Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Non-Invasive Glucose Monitoring Using NIR Spectroscopy

To cite this article: Pulagam Sai Kumar Reddy *et al* 2022 *J. Phys.: Conf. Ser.* **2325** 012021

Non-Invasive Glucose Monitoring Using NIR Spectroscopy

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Abstract: Diabetes Mellitus (DM), a metabolic condition, can lead to major health problems if it is not adequately treated. Traditional blood glucose monitors are intrusive and give people pain and irritation. As a result, the study's goal was to find a non-invasive way to measure blood glucose. To determine blood glucose parameters, this system uses an NIR Spectroscopy-based system with a light source of wavelength 950nm. The light source illuminates the skin of the wrist, and a photodiode receiver captures the reflected beam. An Arduino UNO microcontroller receives the conditioned signal and digitalizes it. The spectrum is calculated by the Arduino board based on the subject's blood glucose levels. Pre-processing and segmenting the raw waveforms are required to obtain the peaks of the NIR spectrum and to compute the regression model.

Keywords: Photoplethysmography, CGM (Continuous Glucose Monitoring), Spectroscopy, Non-Invasive.

1. INTRODUCTION:

When a person's insulin level is out of control and the glucose concentration in the blood isn't processed properly, a slew of issues develops. Diabetes, a disease characterized by a high blood glucose level, develops because of this incapacity. The treatment of diabetes must be precise and managed carefully in-order to prevent sugar build-up in the blood and glucose intolerance, which increase the risk of serious vascular complication (such as heart attacks), peripheral vascular problems, kidney failure, and stroke. Diabetic neuropathy, also known as peripheral neuropathy and autonomic neuropathy, is also associated with increased risk of fatal complications. According to recent studies, there are 424.9 million diabetic people worldwide, with the number anticipated to rise to 628.6 million by 2045. Glucose monitoring on a regular basis using invasive method is expensive as well as time taking and may causes infections. Many diabetic patients are often attacked with cardiovascular strokes or diseases. There are many who doesn’t monitor their glucose levels on a regular basis and remains undiagnosed and this leads to several health issues. Glucose monitoring on a regular basis is very important to avoid major health issues that are caused due to it. In this regard, many people are desiring for the non-invasive glucose measurement ahead of the invasive methods where we use painful methods. In this project, we are designing a non-invasive method for measurement of glucose value in the blood.

2. Existing Models, Proposed Model, Literature Survey

2.1 EXISTING MODELS:

Glucose is currently measured using standard methods and Continuous Glucose Measurement (CGM) and other devices which involves invasive method of measurement. To calculate the glucose level in invasive methods blood sample is required and if it is done regularly, it may cause infections and even time-consuming process. It motivates to develop the next generation devices, which are minimally invasive, and it involves small needle in the skin and Continuous glucose monitoring. In the next generation of devices where the glucose is measured totally noninvasively and real time continuous monitoring and remote monitoring, but this generation of devices are still in trails and development stages

2.2 PROPOSED MODEL:

In this proposed method, we measure glucose non-invasively using spectroscopic method. In this method, the glucose measurement is done using NIR spectroscopy. We use PPG technique and regression techniques for the measurement of concentration of glucose from the output obtained from the photodiode that is used to detect the light after absorption and transmission from glucose particles in the blood when LED light is passed through the fingertip or ear lobule.

2.3 LITERATURE SURVEY:

In the study, many researchers tried to analyse the different type of devices that are used for glucose measurement and try to summarize those into four generations. The classification is mainly done on invasiveness of the method. In the initial stages of developments in early 1970s, they have used reflectance technology which are made of heavy devices which requires very high amount of blood, and later due to availability of resources and latest technologies that made smaller devices with budget friendly prices where people are allowed to use personally.

One of the most well-known invasive methods is finger pricking where it only collects just 2-3 drops of blood, where people who frequently get tested may feel uncomfortable and become infectious. The next generation devices started being minimally invasive that includes small needles on skin which enables Continuous Glucose Monitoring (CGM).

Since these types of medical devices are still at an early stage of development, the emergence of the next generation of these devices is still more of an option than it is an actual application for them. In any case, we will represent them as fourth-generation medical gadgets since they provide real-time remote monitoring from a remote location and do not require traditional invasive approaches. The non-invasive techniques avoid invasive bodily contact and rely on techniques such as spectrometry and other measurements related to glucose levels.

Various types of non-invasive glucose testing methods are available. In addition to non-invasive glucose measurements that involve many approaches, other non-invasive glucose measurement methods include transdermal glucose measurement and optical glucose measurement. Mid-infrared spectroscopy, infrared spectroscopy, and near-infrared spectroscopy are used in optical non-invasive glucose testing. Raman spectroscopy and ocular spectroscopy are two types of spectroscopies.

We can determine the tissue's impedance. When an alternating current is passed through a tissue and the impedance frequency spectrum is measured in range of 100Hz to 100MHz, which is determined by the interaction of glucose with red blood cells. The results are a measure of the dielectric properties of that tissue.

A non-invasive optical glucose measurement method measures glucose in biological tissue by reflecting, scattering, and transmitting light in proportion to the sample's structure and chemical composition, which is the basis for many optical non-invasive glucose measurement methods. Based on the studied band of electromagnetic radiations and interpretation of the received spectrum and glucose levels, a combination of selectivity, interference to other compounds, multivariate calibration vectors, and several detection and multistage separation principles can be employed to distinguish these.

Using photoplethysmography or regression techniques, the glucose value is estimated in spectroscopy. Many factors influence non-invasive glucose measurement. The precision of the glucose reading is influenced by these factors. The measurement is imprecise due to the factors of water content, which can efficiently absorb a certain range of wavelengths, and tissues and their fluid, which impact the light passing through them. We learn through this study that there is a wavelength range (850nm-970nm) that is unaffected by the factors we considered.

Similarly, other researchers used ML and NN to create prediction models based on various criteria. However, some experiments have shown that the solution can be directly brushed on the sensor component to measure glucose levels, while others failed in error analysis, resulting in clinically significant inaccuracies. Despite the fact that some fourth-generation medical devices, such as Diasensor and MedOptix, were developed utilising optical spectroscopy, they have yet to be commercially viable.

3.Components Used, Block Diagram

3.1 Components Used

S. No	Component Name	Specification	Number
1	**Arduino Uno R3**	**Atmega328P microcontroller**	**1**
2	**Amplifiers**	**LM358**	**2**
3	**Resistors**	**6.8k**	**3**
		68k	**2**
		680k	**2**
		330	**1**
		47k	**1**
4	**Capacitors**	**100nF**	**3**
		1uF	**2**
5	**IR LED and Photodiode Pair**		**1**
6	**O-LED Display**		**1**

3.2 BLOCK DIAGRAM:

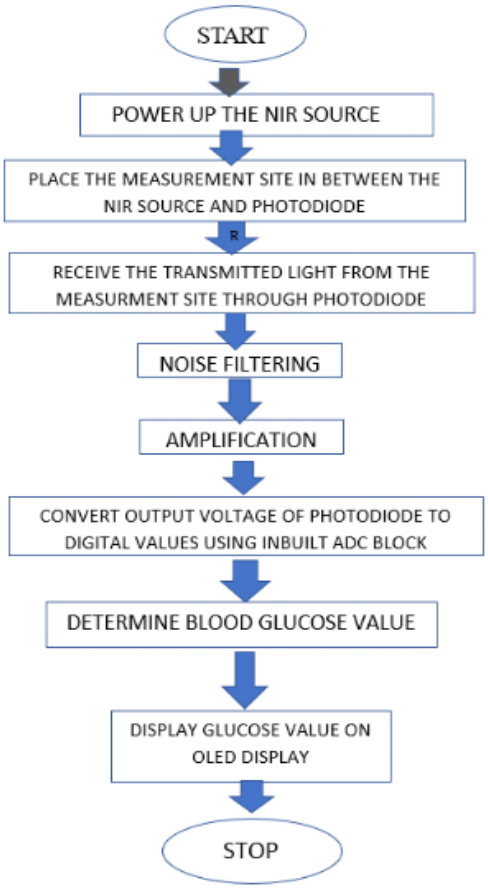

Figure 1: Block Diagram

4 IMPLEMENTATION TECHNIQUES:

4.1 Spectroscopy:

Spectroscopy is classified according to the wavelengths of the electromagnetic spectrum, such as IR spectroscopy, UV spectroscopy, and so on.

In the proposed model, we used NIR spectroscopy.

4.1.1 NIR Spectroscopy:

The concept of near infrared (NIR) spectroscopy is based on the absorption of electromagnetic radiation (EM) at wavelengths ranging from 780 to 2,500 nm. During light interaction with the sample, a detector measures its transmittance and absorbance. NIR spectroscopy is interested in both electronic and vibrational transitions. A NIR spectrophotometer measures light scattered off and through sample materials, enabling quick and accurate evaluation of their properties. The graph below shows an example of the absorption spectra of haemoglobin with and without oxygen as measured by NIR spectroscopy.

4.1.1.1 Versatility of NIR Spectroscopy

In many ways, NIR spectroscopy is extremely versatile. First and foremost, it is extremely versatile in its applications. NIR spectroscopy can be used in a laboratory, a factory, a hospital, a field, and a field laboratory.

4.2 REGRESSION:

Regression is a statistical method used to investigate and examine the nature and strength of the relationship between one variable (usually denoted by Y) and other variables (dependent variables) in finance, investments, and other fields. General form of relationship between variables using regression model:

$Y = b + a1X1 + ... + akXk + c$

Y is dependent variable, X1, ……Xk are independent variables, c is a residual constant

4.2.1 Polynomial Regression

The percentile of degree in a polynomial, which represents the coefficients of the relationship between an independent variable, x, and the dependent variable, y, is called Polynomial regression. Polynomial regression, denoted E(y |x), This type of regression fits a nonlinear relationship between values of x and mean y.

4.2.1.1 Polynomial Regression Model:

The least squares method is commonly used to fit polynomial regression models. Using the least-squares method, one can minimize the variance of the unbiased estimators of coefficients provided under the conditions of the Gauss-Markov theorem. It's a subset of multiple linear regression.

A polynomial regression's general equation is:

$Y=ao + a_1X + a_2X^2 + \ldots + a_mX^m + c$

4.2.2 Quadratic Regression:

Quadratic regression is a type of linear regression that is more complex than simple linear regression. It is a method which allows simulation of a relationship between two sets of independent variables. A quadratic regression model is used to determine which parabola equation is most conducive to fitting a set of data. In this data set, we have defined a predetermined set of graph points that take the form of a parabola.

The general form of a quadratic equation is y=a*x2+b*x+c, where a=0.

The R2 model is another name for it.

5 ILLUSTRATIONS OF PROCESS

5.1 CIRCUIT DIAGRAM:

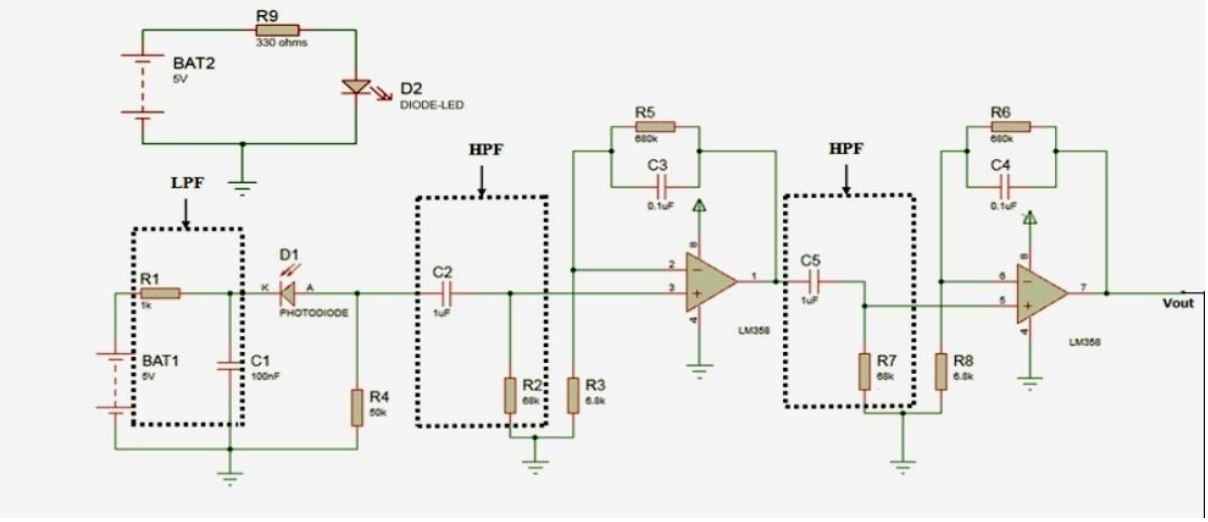

Figure 2: Circuit diagram

5.2 ILLUSTRATION:

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 hardware configuration as illustrated in Figure 3, with the results summarised in Table 1. The transmitted light from the IR LED is passed through the finger and the transmitted light is observed by the IR photodiode which is placed on the other side in the measurement site. The voltage is observed at the measurement site is then passed through the two amplifier circuits where voltage amplification is done. The output is given to the Arduino where the microcontroller digitizes the voltage value and it is used to calculate the glucose value.

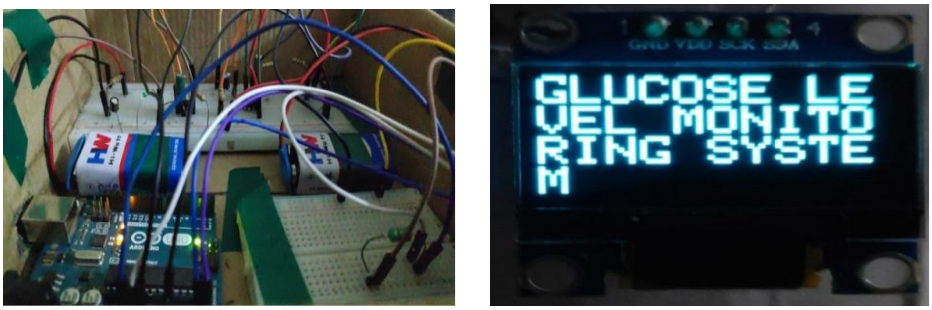

Figure 3: Designed model

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

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.

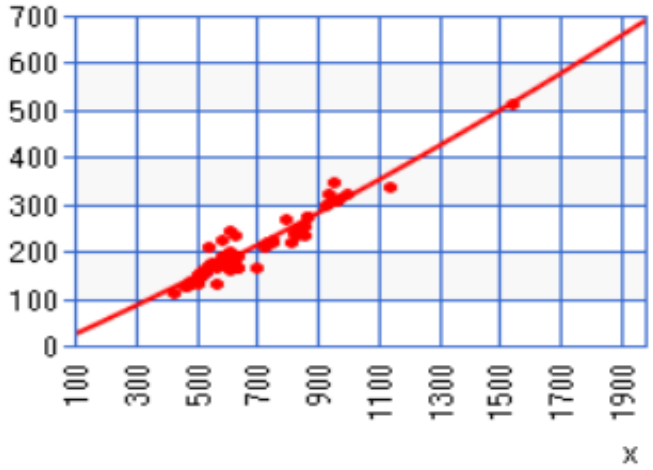

Figure 4: Quadratic Regression plot

The Arduino programme calculates the glucose level for a specific analogue voltage. The continuous Analog voltage readings obtained from the photo detector while positioning the finger between the Near Infrared LED and the photo detector are averaged and stored in an array. The glucose value corresponding to this average Analog voltage is computed by the microcontroller and shown on the O-LED display.

6 Result and VALIDATION:

The proposed model is assessed by collecting and comparing the glucose levels of 75 people using both the traditional invasive method and newly proposed model, and the results are tabulated in table 2. The proposed glucose measurement device is accurately evaluated with Clarke Error Grid Analysis.

Table 2: Comparison of Invasive Glucose and Non-Invasive Glucose Values

S.No	Invasive Glucose Values	Non-Invasive Glucose Values	Difference
1	117	120	-3
2	143	141	2
3	166	162	4
4	134	151	-17
5	145	139	6
6	120	129	-9
7	123	118	5
8	157	142	15
9	193	192	-1
10	106	103	3
11	245	214	31
12	134	148	-14
13	299	252	47
14	205	219	-14
15	164	170	-6
16	186	186	0

17	110	117	-7
18	157	142	15
19	120	129	-9
20	156	145	11
21	100	108	-8
22	250	235	15
23	92	85	7
24	195	181	14
25	145	154	-9
26	170	162	8
27	148	157	-9
28	192	220	-28
29	131	128	3
30	316	268	48
31	129	136	-7
32	220	198	22
33	130	104	26
34	149	160	-11
35	227	258	-31
36	165	152	13
37	110	152	-42
38	113	108	5
39	170	161	9
40	149	138	11
41	193	190	3
42	247	253	-6
3	301	289	12
44	231	245	-14
45	155	165	-10
46	278	254	24
47	130	141	-11
48	164	160	4
49	181	193	-12
50	196	190	6
51	252	267	-15
52	221	248	-27
53	190	187	3
54	175	182	-7
55	146	140	6
56	133	153	-20
57	157	160	-3
58	199	208	-9
59	137	122	15
60	189	176	13
61	172	190	-18
62	163	159	4
63	154	160	-6
64	183	211	-28
65	169	173	-4

66	123	123	0
67	175	165	`10
68	276	277	-1
69	321	319	2
70	247	260	-13
71	196	191	5
72	224	229	-5
73	187	189	-2
74	177	177	0
75	142	156	-14

The Clarke error grid analysis is used to assess and evaluate the clinical significance of precise value in the measurement of glucose level. It is performed in MATLAB giving the values of invasive and non-invasive values in table 2 as inputs.

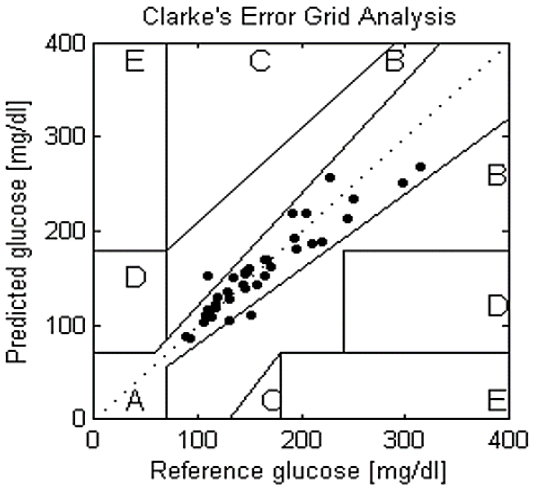

Figure 5: Result of Clarke Error grid analysis

Region A:

The difference between meter values and reference values is less than 20%.

Region B:

The difference between meter values and reference values is larger than 20%.

Region C:

Large correction and difference in values leads to unnecessary treatment.

Region D:

Values indicating a potentiality dangerous failure to detect hypoglycaemia or hyperglycaemia.

Region E:

Values that would confuse treatment of hypoglycaemia for hyperglycaemia and vice versa.

The results reveal that 82 percent of the anticipated glucose values fall within area A, which is a clinically acceptable range for glucose monitoring equipment. The results show that the proposed model or proposed approach when compared with the traditional method it gives 82% of accuracy in the values.

7. CONCLUSION:

The invasive glucose computation approach is uncomfortable, costly, and inconvenient. Furthermore, it does not provide long-term monitoring and there is a high risk of infection. This research presents a non-invasive approach for blood glucose testing utilising near-infrared LEDs to solve the drawbacks. The glucose level in the blood as detected by the photodetector is displayed on the O-LED display. By analysing error grids, it validates the proposed method. An innovative non-invasive portable blood glucose computing devices are an effective way to manage diabetic patients' health, this blood glucose monitor is portable and non-invasive. Patients can utilise the suggested model anywhere, and health care facilities can use it as well.

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