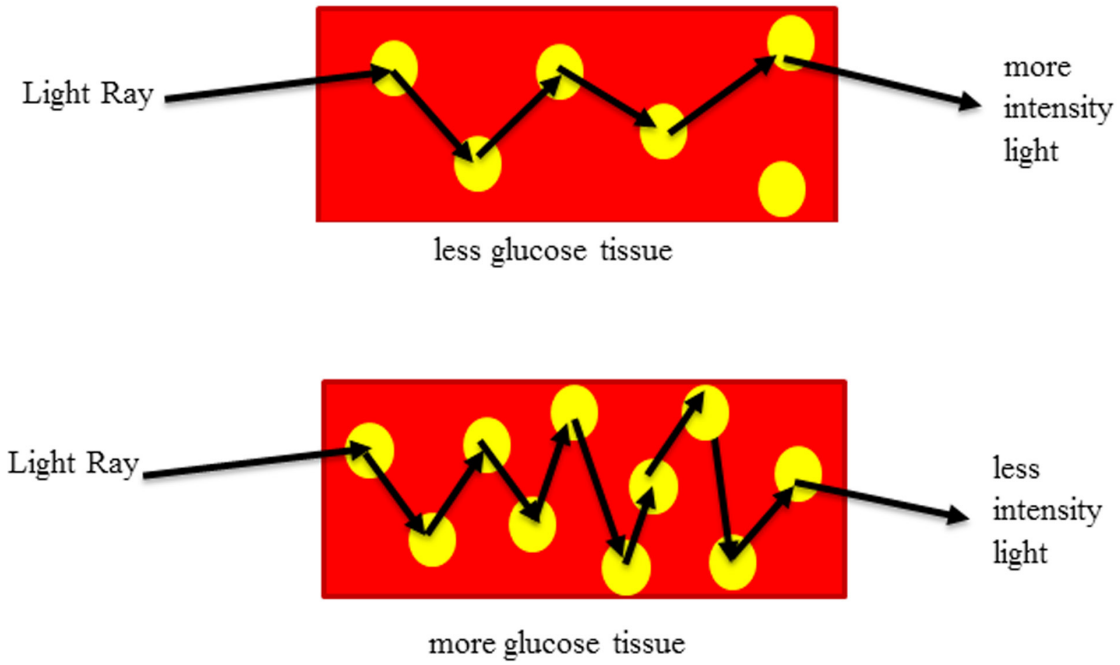


Figure 1. Effect of Glucose On light Path.

depends on the coefficient known as effective attenuation coefficient (μ_{eff}), which is defined as

$$\mu_{eff} = \sqrt{3\mu_a(\mu_a + \mu_s')} \quad (2)$$

The absorption coefficient (μ_a) is describes as the probability of absorption of photons inside tissue per unit path length and is given by

$$\mu_a = 2.303 \in C \quad (3)$$

ϵ is the molar extinction coefficient and C is the tissue chromophore concentration and the reduced scattering coefficient (μ_s') is given by eq.4[20]

$$\mu_s' = \mu_s(1-g) \quad (4)$$

where, g defines the average of the cosine of the scattering angles which has a representative value of 0.9[1] and μ_s defines the scattering coefficient.

With increase the glucose concentration path length decreases. With the assumption that refractive index of blood cell remains constant (approximately 1.350-1.460) with increase in the glucose concentration scattering properties decreases[19]. From the equations above (1-4) it can be concluded that μ_a also depends on the blood glucose concentration, the increase in the glucose concentration increases the value of absorption coefficient μ_a and hence the effective attenuation coefficient μ_{eff} also increases which in terms results in increase in the attenuation level. Hence from equation (1) it can be

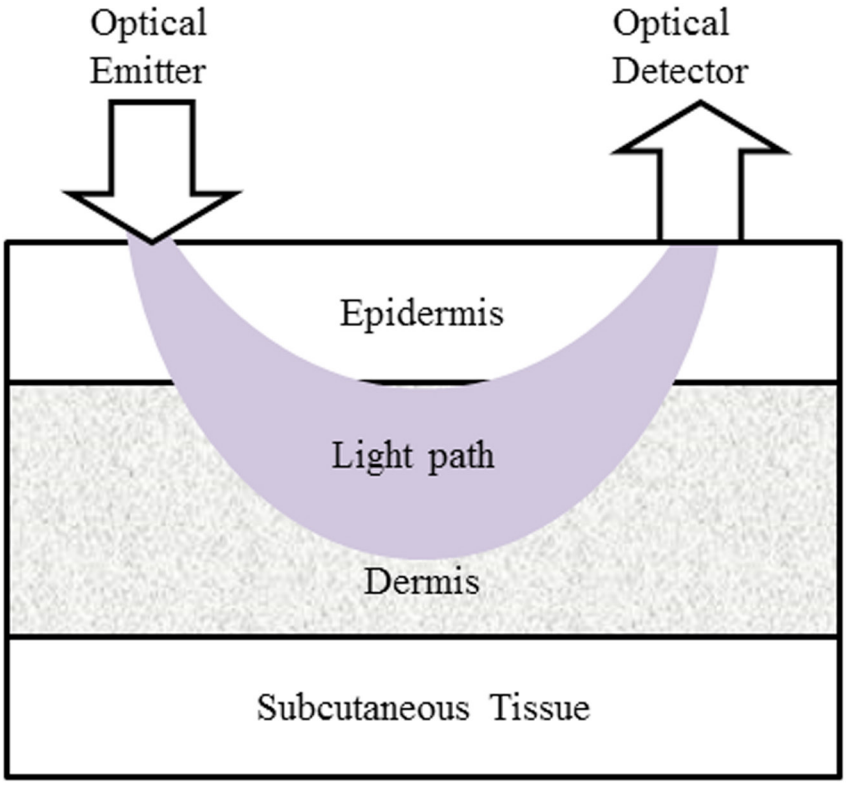


Figure 2. Cross Section of Skin and Light Path.

concluded that increase in attenuation decreases the intensity of reflected light.

Human finger skin tissue consists of epidermis, dermis and subcutaneous tissue layers. When optical signal is sent perpendicularly into the human body part the signal passes through epidermis layer and gets reflected in dermis layer and follows banana shaped path as shown in Figure 2[18].

3. System Design

3.1 Selection of wavelength

Light in the range of 700 nm to 2500 nm comes under the near infrared region which interact with the tissue with low energy radiation. 600 nm to 1300 nm is considered as the near-infrared window[22] which is also known as therapeutic window or optical window. The range of wavelengths where light possesses its maximum penetration depth in tissue is referred as Near Infrared window.

Glucose has light absorption peaks at wavelengths of 940 nm, 970 nm, 1197 nm, 1408nm, 1536nm, 1688nm, 1925 nm, 2100nm, 2261nm and 2326nm[1], But at 940 nm wavelength the attenuation of optical signals by other constituents of the blood like water, platelets, red blood cells etc. is minimum[20], hence a desired depth of penetration can be achieved and actual glucose concentration can be predicted.

3.2 System Hardware

Figure 3 shows the block level description of the desired system. Everlight's LED IR-333A is chosen as emitter as it emits optical signals of 940 nm wavelength. Its physical dimensions are smaller and it is less costly than LASER.

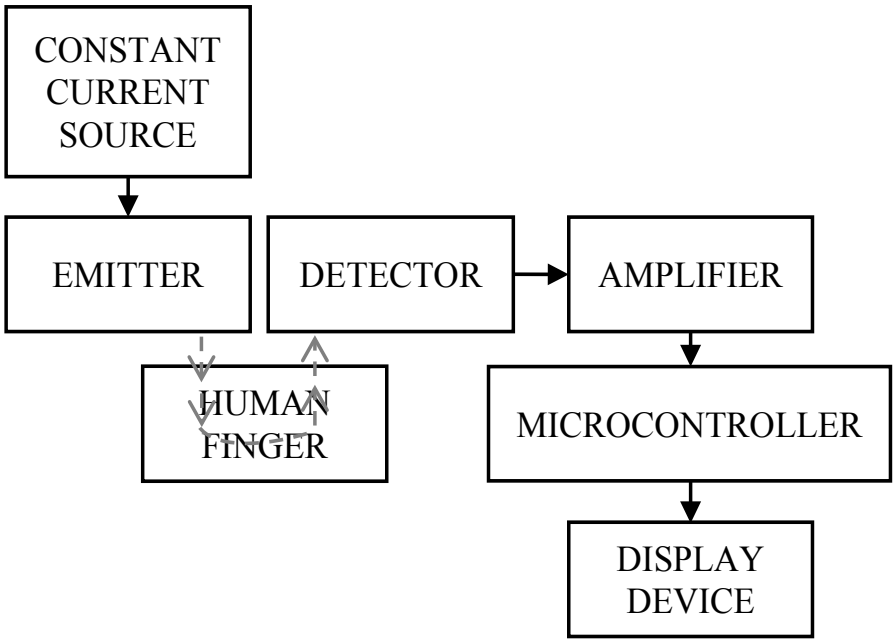


Figure 3. Block level description of the system.

LASER also affects the biological tissues and also costly. Hence LED is the best option to be considered as an emitter in biological systems. For maintaining strength of emitted optical signal to be constant, emitter is powered with a constant current source[3]. Everlight's phototransistor PT333C which is having peak sensitivity at 940 nm is used to detect the attenuation of optical signals with change in the glucose concentration in the blood. Transistor is connected in the common emitter configuration. Output of the detector circuit is passed through an instrumentation amplifier to increase the output signal strength and the output range. Microcontroller is programmed considering the regression equation formed and the liquid crystal display is used to display the blood glucose concentration.

To detect the reflected signals properly, emitter and detector are placed besides each other on the same side of the finger as there occurs a phase shift of 1800 between transmitted and reflected signals.

3.3 Experimental Analysis

With the help of designed system and commercially available, most popular One Touch Ultra glucometer[23], glucose is measured for different people for different conditions like before and after meal and corresponding voltage values at the amplifier output terminal are recorded.

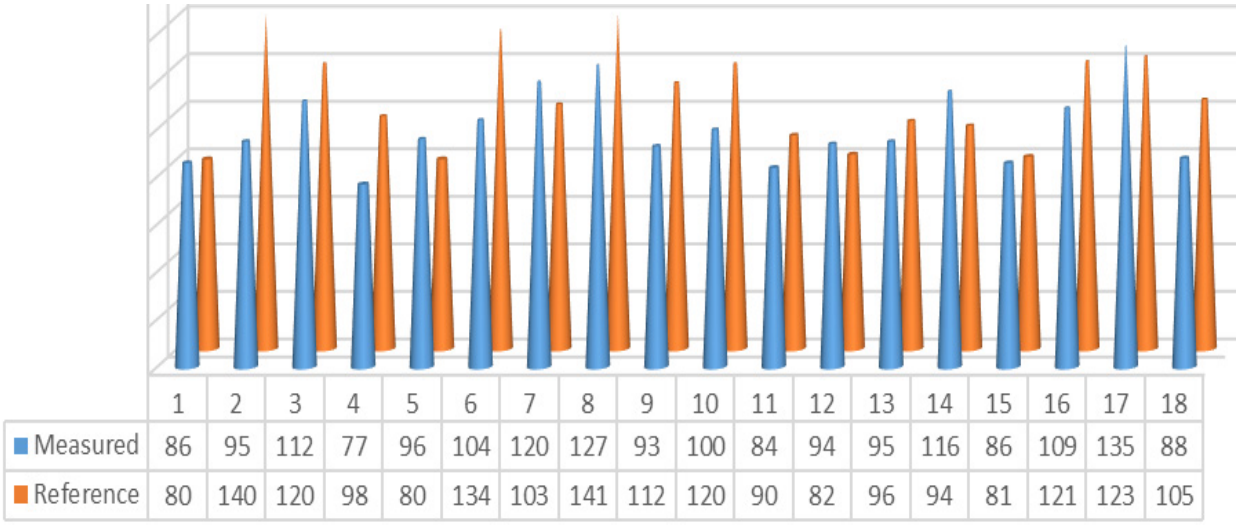
Figure 4 shows the graph of recorded values of voltage measured at the output terminal of the amplifier and the corresponding glucose concentration measures with the help of glucometer for the reference.

Based on the recorded voltage values and corresponding glucose concentration a 2nd order polynomial regression equation is computed (5).

$$concentration = 21.998v^2 - 157.73v + 335.55 \quad (5)$$

4. Experimental Results

The desired system is designed and developed for the measurement of blood glucose level using non-invasive NIR optical technique. Microcontroller is programmed by considering the regression equation (5). This equation is formed so that the glucose concentration can be measured non-invasively.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Measured	86	95	112	77	96	104	120	127	93	100	84	94	95	116	86	109	135	88
Reference	80	140	120	98	80	134	103	141	112	120	90	82	96	94	81	121	123	105

Figure 5. Measured and Reference Glucose Concentrations.

With the help of developed system glucose concentration is measured non-invasively and a good correlation is found between the concentration value obtained by the designed system and value by glucometer. Figure 5 is the result mapping chart which shows the glucose concentration measured by the designed system and at the same time, for the same person glucose concentration measured by the glucometer.

5. Conclusion

In this paper a brief description about near infra-red optical technique based non-invasive measurement of blood glucose is discussed. A good correlation is observed between the glucometer measurements and designed system measurements. The results obtained also show the feasibility of using NIR based non-invasive blood glucose measurement technique. The performance of the system can be increased by developing suitable signal conditioning circuit to remove interferences caused.

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