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Cairo University

MEDICAL PHYSICS TASK II

GLUCOSE MONITORING SYSTEM UTILIZING NEAR-INFRARED TECHNOLOGY

UNDER SUPERVISION OF:

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Table of Contents

Abstract

Regular monitoring of glucose concentration is essential and urgent, especially for diabetics. However, those methods which involve finger puncturing are invasive, expensive as well as painful. Also, there are risks of infectious diseases using these techniques due to the contact of the needle on human skin. This project proposes a non-invasive glucose monitoring system utilizing near-infrared (NIR) light to measure the glucose concentration in human blood. The designed system uses a NIR LED transmitting through D-glucose phantom samples, two phototransistors which are photodetectors that convert light into electrical current with an amplifying transistor built-in. They are used in NIRS systems for detecting small changes in the intensity of the light, and an Arduino UNO microcontroller. For calculating the values of glucose concentration, regression algorithms are used.

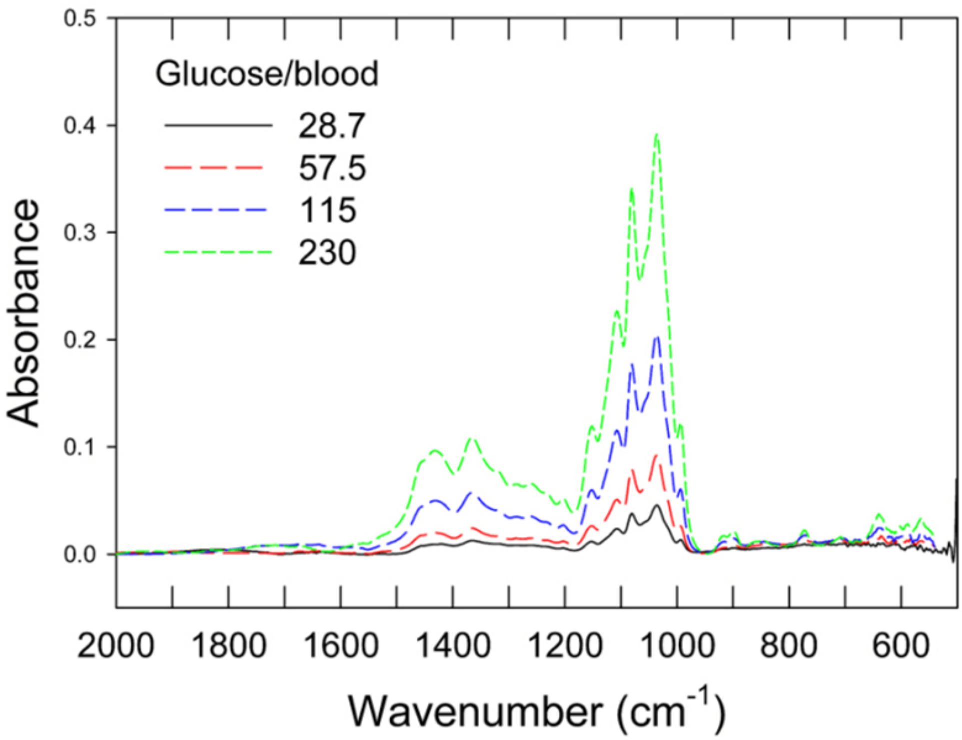
Introduction

Diabetes is a pathological metabolic condition that occurs when the amount of glucose (sugar) in the blood is too high, which affects other organs if not diagnosed and left untreated. Nowadays, it has become a significant health problem globally, and the number of people getting diabetes is rising, and the need for blood glucose monitoring is the obvious outcome. Checking their blood pressure regularly not only lets people know what state they are in but also helps them to prevent diabetes . With the available devices, users can check their blood glucose quickly and regularly. The most popular device is the invasive type. The user must make a finger prick by using a test strip, and the device uses their blood to calculate the glucose amount. Although giving precise results this method has some disadvantages: not suitable for people who are afraid of needles, waste of money and time to buy the test strip, painful and uncomfortable. Moreover, using the invasive method could increase the risk of infection. Hence, finding another method is the concern now. Indeed, there is a sharp rise in the non-invasive method for checking the blood glucose level. Most of these methods are the application of the LED and the properties of light for measurement. These devices can deliver painless and comfortable progress for the users. Although this type of method is new, it shows the potential of making a device that is more user-friendly, painless, and could give a reliable result.

The non-invasive method works based on light properties. For each substance, there is always a specific wavelength at which the absorbance of that substance is the strongest. Each substance has its wavelength. Using this property, the system consists of two main components which are the LED and the photo sensor. The LED emits the light through the skin area where it is put, and the photo-sensor is placed on the opposite side. By choosing the appropriate wavelength, which is absorbed mostly by blood glucose, the amount of light that reaches the phototransistor is calculated and analyzed. Choosing the appropriate wavelength for the system is the most important key. To achieve a good result, the wavelength must be the one that has the most interaction with blood glucose and also not be affected too much by the other substances. There have been many options for the wavelength that is proposed by the previous research since glucose has light absorption peaks at wavelengths of 940, 1150, 1450, 1536 nm [1–5]. At these wavelengths, the attenuation of optical signals by other constituents like platelets, red blood cells or water is at a minimum.

The project idea

The project idea is to develop a non-invasive glucose monitoring system that utilizes near-infrared (NIR) light to measure glucose concentration in human blood. This method offers a more user-friendly and painless alternative to the invasive finger puncture method for monitoring glucose levels.



Parameters related to light signals

Some Physical parameters are crucial for the system's accuracy. The appropriate wavelength must be chosen to have the most interaction with blood glucose and be minimally affected by other substances There have been many options for the wavelength that is proposed by the previous research since glucose has light absorption peaks at wavelengths of 940, 1150, 1450, 1536 nm [1–5]. At these wavelengths, the attenuation of optical signals by other constituents like platelets, red blood cells or water is at a minimum.

The system consists of several components, including a 750 nm-wavelength NIR LED, two phototransistors containing amplifiers, and an Arduino UNO microcontroller. The LED emits light through the skin, and the phototransistors measure and amplify the amount of light that reaches it. The microcontroller processes the data and calculates glucose concentration.

The methodology for calculating glucose concentration involves a polynomial regression algorithm, which predicts the correlation equation between collected voltage and glucose concentration. The obtained glucose level is displayed on the system's screen or sent to the user's mobile phone. The advantages of non-invasive methods for monitoring glucose levels include being more user-friendly, painless, and carrying a lower risk of infection.

Although the proposed system shows promising results, the potential for further improvement and development exists. Improvements such as adjusting the angle of the LED, using LED with more appropriate wavelength, using an optical instrument, and improving the filtering and amplification procedures could lead to more accuracy.

Tissue properties

Near-infrared (NIR) technology relies on the absorption of light by molecules in the tissue to measure blood glucose levels. The absorption of light by molecules is dependent on the tissue properties of the sample being measured. Here are some important tissue properties to consider:

Scattering: Scattering refers to the way that light is redirected as it passes through or interacts with the tissue. Scattering affects the path length of light in the tissue and can impact the accuracy of the blood glucose measurement.

Absorption: Absorption refers to the amount of light that is absorbed by different molecules in the tissue, such as water, lipids, and glucose. The amount of light absorbed by glucose is dependent on the glucose concentration in the tissue. NIR technology uses the absorption of light by glucose to measure blood glucose levels.

Chromophores: Chromophores are molecules that absorb light at specific wavelengths. In the case of NIR technology, the chromophores of interest are those that absorb light in the near-infrared range, such as glucose and water.

Scattering coefficient: The scattering coefficient is a measure of the amount of scattering that occurs in the tissue. It is dependent on the size and shape of the scattering particles in the tissue.

Attenuation coefficient: The attenuation coefficient is a measure of the total amount of light that is absorbed and scattered as it passes through the tissue. It is dependent on the tissue properties of the sample being measured.

Understanding these tissue properties is important for developing reliable blood glucose measurement techniques using NIR technology. By optimizing the design of the measurement system and taking into account the tissue properties of the sample being measured, researchers can improve the accuracy and reliability of blood glucose measurements using NIR technology

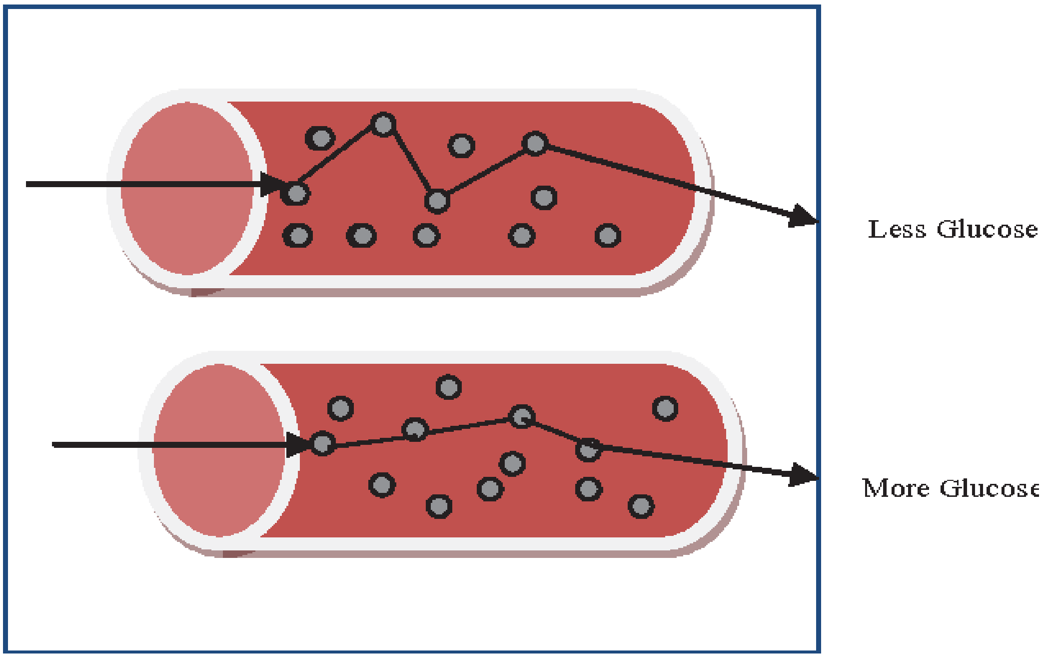
Wave-Tissue Interaction

There are several types of wave-tissue interactions that can be used in glucose monitoring systems that utilize Near-Infrared (NIR) technology. One approach is to use NIR spectrometry to estimate glucose levels in the blood. This technology is low-cost and simple but can suffer from scattering and poor correlation with glucose in the blood 1.

Another approach is to use Photoplethysmography (PPG) signals acquired using NIR waves of specific bandwidths for blood glucose estimation 1. This method involves extracting features from PPG signals and using machine learning methods to predict blood glucose levels.

These are just a few examples of the types of wave-tissue interactions that can be used in glucose monitoring systems utilizing NIR technology. There is ongoing research and development in this field to improve the accuracy and reliability of these systems.

In this project, however, we are focused on utilizing NIR. The main parameter featured in this WAVE-TISSUE interaction is *Absorption*. The NIR spectroscopy makes use of different absorption wavelengths for different materials in Order to detect their presence. In a NIR glucose monitor, the NIR waves are used to detect glucose concentration in the bloodstream. This is due to the effective mix of the NIR waves' extreme penetration ability and the weakness of biological material when faced with them.



Schematic Diagram and Simulation

This project needed actual data. So, the data shown below is cited from “Non-invasive Glucose Monitoring System using NIR Spectroscopy and Arduino”

The below table represents the voltage values that are calculated for corresponding invasively measured glucose values

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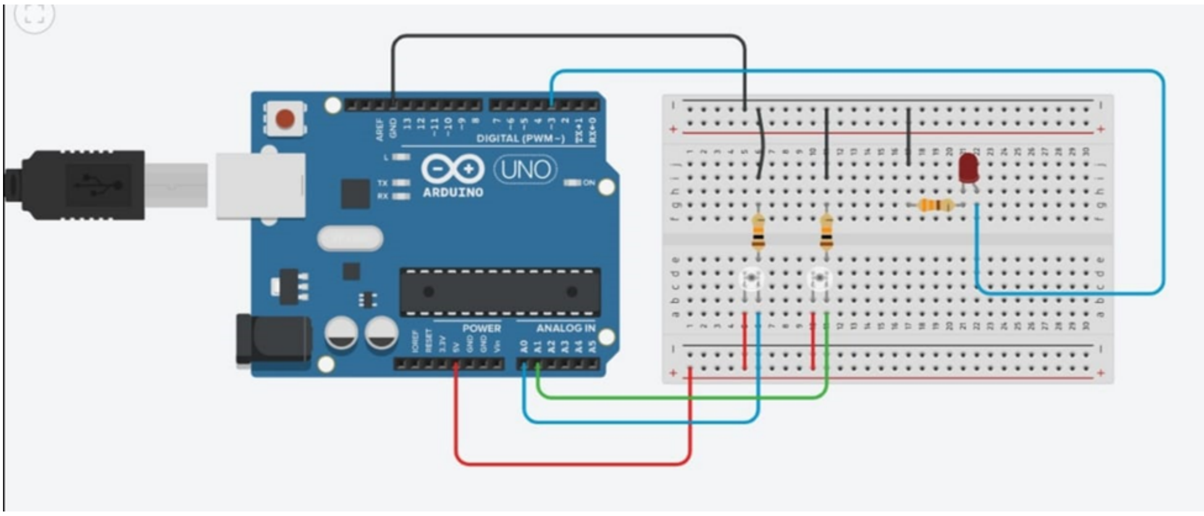
Table 1: Analog Voltage vs Glucose Level of Samples.

S.no	Analog Voltage(mV)	Glucose Values(mg/dl)	S.no	Analog Voltage(mV)	Glucose Values(mg/dl)
1	499	142	41	609	163
2	509	146	42	602	174
3	519	156	43	423	111
4	519	157	44	584	177
5	548	177	45	502	145
6	524	159	46	524	163
7	543	209	47	541	172
8	568	133	48	517	153
9	573	179	49	511	147
10	583	224	50	522	158
11	592	175	51	489	137
12	597	187	52	473	125
13	607	196	53	507	151
14	627	191	54	597	178
15	695	167	55	583	189
16	735	220	56	503	132
17	612	244	57	595	178
18	847	247	58	598	184
19	833	248	59	567	165
20	867	276	60	495	143
21	935	302	61	749	225
22	999	321	62	630	234
23	636	178	63	798	267
24	538	162	64	481	139
25	950	350	65	834	248
26	821	241	66	967	315
27	611	199	67	633	193
28	929	301	68	746	221
29	864	272	69	629	183
30	512	154	70	637	167
31	593	179	71	511	156
32	603	186	72	866	276
33	577	174	73	957	309
34	741	221	74	831	237
35	589	183	75	597	179
36	599	191	76	964	310
37	532	157	77	735	217
38	497	141	78	721	209
39	854	233	79	599	195
40	477	132	80	594	187

y = (3*10^-5) *x^2 + 0.2903*x - 4.798 where x and y are Analog voltage (mV) and glucose level (mg/dl) respectively.

Experimental data used

To derive the polynomial regression equation, 80 diabetics of both genders were studied. These people' glucose levels are tested in the laboratory using a traditional invasive method, and simultaneously, the Analog voltage relative to their glucose level which is measured using the proposed stimulated configuration.



Project Simulation

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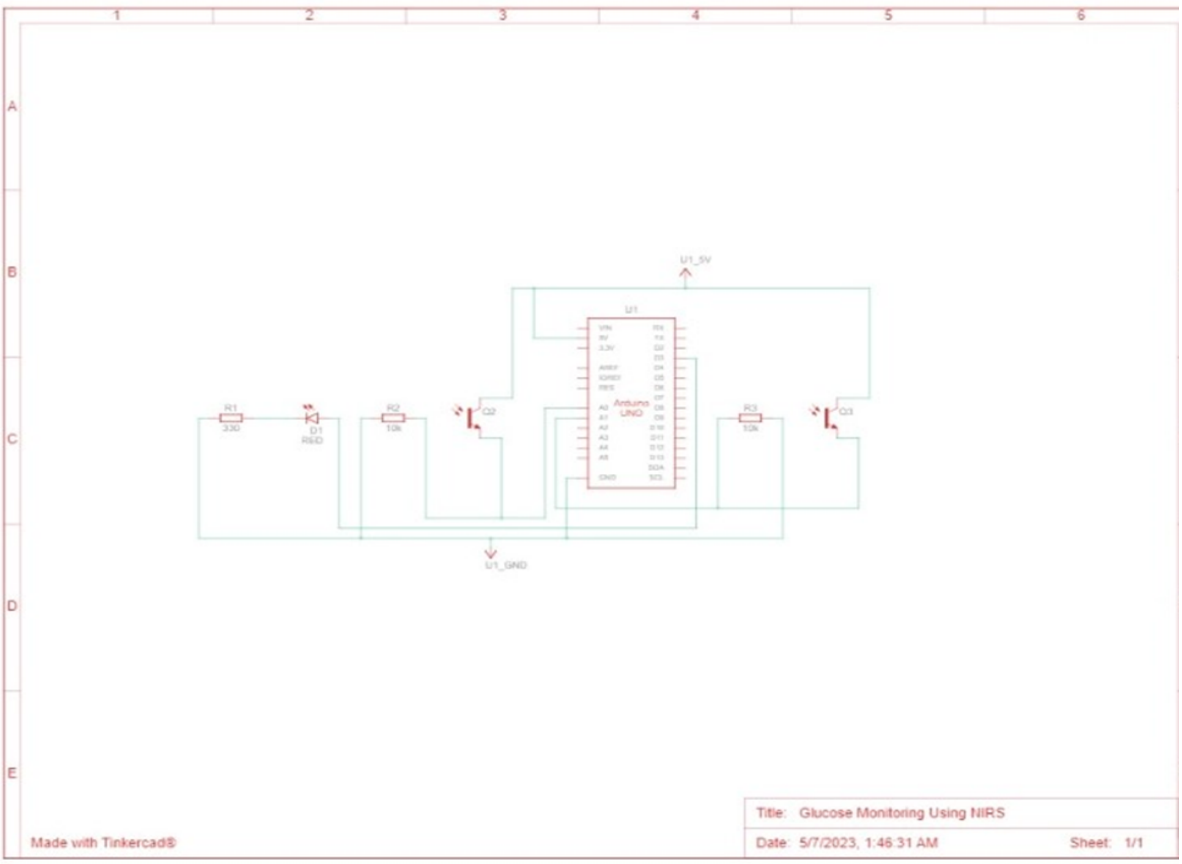

Schematic Diagram

Arduino code

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```
const int PT1_PIN = A0; // phototransistor 1 pin (blue)
const int PT2_PIN = A1; // phototransistor 2 pin (green)

const int led = 3; // led pin

double y;

// function to convert raw analog value to NIR absorbance
double analogToGlucose(double analogValue) {
  y = (3*pow(10,-5)) *pow(analogValue,2) + 0.2903*analogValue - 4.798;
  return y; //y is the glucose concentration.
}

void setup() {
  pinMode(led, OUTPUT);
  Serial.begin(9600);
}


void loop() {
  digitalWrite(led,HIGH);
```

```
  // read raw analog values from phototransistors
  int pt1Value = analogRead(PT1_PIN);
  int pt2Value = analogRead(PT2_PIN);

  //taking the average of the raw data
  double averageValue = (pt1Value+pt2Value)/2.0;
  // calculate glucose concentration from voltage
  double glucoseConcentration = analogToGlucose(averageValue);

  // display glucose concentration
  Serial.print("Glucose concentration: ");
  Serial.print(glucoseConcentration);
  Serial.println(" mg/dL");

  // delay before taking the next measurement
  delay(1000);
}

/*
// for testing purpose
void loop() {
  digitalWrite(led,HIGH);
  Serial.println("Enter a value:");

  // wait for user input
  while (Serial.available() == 0) {
        // do nothing
  }
```

```
  // read the user input
  String analogValue = Serial.readString();
  // convert the input to an integer
  double value = analogValue.toDouble();

  // read raw analog values from phototransistors
  int pt1Value = analogRead(PT1_PIN);
  int pt2Value = analogRead(PT2_PIN);

  //taking the average of the raw data
  float averageValue = (pt1Value+pt2Value)/2.0;

  // calculate glucose concentration from voltage
  double glucoseConcentration = analogToGlucose(value);

  // display glucose concentration
  Serial.print("Glucose concentration: ");
  Serial.print(glucoseConcentration);
  Serial.println(" mg/dL");

  // delay before taking the next measurement
  delay(1000);
}*/
*******************************************
```

References

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- Minimally invasive technology for continuous glucose monitoring | SpringerLink. [online]. Available at: Minimally invasive technology for continuous glucose monitoring | SpringerLink