A Study on Non-Invasive Blood Glucose and CholesterolMonitoring Device

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Abstract

Diabetes Mellitus is a metabolic disease where the body is irregular to dissolve the body glucose properly. If the diabetes remains untreated over the period of time, it may cause heart stroke, kidney disease, lower limb amputation and blindness. Cholesterol is a fat that body needs to function properly. However, too much cholesterol can lead to heart disease, stroke, atherosclerosis and peripheral arterial disease. Therefore, Continuous monitoring of blood glucose and cholesterol is an important aspect of healthcare. Most of the existing methods for glucose and cholesterol measurement is based on invasive systems which require finger pricking. To avoid the discomfort of intrusive procedures, a low-cost non-invasive blood glucose and cholesterol monitoring device is desirable. In this paper, a detailed study on existing methods for glucose and cholesterol level estimation is made based on available literature. After an extensive review, it was noted that Near Infrared wavelength is the best suited region for blood glucose and cholesterol measurement non-invasively.

Keywords :-Non-invasive, Near-Infrared, Arduino, Machine Learning, Internet of Things, Spectroscopy, Blood Glucose, Cholesterol, Regression techniques**.**

I. INTRODUCTION

Cholesterol is found in every cell in the body and is created by the body or consumed through dietary food, with lipoproteins transporting it throughout the body in the blood. Low-density lipoproteins (LDL: "bad cholesterol") and high-density lipoproteins (HDL: "good cholesterol") are two forms of lipoproteins that can transport cholesterol throughout the human body. Very low-density lipoproteins VLDL, are lipoproteins that transport cholesterol from the liver to the body's organs and tissues. It is critical to maintain appropriate levels of both types of lipoproteins, as high LDL levels suggest an increased risk of heart disease, whilst high HDL levels indicate a healthy heart. LDL cholesterol, HDL cholesterol, and VLDL cholesterol make up total cholesterol. According to a clinical study, an optimal total cholesterol level is less than 200 mg/dL, while a level of more than 240 mg/dL is a dangerous condition.

Diabetes mellitus (DM), commonly referred to as Diabetes, is a leading cause of death and morbidity in all countries. The insulin hormone is in charge of regulating the amount of blood sugar in our bodies. A diabetic's body, on the other hand, either does not create enough insulin or the insulin it does make does not operate effectively. As a result, the blood sugar level rises.This leads to a slew of problems, including the degradation of various body organs. Type

1, type 2, and gestational diabetes are the three kinds of diabetes mellitus.Type 1 diabetes occurs when the body does not create enough insulin, while Type 2 diabetes occurs when the body produces too much insulin that is not adequately utilized. Pregnant women are more likely to develop gestational diabetes. Hypoglycemia, normal blood glucose level, and hyperglycemia are the three primary types of blood glucose levels. Frequent checking of blood glucose can reduce the odds of fatal diabetic complications.

There are three systems namely: Invasive, Minimally Invasive and Non-invasive.Invasive method refers to a medical practice that invades or enters the body by cutting or puncturing the skin or putting tools into the body. In minimally invasive technique, tiny are made with assistance of small flexible instruments instead of a large opening. Due to smaller incisions, there is less pain and quicker recovery. In the Non Invasive technique, there is no damage to the skin without cutting or putting instruments inside body. The major difference between invasive and non-invasive tests is that invasive tests are done by cutting or entering a body part using medical instruments, whereas non-invasive tests do not require breaking the skin or entering the body.

The traditional and conventional existing is the invasive method carried out by trained medical providers to use instruments that cut skin. Examples of invasive tests include biopsy, excision, cryotherapy, and endoscopy. There are many drawbacks of invasive procedures, it is painful, expensive, patient discomfort, damage of tissue and it can cause infection. Also, the use of invasive techniques in the case of pregnant women increases the chances of abortion and mental stress. Thus, continuous monitoring is not possible in this method as it is not advisable to puncture skin often for testing purpose.A Non Invasive system can overcome these difficulties by making the system simple, reliable, and painless as there is no incision or insertion of medical instruments to the body.

(a)(b)

Figure 1. (a)Invasive technique – requires droplet of blood for measurement purpose.
(b)Non Invasive technique – uses optical methods for measurement purpose.

II. LITERATURE REVIEW

Betty Elisabeth Manurung et.al***[1]*** demonstrated the use of Sequential model of Keras using Tensor Flow tool and neural networks concept to train the datasets. The system adopts Spectrophotometric method and uses low energy radiation NIR wavelength. A Photoplethysmography wave is obtained from the photodiode receiver. Trans Impedance Amplifier is used to convert Current generated from the photodiode to voltage and then the voltage signal is amplified by 30.3x times. The Arduino Nano microcontroller is utilized for processing, and the inbuilt ADC is used to convert the voltage signal from analogue to digital. Voltage to mg/dL value prediction is done by the Keras Sequential model of the Machine Learning Algorithm. The output of the model is compared with the output of invasive techniques to calculate the mean Absolute Error of the model which is around 5.85mg/dL. Better results can be obtained by using large number of datasets for training or by optimization of analogsignal.

The workby Tuhong Zheng et.al***[2],*** the four parts of the hardware framework consists of:

- NIR unit transmitter, receiver, and signal amplifier. NIR region is chosen because of its high S/N ratio and low absorbance in skin tissue and its non-destructive nature to the human skincells.
- Arduino Uno is used as the CPU for data processing because of its affordable price and the active open-source community environment with numerous projects, shields, and tutorials available fordeveloping variousprojects.
- LCD Display is used to display real time blood glucose values and is interfaced with theArduino.
- Mobile application is developed so that the users can understand and monitor the changes from time to time. Bluetoothmodule is used to connect the Arduino and mobile application.

Although the device can measure blood glucose levels, the accuracy of the data can be improved by decreasing confounding factors such finger thickness and physiological variances. More precise glucose measuring methods can be created to assist physicians and patients.

The work carried out byI.M.M. Yusoff et.al***[3]***suggestthat Non Invasive detection of lipid molecules (Lipoproteins) in blood to predict the cholesterol level is possible. The NIR spectrum is chosen as they are closely spaced, and they minimize the interference phenomenon of light inside the blood stream. Absorbance property of lipid molecules is found to be the most effective at around 1720nm considering the varying aspect of solute concentration in the blood. The Photodiode used for reception of NIR would be InGaAr as it provides great response for wavelengths in IR range.

Near infrared (NIR) detection, ultrasound and dielectric spectroscopy are the few existing noninvasive techniques that are used to calculate the blood glucose levels. The algorithm developedby Gayathri B, et.al ***[4],*** using the scattering property of glucose molecules and the photoplethysmography concept, a linear regression model was developed. The glucose

molecules in blood absorbs, scatters and reflects more light than its surrounding tissue and the intensity of reflected light is proportional to the blood glucose concentration.
In reflection photoplethysmography, the glucose level and voltage intensity are directly related. The correlation co-efficient of linear fit model of invasive data sets: slope and intercept values are substituted in equation Y=*m*X+ C to calculate non-invasive glucose concentration in the blood. The error of around ±12 mg/dL can be observed in this model.

In thework published by, Preya Anupongongarch***[5],*** an IR sensor with wavelength of 1200nm and a red light is used in transmitter, while photodiode is used as receiver. Arduino nano is used for signal processing along with signal conditioning circuit. The relation between the concentration of cholesterol in the blood in milligrams per decilitre and the digital output is obtained by forming a calibration equation between blood cholesterol concentrations with digital output. Multiple regression analysis is done to get the calibration equation. During the sensor testing, average percentage error was found to be 2.52% when compared with results from bloodcollection.

The work by Megha.S.Asekar ***[6],*** suggests that glucose absorbanceis the highest at 940nm and is selected for noninvasive measurement using NIR Spectroscopy. The sample thickness and sample ingredient concentration are found to be proportional to the light intensity. Thus, it can be said that, Absorption α Concentration. The current output from the receiver is converted to voltage, and the signal is amplified and conditioned using Notch and Second order Butterworth filters.

In the work publishedby SainaSunny,et.al ***[7],*** describesvarious methodologies used inExisting Non-Invasive Optical technology. Summary of available methodologies include:

- Light absorption Spectroscopy – The spectroscopic studies are carried out in the NIR region (visible and near infrared), which is roughly 590nm-1180nm. Per unit of body composition, glucose produces the weakest NIR absorption signal. The penetration value of NIR is measured at a depth of 1-100mm, and as the wavelength increases, the penetration value drops. As a result, the earlobe, finger cuticle, and skin are the most commonly observed bodily parts.
- FIR spectroscopy – For examinations that do not require an external source, body heat and thermal emissions are utilized.
- Raman spectroscopy - Transmitting light is scattered and its value varies due to oscillations and rotation.
- Photo acoustic spectroscopy - As a result of the absorption of pulsing light, an ultrasonic wave is produced. When laser beams strike biological tissues, pressure differences occur as a result of heat variations.
- Fluorescence - sensing technology is carried out through tears in a painless manner.

Joseph Devakumar***[8]*** suggests aNon-invasive method using power LED and photodiode for calculating the thickness and density of blood. Infrared light is passed through the skin which is absorbed by blood. Depending upon the concentration of the blood the current will be generated and captured by photodiode sensor. Photoplethysmography (PPG) is a simple optical non-invasive method that makes use of low-intensity infrared (IR) light for surface

level measurements. When light travels through biological tissues it is absorbed by bones, skin pigments and both venous and arterial blood. Since light is more strongly absorbed by blood than the surrounding tissues, the changes in blood flow can be detected by PPG sensors as changes in the intensity of light is obtained. Thus, greater the concentration of glucose there will be reduction in the scattering property of blood and only fewer photons are absorbed and therefore light intensity increases.The wavelength ranges from 700nm-2500nm.The output from the sensor is given to the Arduino dumped with the program and the output is displayed on the LCD display. When invasive and non-invasive readings were measured the tolerance was found to be 0 to0.3.

P.Daaraniet.al ***[9],*** calculated blood glucose by measuring the intensity of NIR light 940nm after passing through fingertip because light scattering occurs in biological tissues due to the mismatch between the refraction indices of cellular components. Beer Lambert Law is used to determine the relationship between the absorbance of light through any solution which is in proportion with the concentration of the solution and the length path traveled by the light ray. A phase shift of 180˚ is used to ascertain the angle between the scattered/transmitted and reflected signals. Hardware system consisting of Atmel SAM3X8E microcontroller is selected and the converted current into voltage value is given to the inbuilt ADC, which provides digital voltage value and by regression analysis blood glucose value is predicted by the model. Accuracy of the system can be checked either by Clarke Error Grid Analysis or Surveillance Error grid analysis.

Masab Ahmad et.al***[10],*** suggested the use of Near Infrared (NIR) spectroscopy to determine blood glucose levels based on transmittance spectroscopy on the ear lobe including parameters like tissue thickness, blood oxygen saturation and proposes a linear regression-analysis based calibration system. A NIR wavelength of 1550nm is chosen due to its high signal-to-noise ratio for glucose signals and its high response photodiode InGaAs photodiode from Marktech as the conventional silicon photodiodes have limited spectral bandwidth. The amount of blood and transmittance of light is inversely proportional. Increasing the path length would lower transmittance rate as well.

In the work proposed by Prof. Mrs.A.A.Shinde***[11],*** the technique of occlusion spectroscopy is adopted. Optical fibers and IR sensors are used and FFT is applied to the response of the optical signal using spectrum analyzer. The frequency spectrum is observed before occlusion and after occlusion. The methods used for NI determination depends on: Tracking intrinsic property of glucose or by measuring effect of glucose on optical properties of tissues. The frequency variations also depend upon underlying health conditions of the humans.

Chi Fuk So et.al***[12]***suggested thatInvasive methods have several disadvantages such as risk of infection and finger pricking by glucometer over the long term can result in damage to the finger tissue and is not practical for continuous monitoring. Although the non-invasive concept was launched morethan30 years ago, most of the non-invasive technologies are still in their early stages of development. Challenges ahead for non-invasive measurements include relatively poor in signal-to-noise ratio in relation to blood glucose concentration and spectra response forabsorption spectroscopy. During calibration, factors such as light intensity affect the prediction model and often calibration error is encountered due to time lag between

measurements of blood glucose content from different parts of body. A lot of work is still required to be done to produce a commercially available, clinically reliabledevice.

The work by Parag Narkhede et.al ***[13]***shows thatNIR spectroscopy enables the penetration of signals inside the tissue within the range of 1 to 100 millimeters depth. Penetration decreases when signal wavelength increases. If refractive index of blood cell remains constant, increase in the glucose concentration causes scattering properties to decrease, resulting inincrease in the value of absorption coefficient and therefore the effective attenuation coefficient also increases which leads to the increase in the attenuationlevel.

Analysis made by Afreen Khanum et.al**[14]**suggests that visible and infrared light are suitable for blood glucose and cholesterol determination. Accuracy depends on factors like placement of components and placement of finger. Accuracy of the device can be improved by:

- Proper fabrication ofsensor
- Appropriate size of fingerhose.

MeghanaChandrashekar et.al***[15]***has proposed a system for measurement of Cholesterol level as well as Blood glucose level tokeep track of patient health by smart patient health tracking application. Sensors and microcontroller provide precautionary messages when the system detects any abrupt changes in the patient's health conditions and alerts the user on the mobile application. Thus, IoT based patient health tracking system effectively uses wireless communication to monitor the health of the patient to avoid emergencies. IoT typically includes the advanced connectivity of the devices, systems, and services. IoT -based healthcare services are expected to reduce costs, increase the quality of life, and enrich the user'sexperience.

Varsha Apar et.al ***[16]*** has proposed a system hardware that uses Arduino Uno as CPU to perform analysis and processing of the signal. E- health Sensor V2.0 is used for body monitoring as it helps in detection of SpO2, body temperature and glucose molecules. Hemoglobin and Oxy-Hemoglobin in the blood are differentiated by Red and Infrared (IR) light by Oximetry which provides oxygen saturation level. Data from the database is classified and processed in MATLAB. The neural network pattern recognition tool and ANFIS toolbox are powerful tools used for data classification which will help in prediction of required parameter from the feddatasets.

A non-invasive blood sugar level measuring device using Max30100 integrated with IoT (Internet of Things) is suggested by Eko Agus Suprayitno et.al***[17]***. The Max30100 is an integrated pulse Oximetry and Heart rate monitor sensor which combines two LEDs, a photo-detector, optimized optics, and low-noise analog signal processing to detect pulse Oximetry and heart-rate signals. The digital values of the Oximetry and heart rate signals are provided as input to the linear regression model which would in-turn return the glucose level saturation in the blood.

The work by Rachel J. Dotson et.al ***[18]*** suggests that Cholesterol is widely known to alter the physical properties and permeability of membranes and tissues. The normal oxygen level of tissues varies according to the tissue type and most of the normal tissues have cholesterol

content in the range 20–40 mol % whereas some have higher levels. Several works mention that cell membrane cholesterol acts as a barrier to tissue oxygenation. Molecular dynamics simulations are adopted to provide atomic-resolution insight into the influence of cholesterol on oxygen diffusion across and within the membrane. Simulation results shows that high cholesterol content reduces the overall solubility of oxygen within the membrane.

III. CONCLUSION

After a thorough review of the published papers, it can be concluded that NIR spectroscopy is best suited to determine the concentrations of glucose and cholesterol levels in blood non-invasively with the help of Regression model by feeding training and testing datasets to incorporate supervised learning to the model. A summary and comparative study on the above literature survey is highlighted in Table1.Table 1 summarizes the type of spectroscopy, wavelength, algorithm used and hardware system developed to detect glucose and cholesterol levels. Also, extensive literature review suggests that Linear regression model results in good accuracy. Among the various spectroscopic techniques, the Near Infrared methodology is the most promising approach as it exhibits low scattering losses, good bio-molecule absorption and does not damage the human cells or tissues exposed to it.Through rigorous studies and research, non-invasive health monitoring devices are getting better but due to lack of precision and clinically acceptable accuracy, these devices never met the standards of the market requirement. Thus, a device that would overcome these inaccuracies would be a breakthrough invention in the health care domain.

Paper	**Spectroscopy**	**Wavelength**	**Algorithm used**	**Hardware System**
1.	Photoplethysmography	-	Sequential Keras model	Arduino nano microcontroller
2.	Near Infrared (NIR)	730nm-2500nm	-	Arduino Uno microcontroller
3.	Near Infrared (NIR)	1750nm	-	Arduino Uno microcontroller
4.	NIR - reflection photoplethysmography	730nm-2500nm	Linear regression model	MSP430G2553.
5.	Near Infrared (NIR)	1200nm	Multiple regression model	Arduino nano 3.0
6.	NIR based Photoplethysmography	940nm	Photoplethysmography signal analysis	MSP430
8.	Photoplethysmography	940nm-2500nm	-	Arduino Uno
10.	Near Infrared (NIR)	1550nm	Linear regression model	32-bit ARM microcontroller with pulse oximeter
11.	Occlusion	-	FFT analysis	Infrared

	Spectroscopy			transmitter and receiver
13.	Near Infrared (NIR)	940nm	Regression analysis	Laser light and microcontroller
14.	IR spectroscopy	900nm to 1mm	-	Arduino Mega and GSMSim900 module
15.	Near Infrared (NIR)	920nm	Linear regression model	AtmelSamX3E
16.	IR based Oximetry	1550nm	MATLAB and neural network pattern recognition	Arduino Uno and SpO2 sensor
17.	Near Infrared (NIR)	-	-	Max30100 and Node MCU Microcontroller

Table1. Comparison Study

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