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Pre-Clinical Test for Non-Invasive (In Vitro) Blood Glucose Levels Measuring at Visible Light Wavelengths

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Abstract. The wavelength convention for non-invasive blood glucose measurement remains inconclusive. We have done this experimental observation to measure wavelength candidate performance for non-invasive blood glucose level measurement optical device in the visible range. We run this observation in Electronic Material Physics Lab, IPB University, Bogor, July 2019. We have measured two levels the blood glucose level control in cuvettes using LEDs and photodiodes from Thorlabs. The LEDs are between 450 nm to 670 nm. BioRad has provided The 100 mg/dl and 3030 mg/dl blood glucose level control for this study. We have modulated The LEDs intensity in 10 different values in a ladder setting. We have used a custom made probe to make sure there is no residual light effect from the environment. We have analysed the photodiodes readings using multi formulated regression to find the appropriate equation for predicting blood glucose level. We have found that LED in 645 nm wavelength gave the highest accuracy at 0.71. The second highest accuracy is 0.70 by LED 610 nm. The R^2 value is 0.97. We concluded that LED 645 nm might appropriate for non-invasive blood glucose level measurement optical device. Further research shall confirm this trial with human observation.
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INTRODUCTION

Measurement of blood glucose levels is an integral part of patient management and diagnosis of diabetes [1,2]. Conventional methods involve the process of taking blood from the recipient of measuring blood glucose levels. The main danger of blood sampling is the incidence of infection due to disease vectors and other health problems through the blood [3]. A variety of new methods are needed to measure individual blood glucose levels, especially to reduce or even eliminate the disadvantages of conventional methods of measuring blood glucose levels [4-5] and to overcome the shortcomings of the method. measurement of currently available blood glucose levels [6].

The most sought-after method is the non-invasive method, which is a method of measuring body biomarkers that does not apply destruction of body parts to obtain blood samples [7]. Non-invasive measurements can take advantage of the optics of the occurrence of light absorption at specific wavelengths of blood glucose (400 nm to 700 nm visible light and 939 to 2326 nm infrared) [8]. The hypothetical relationship between wavelength range and absorption range which may be related to glucose concentration based on physical mechanisms has been observed in previous studies [9]. A non-invasive approach will result in effective blood glucose clinical monitoring [10]. The spectrophotometric

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method is the most widely observed non-invasive method of measuring blood glucose levels [11] and is known for its potential for non-invasive measurement of blood glucose levels [12]. To produce more accurate data, a tool that can detect blood glucose levels is needed quickly [13]. A sensor that can respond to light with a more specific wavelength is needed, namely a photodiode sensor [14-16].

A non-invasive measurement of blood glucose levels has been successfully made in previous researchers using a photodiode sensor. The study used synthetic blood glucose fluids that were positive for glucose reduction and were not directly measured from the blood of diabetics. The test results show that the value of light intensity received by the photodiode sensor will change along with changing the value of blood glucose levels with the equation $y = 1.116x - 11.046$. The coefficient $R^2 = 0.97$ indicates that x has a large effect on y, so it can be concluded that the photodiode sensor can function properly as a non-invasive sensor measuring blood glucose level that has been designed. Based on this, this study aims to test and determine the accuracy of a non-invasive measurement of blood glucose levels at visible light wavelengths using a photodiode sensor. and obtain mathematical equations to be applied to measuring blood glucose levels using *Multi Formulated Regression.*

MATERIALS AND METHODS

Hardware Design

The LED and sensor circuit has 3 main circuits consisting of an LED circuit, a non-inverting amplifier circuit and a low pass filter sensor circuit. The output signal received by the circuit will be processed on the Raspberry Pi. Electronic components such as capacitors, resistors, ADS1115 ADC, LEDs and sensors are assembled into one circuit. All components used are placed in a white casing made of acrylic with dimensions of 23 cm x 14.5 cm x 6 cm. Other components such as LEDs and sensors are designed in reverse and placed on a probe which is used to take glucose measurements. The probe is printed using a 3D printer which consists of 4 parts, namely the body of the probe (2.00 cm x 2.00 cm x 4.00 cm), the photodiode sensor probe and the LED (3.50 cm x 1.50 cm x 0.40 cm) and the probe cover (2.00 cm x 2.00 cm). x 1.80 cm). This study also used 2 cuvettes placed in a probe.

Tool Calibration Process

The tool calibration process aims to obtain the relation between blood glucose levels and the ADC (Analog to Digital Converter) value. Data collection and tool testing were carried out using 2 synthetic blood glucose samples produced by Bio-Rad (Lyphochek, namely C-310-5 and C-315-5) which have a reference standard of concentration including 100 mg / dL and 303 mg / dL. The synthetic blood samples were each poured into a sterile cuvette of 1.5 ml - 2 ml and placed into the probe and tightly closed so that there was no gap for outside light to enter. The cuvette containing the glucose sample will be passed through the light emitted by the LED where some of the LED light intensity will be absorbed and some other LED light will be captured by the photodiode sensor. The glucose concentration in the sample will be proportional to the intensity captured by the photodiode sensor. The data captured by the photodiode sensor is analog data and transformed using discrete Fourier transforms. Block processing functions to process data and convert analog signals to digital signals generated by the signal processing circuit. The results of measuring blood sugar levels are displayed on the display block. The block diagram can be seen in Fig.1.

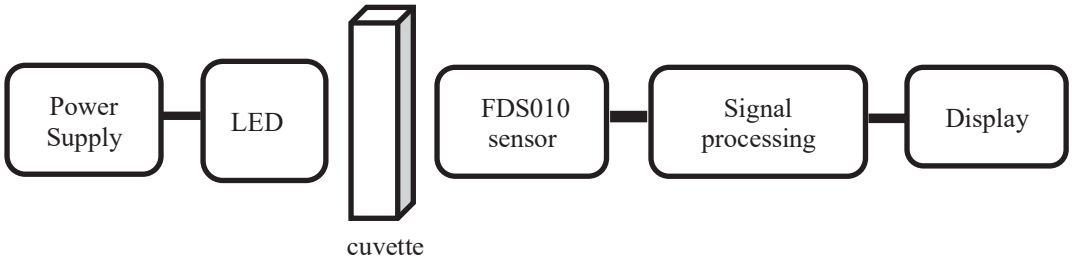

FIGURE 1. Block Diagram of Non-Invasive Blood Glucose Level Meter

Data Analysis

Measurement data that has been transformed using the Discrete Fourier Transform will be compared with the blood glucose concentration in order to obtain the Pearson correlation value [17-19]. Furthermore, these data are combined to get the best mathematical equation using the Multi Formula Regression method with the help of ZunzunSite 3 Online Curve Fitting and Surface Fitting. The equation is searched using 2 independent variables, namely the variable taken from the period combination value for each LED and 1 dependent variable, namely the variable taken from the value of blood glucose concentration. The results of reading blood glucose levels are obtained by entering a mathematical equation that has the highest accuracy into the program in the microcontroller as a function used to convert the ADC value to the value of blood glucose levels. The results of reading the glucose value from the instrument will be compared with the reference standard glucose value.

RESULT AND DISCUSSION

Hardware Design

The hardware design for testing blood glucose measuring instruments by assembling the photodiode sensor and the LED design into one unit can be seen in Fig 2. The characteristics of this photodiode are that the peak wavelength is at 730 nm and the peak of responsiveness is 0.44 A / W. Sensor sensitivity testing is carried out to determine changes in the resistance of the FDS010 sensor when given a different intensity from each LED. The sensitivity of the FDS010 sensor based on the datasheet can be seen in Fig 3.

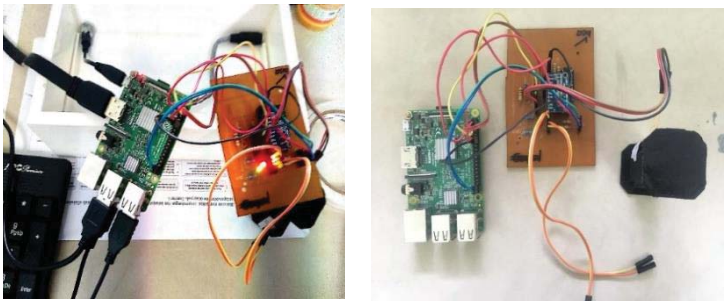

FIGURE 2. A circuits of non-invasive blood glucose measurement tools

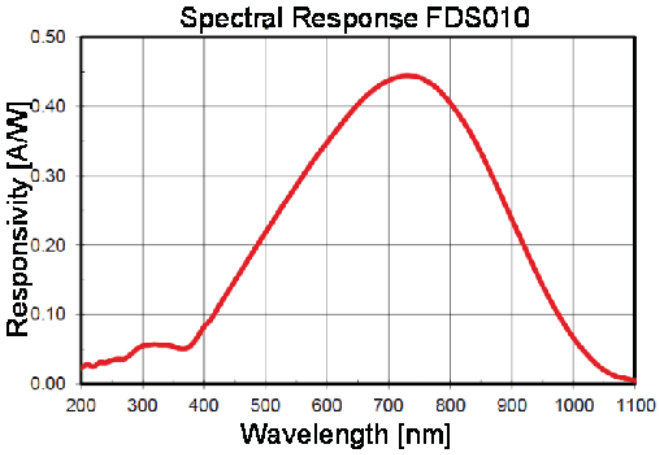

FIGURE 3. FDS010 sensor sensitivity based on the datasheet

The probe consists of 4 parts, including the probe body, LED probe, sensor probe, and probe cover. The probe aims to be a cuvette container containing a stable and closed blood glucose sample in the data collection process. The resulting probe from the design can be seen in Fig 4(a) and 4(b). The cuvette used was a glass cuvette in the shape of a rectangular tube with a size of 1.00 cm x 1.00 cm x 5.00 cm as shown in Fig 4(c).

(a) (b) (c)

FIGURE 4. (a) sensor probe ,(b) the LED probe, (c) cuvette

The glucose sample used is a yellow liquid and does not contain fibrinogen, which is the liquid fraction of all blood collected after blood clots. The content in serum glucose is antigen, antibody, hormone, and consists of 6-8% protein that makes up blood.

Calibration Tool

The software used is QtCreator with C ++ programming language. The source code used in this study was taken from the blood glucose measurement system (Blood Glucose Measurement). This source code is different from each mathematical equation used to be applied to the tool. The measurement calibration process is carried out by measuring the glucose sample and getting the light transmittance value in the form of the ADC value using a blood glucose measuring instrument. Sampling was done at one time, where in one data collection there were 5 repetitions. In this study, data was collected 6 times to obtain more accurate statistical data, so that there were 30 repetitions for each LED.

The data in the software used is taken from the analog value which is then transformed by DFT (Discrete Fourier Transform). The software displays the measurement data of two graphs including a red graph which is the result of processing the discrete Fourier transform to light passing through the blood glucose sample. The blue graph is the relationship between the photodiode sensor's response to light passing through the blood glucose sample. The software display of the tools used to display data can be seen in Fig 5.

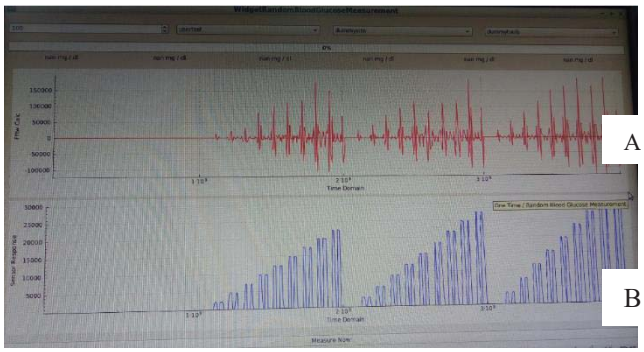

FIGURE 5. Display of *software* (A = The result of Discrete Fourier Transformation to light, B = Photodiode sensor response to light)

Tool testing aims to determine the value of the accuracy and precision of the tools used in this study. The value of accuracy and precision can be calculated based on the following equation.

$$\text{Accuracy} = \left(1 - \left|\frac{A-N}{A}\right|\right) \times 100\% \quad (1)$$

$$\text{Precision} = \left(1 - \left|\frac{Sd}{x}\right|\right) \times 100\% \quad (2)$$

Description :
A = concentration of reference blood glucose level
N = concentration of blood glucose levels from a mathematical equation
Sd = standard deviation of blood glucose concentration based on mathematical equations
x = average accuracy of blood glucose concentrations based on mathematical equations

Measurement Result

Data reading was done with 30 repetitions and each repetition had 40 periods on each LED and there were 11 LEDs for 1 glucose sample. Each period is described under several conditions. The first condition is in period 1-10 the second LED is off, the second condition is in the 11-20 period the first LED is on and the second LED is off. The third condition is in the 21-30 period the second LED is on and the first LED is off. The fourth condition is that in the 31-40 period both LEDs are lit so that the sensor can read the signal and the LED intensity reaches the maximum value.

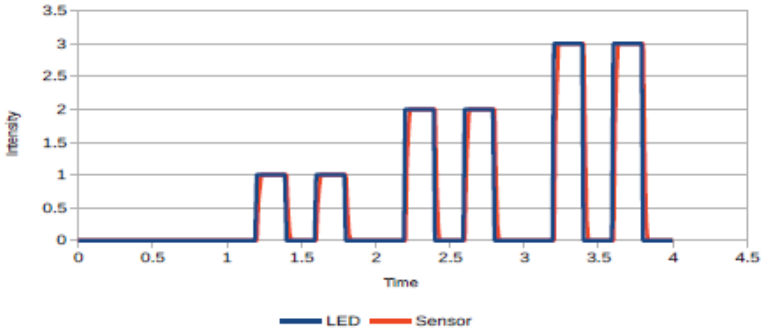

FIGURE 6. Conceptual design of the light intensity ladder modulation pattern on the sensor probe

Each condition has 10 periods, where in the second condition the first period the LED states not lit, the second period states the LED lights up with an intensity of 11%, the third period states the LED lights up with an intensity of 22%, the fourth period states the LED lights up with an intensity of 33%, until at period ten the LED is lit at 99% intensity. The intensity modulation pattern is shown in Figure 6. The results of each reading are stored by the software into a file that can be viewed later. Next, the data that has been transferred to Microsoft Excel software is then searched for the maximum and minimum values for each period. Then the maximum and minimum values are compared with the synthetic reference blood glucose concentration values.

Data Analysis

Pearson's correlation in this study was used to see how big the correlation between the maximum and minimum values resulted from the DFT (Discrete Fourier Transformation) value. Variables are said to be correlated if the closer to numbers 1 and -1, the relationship between the two variables is getting stronger and vice versa. If the correlation value is close to 0, the relationship between the two variables is weak or non-linear.

TABLE 1. Pearson correlation coefficient between the maximum value for each period and the concentration of glucose

	Period									
LED	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
670	0.244	0.256	0.207	0.256	0.245	0.231	0.253	0.276	0.247	0.264
660	-0.234	-0.256	-0.529	-0.535	-0.334	-0.300	-0.137	-0.053	-0.011	0.322
645	-0.101	-0.252	-0.451	-0.399	-0.273	-0.473	-0.158	-0.303	0.045	0.227
630	-0.141	-0.489	-0.480	-0.566	-0.541	-0.358	-0.058	-0.255	-0.277	0.182
625	0.008	0.200	0.252	0.084	0.172	0.174	0.045	0.218	0.185	-0.020
610	-0.257	-0.084	0.073	-0.015	-0.152	-0.067	-0.270	-0.056	-0.248	-0.139
600	0.067	0.216	-0.117	-0.030	-0.026	-0.248	-0.337	-0.355	-0.389	-0.294
590	-0.069	0.246	0.040	-0.038	0.026	-0.026	0.032	0.017	0.006	-0.310
570	-0.046	-0.181	-0.051	-0.125	0.268	-0.038	-0.075	0.092	-0.106	-0.143
555	0.116	0.047	0.244	0.183	0.220	0.173	-0.062	0.023	0.020	0.178
450	0.084	-0.138	-0.068	-0.275	-0.055	0.150	0.190	0.065	0.220	-0.128

	Period									
LED	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
670	0.212	0.236	0.197	0.236	0.225	0.230	0.233	0.256	0.227	0.254
660	0.091	-0.398	-0.613	-0.458	-0.138	0.039	0.101	0.268	0.456	0.289
645	-0.224	-0.004	-0.306	-0.343	-0.417	-0.362	-0.382	-0.337	-0.345	-0.031
630	0.005	-0.193	-0.327	-0.198	-0.279	-0.249	-0.317	-0.238	-0.112	0.101
625	0.224	-0.118	0.260	0.054	0.221	0.223	0.183	0.050	-0.180	-0.020
610	-0.080	-0.045	0.136	0.176	-0.228	-0.268	0.038	0.149	0.032	-0.014
600	0.067	0.203	-0.190	-0.182	-0.106	-0.517	-0.556	-0.463	-0.477	-0.213
590	-0.139	0.038	-0.011	-0.006	0.265	0.157	0.247	-0.029	-0.285	-0.285
570	-0.069	0.234	0.245	0.177	0.059	0.143	-0.041	-0.176	0.121	-0.215
555	0.136	0.128	0.118	0.064	0.160	0.276	0.097	-0.124	0.173	0.134
450	0.049	0.172	0.039	-0.165	0.037	0.360	-0.093	0.039	0.116	-0.002

	Period									
LED	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
670	0.202	0.226	0.177	0.216	0.205	0.220	0.213	0.256	0.217	0.234
660	0.089	-0.379	-0.398	-0.244	-0.323	0.243	0.272	0.235	0.361	0.159
645	-0.105	-0.059	-0.205	-0.402	-0.462	-0.062	-0.082	0.213	0.302	0.393
630	0.184	-0.106	-0.267	-0.386	-0.166	-0.111	-0.036	0.146	-0.028	0.323
625	0.070	0.112	0.159	-0.023	0.240	0.079	-0.007	0.099	0.207	0.182
610	-0.119	0.054	0.097	0.068	-0.138	-0.095	-0.145	-0.135	-0.108	-0.165
600	-0.078	-0.035	-0.124	-0.278	-0.302	-0.352	-0.611	-0.425	-0.600	-0.325
590	0.098	-0.024	0.069	-0.068	0.089	0.141	0.103	-0.472	-0.125	-0.040
570	-0.005	0.175	0.244	-0.016	-0.028	0.117	-0.230	-0.572	-0.238	-0.138
555	0.348	0.109	0.137	-0.040	0.161	-0.025	0.093	-0.085	-0.137	-0.037
450	0.156	-0.045	-0.026	0.025	0.012	0.172	0.060	0.040	0.125	0.142

TABLE 2. Pearson correlation coefficient between the minimum value for each period and the concentration of glucose

	Period									
LED	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
670	-0.381	-0.392	-0.397	-0.389	-0.395	-0.392	-0.398	-0.416	-0.400	-0.419
660	-0.065	0.353	0.314	0.293	0.248	0.327	0.116	-0.007	0.002	0.063
645	0.010	0.199	0.362	0.422	0.340	0.128	0.345	0.148	0.283	0.028
630	-0.020	0.148	0.376	0.650	0.472	0.166	0.223	0.127	0.170	0.110
625	0.065	0.013	0.041	0.060	-0.360	-0.376	0.074	-0.310	0.104	-0.116
610	0.114	0.159	-0.085	-0.180	0.108	-0.014	0.319	0.163	0.186	0.092
600	-0.156	-0.135	-0.148	-0.143	0.002	0.093	0.356	0.192	0.335	0.188
590	0.252	0.017	0.205	-0.050	-0.182	-0.176	0.189	0.291	0.097	0.037
570	0.031	-0.133	0.032	-0.460	-0.138	-0.152	0.043	0.056	0.210	0.518
555	-0.169	-0.146	0.069	-0.091	0.205	0.151	0.025	-0.112	-0.294	0.161
450	-0.036	0.088	-0.181	0.056	-0.014	0.001	-0.139	-0.029	0.162	0.074

	Period									
LED	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
670	-0.371	-0.372	-0.387	-0.369	-0.375	-0.382	-0.378	-0.414	-0.390	-0.402
660	-0.027	0.379	0.354	0.386	0.262	0.320	0.075	-0.053	0.117	-0.103
645	-0.142	0.175	0.423	0.663	0.321	0,474	0.345	0.326	0.277	0.045
630	-0.099	0.205	0.307	0.476	0.068	0.242	0.282	0.264	0.078	0.090
625	-0.188	-0.189	0.123	-0.380	-0.380	-0.280	-0.225	-0.075	0.001	-0.049
610	0.090	0.065	-0.166	-0.176	0.318	0.308	-0.058	-0.148	-0.037	0.024
600	0.070	-0.199	0.103	-0.244	-0.025	0.488	0.323	0.422	0.478	0.416
590	-0.004	0.007	0.012	0.150	-0.124	-0.035	0.069	0.206	0.308	-0.066
570	0.123	-0.020	-0.145	-0.090	-0.226	0.048	0.107	0.295	0.132	0.262
555	0.132	0.030	-0.264	-0.172	-0.149	0.011	0.096	0.110	-0.040	0.363
450	0.024	-0.019	0.088	0.022	-0.016	-0.122	0.035	0.130	0.174	0.006

	Period									
LED	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
670	-0.371	-0.371	-0.377	-0.367	-0.373	-0.362	-0.376	-0.404	-0.370	-0.400
660	0.038	0.409	0.356	0.477	0.278	0.028	0.060	0.021	-0.217	0.067
645	0.046	0.340	0.551	0.500	-0.013	0.208	0.032	0.103	-0.054	-0.288
630	0.073	0.099	0.274	0.493	0.146	0.181	-0.013	0.150	0.111	-0.109
625	-0.110	-0.092	-0.058	-0.306	-0.282	-0.109	-0.159	-0.123	-0.127	0.031
610	0.219	-0.054	0.077	-0.068	-0.278	0.085	0.145	-0.235	0.110	0.185
600	-0.012	0.078	-0.232	0.065	0.150	0.386	0.508	0.533	0.444	0.363
590	-0.101	0.223	-0.074	-0.013	-0.254	-0.074	0.352	0.263	0.093	0.014
570	-0.068	-0.182	-0.292	-0.173	-0.005	-0.047	0.093	0.299	0.299	-0.019
555	-0.248	-0.152	-0.218	-0.148	-0.118	0.081	-0.090	0.111	-0.057	-0.358
450	-0.095	-0.053	0.151	0.063	-0.007	0.062	0.017	0.077	0.221	0.061

The maximum and minimum Pearson correlation coefficient data shown in Table 1 and Table 2 are the results of the correlation value between the maximum and minimum values for each period with the reference standard concentration of glucose on each LED. Based on the table, it can be stated that each period on the LED with different wavelengths produces a different correlation coefficient. This is due to the difference in intensity in each period where the LED intensity increases by 11% in each period. The highest correlation on the 670 nm LED is at the maximum 18 period and the minimum 20 period. The 660 nm LED is on the maximum 29 period and the minimum 24 period. The 645 nm LED is on the maximum 26 period and the minimum 24 period. The 630 nm LED is on the maximum 40 period and the minimum 33 period. The 625 nm LED is on the 23 maximum and 25 minimum period. The 610 nm LED is on for the maximum 17 period and the 17 minimum period. The 600 nm LED is on the maximum 37 period and the minimum 38 period. The 590 nm LED is on the maximum 38 period and the minimum 37 period. The 570 nm LED is on the maximum 38 period and the minimum 33 period. The 555 nm LED is on the maximum 31 period and 30 minimum period. The 450 nm LED is on the maximum 26 period and the minimum 29 period.

Furthermore, mathematical equations will be obtained from various period combinations obtained from the multi formula regression method with the help of the online site ZunZunsite. Multi Formulated Regression is a regression methods where the result is formulas rather than constants. Based on Table 3, it can be seen that the best mathematical equation is at LED 645 using a combination of period 26 (maximum value) and period 24 (minimum value) which has an accuracy of 71%. LED 600 has the second best mathematical equation using a combination of period 37 (maximum value) and period 38 (minimum value) which has an accuracy of 70%. The value of the LED

645 measurement calculated by the mathematical equation has an average of 261.14 mg / dl and 141.85 mg / dl. A difference of 1% could differ the LED 645 and 600 measurement results. This is because without actually tried both LEDs in a real non-invasive device environment, every judgement of the accuracy different is too soon.

TABLE 3. The best mathematical equations for each LED

LED	Combination	Equation	Accuracy (%)
670	P18 Max & P20 Min	z = (a + bx + cy + dxy)/(1 + fx + gy + hxy)	59.3
660	P29 Max & P24 Min	z = a + bx + cy + dx^2 + fy^2 + gxy	68
645	P26 Max & P24 Min	z = a + b*ln(g*x+h) + c*ln(i*y+j) + d*ln(g*x+h)^2 + f*ln(i*y+j)^2	71
630	P40 Max & P33 Min	z = a + b*ln(m*x+n) + c*ln(o*y+p) + d*ln(m*x+n)^2 + f*ln(o*y+p)^2 + g*ln(m*x+n)^3 + h*ln(o*y+p)^3 + i*ln(m*x+n)*ln(o*y+p) + j*ln(m*x+n)^2*ln(o*y+p) + k*ln(m*x+n)*ln(o*y+p)^2	65
625	P23 Max & P25 Min	z = a + b*ln(g*x+h) + c*ln(i*y+j) + d*ln(g*x+h)^2 + f*ln(i*y+j)^2	47.3
610	P17 Max & P17 Min	z = a + bx + cy + dx^2 + fy^2 + gx^3 + hy^3 + ixy + jx^2y + kxy^2	51
600	P37 Max & P38 Min	z = a + b/x + c/y + d/x^2 + f/y^2 + g/(xy)	70
590	P38 Max & P37 Min	z = (a + bx + cy)/(1 + dx + fy)	53
570	P38 Max & P33 Min	z = (a + bx + cy + dxy)/(1 + fx + gy + hxy)	62
555	P31 Max & P40 Min	z = a + bx + cy + dx^2 + fy^2 + gxy	52
450	P26 Max & P29 Min	z = a + bx + cy + dx^2 + fy^2 + gx^3 + hy^3 + ixy + jx^2y + kxy^2	45

The mathematical equation on LED 645 is entered into the program in the microcontroller as a function used to convert the ADC value to the value of blood glucose levels. Testing of the measuring instrument system was carried out 6 times (measurement) for each synthetic blood glucose sample using 645 LEDs. The blood glucose measuring system will display the results of testing blood glucose readings which can be seen in Table 4. Based on the literature, the wavelengths used to perform The analysis is the wavelength where a substance provides the highest absorption, namely the maximum λ, accurate data will be obtained, in this study the maximum λ is at 645 nm so that the data obtained on the LED 645 is accurate enough to measure blood glucose levels.

The results of blood glucose levels were compared with the reference glucose concentration values, namely 303 mg / dl and 100 mg / dl. Low blood glucose levels are thinner than high blood glucose levels (thicker) and will affect absorption from light sources. The amount of light absorbed depends on how many molecules interact with the light. High glucose levels will result in high absorption because many molecules interact with light so that the light intensity is transmitted slightly. As for low glucose levels, absorption is low because the molecules that interact with light are less so that the light transmitted is greater. This is in accordance with the research that obtained an average value of low glucose levels close to the concentration of reference glucose levels, namely 100.55 mg / dL, while at high glucose levels, the average glucose level was 327.10 mg / dL. As for this study, the standard deviation is 0.32 and 11.05.

TABLE 4. The results of testing blood glucose levels using a glucose measuring system

LED	BLOOD GLUCOSE LEVELS (mg/dL)		Average Non Invasive Glucose	Standard Deviation	Accuracy (%)	Precision (%)
	Non Invasive Tool	Concentration Glucose Standard	(mg/dl)			
645	327.42	303	327.10	0.32	91.94	99.70
	326.98				92.08	
	328.48				91.59	
	327.58				91.89	
	325.63				92.53	
	326.52				92.24	
	114.55	100	100.55	11.05	85.45	70.59
	90.76				90.76	
	129.03				70.97	
	73.70				73.70	
	62.07				62.07	
	133.22				66.78	
Average					83.50	85.15

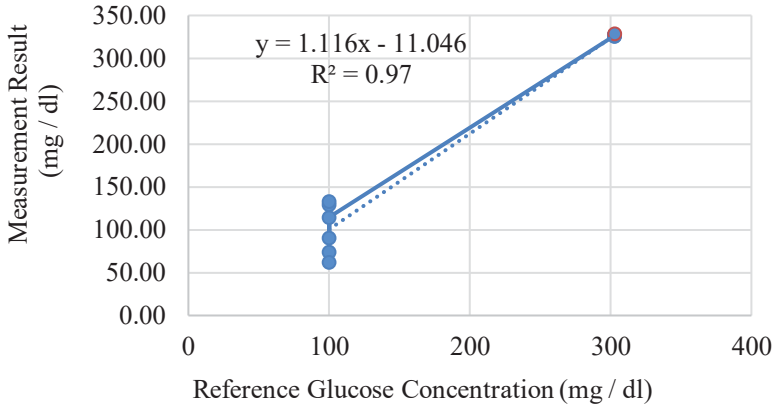

FIGURE 7. Correlation of measured blood glucose levels with reference blood glucose concentrations

The graph in Fig 7 shows that the reading of the measuring instrument and the reference blood glucose concentration has a fairly strong linear relation with a coefficient of 0.97 . It can be said that the blood glucose device is accurate enough to measure blood glucose levels non-invasively. Previous studies have successfully tested a non-invasive blood glucose measuring system on a 940 nm LED. The test results have an average accuracy of 91.80% and an average precision of 97.24%. This is because in previous studies the LED used was an infrared wavelength range so that the reading of the measuring instrument had a high correlation with a correlation coefficient of 0.99 and it can be said that the tool is quite accurate for measuring blood glucose levels. In this study, the optimum wavelength was obtained, namely the LED 645 proving that the measurement was accurate enough to measure blood glucose levels in the visible light wavelength range with an average accuracy of 83.50% and an average precision of 85.15% so that it could be applied to blood glucose measuring instruments. non-invasive as a reference for further studies using human blood.

CONCLUSION

LED 645 nm may appropriate to be used in non invasive blood glucose level measurement optical device. The trial will be confirmed with human observation.

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We declare no competing interest

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