Near Infrared LEDs-Based Non-Invasive Blood Sugar Testing for Detecting Blood Sugar Levels on Diabetic Care

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Abstract. Diabetes Mellitus (DM), along with its rapid development and various complications that have caused it, has become one of the deadliest diseases in the world. Early detection efforts to raise blood sugar levels can help to avoid various complications. Measuring devices are needed to find out blood sugar levels detect how much sugar is in the blood. The blood sugar measuring device is invasive by taking blood from capillaries tested both in the lab and using portable testing instruments. The use of this tool results in discomfort, pain, and trauma for the patient. The purpose of this study is to determine the degree of sensitivity of the NIR LED (Near Infrared-Light Emitting Diodes) sensor on the thumb to the little finger to the reading of light reflections coming out of body tissues. Currently, the index finger is often used as a medium to find out how much blood sugar is in non-invasive blood sugar measurements. The other four fingers' sensitivity is unknown at this time. Since the index finger used is located in the middle, it can make difficulty to conduct activities at times, information on the sensitivity level of the other fingers is required. This paper discusses the sensitivity of placing the NIR LED sensor on the five fingers to determine the most sensitive finger with the best response. Based on the testing results of 15 samples, although the index finger receives the most significant stress, the correlation and linear regression tests show that the thumb has the closest relationship with the $R^2 = 0.6841$. With this research, a test instrument with higher sensitivity for Diabetes can be developed by placing the sensor in a comfortable area. The implication is that the results of this study can be recommended to use the thumb as an alternative to the placement of the NIR LED sensor to measure blood sugar levels non-invasively in DM patients.

Introduction

Diabetes Mellitus (DM) is a chronic disease that is overgrowing globally, from 108 million in 1980 to 422 million in 2014 or increasing about four times, and it is estimated that in 2040 it will increase to 642 million [1]. In line with this, Basic Health Research in Indonesia discovered a significant increase in the prevalence of Diabetes, from 6.9% in 2013 to 8.5% in 2018, so the estimated number of people with Diabetes in Indonesia reaches more than 16 million people who are then at risk for other diseases, such as heart attack, stroke, blindness, and kidney failure which can even cause paralysis and death [2][3]. If the condition is not taken seriously, it will affect the health financing burden borne by the Government.

Health financing for Diabetes in Indonesia, as reported by the National Health Insurance shows an increase from IDR 700.29 billion in 2014 to 1.877 trillion in 2017, or 33% of total health financing [3].

The Government has carried various policies, including issuing policies through the Minister of Health Regulation number 71 of 2015 concerning preventing Non-Communicable Diseases (NCDs) [4]. The Minister of Health explains that the central Government, local governments, and the Community are responsible for managing NCDs and its consequences through Public Healthcare Endeavour and Individual Healthcare Endeavour. The NCDs prevention through Public Healthcare

Endeavour is carried out with prevention and control endeavors which is emphasized on risk factors control which can be altered, through promotional healthcare activities, early risk factors detection, and special protection. The control is carried out through early case detection and early management activities. The control through Individual Healthcare endeavor is carried out by handling cases.

Health promotion aims to realize a clean and healthy behaviors such us: regular health checks, getting rid of cigarette smoke, physical activity, healthy diet and balanced nutrition, adequate rest, and managing stress [4]. In addition, the Government has diabetes control programs in the 2015-2019 National Health Development Program priority for Indonesia through the Healthy Indonesia Program with the Family approach; Healthy Community Movement as a promotive and preventive effort by activities to increase physical activity, consume vegetables and fruits, and check health regularly; and diabetes management, namely education, food management, physical activity, drug administration, and blood sugar monitoring. Besides, the Government has provided an Integrated Service Center for Non-Communicable Diseases to prevent and control Diabetes through community empowerment [5].

However, the complete government program has not shown significant results as evidenced by the increasing prevalence of Diabetes Mellitus based on blood sugar examinations, increasing from 6.9% in 2013 to 8.5% in 2018 [3].

Qualitative results for families who take care for the elderly with Diabetes reported for the sake of convenience, families and people with Diabetes hope that there is no need for them to come to public health center considering the condition of the elderly who mostly have physical barriers to come to the public health center. Another study concluded that the family empowerment model effectively increases behavior and family support in controlling DM [5], [7], [8].

Furthermore, researchers conducted a preliminary study on self-care efforts with Diabetes during the Covid-19 pandemic. The results showed that 5 out of 8 diabetics expressed their hope to have a device that can detect blood sugar levels that can be used at home because during the Covid-19 pandemic, it is not possible to travel outside. Based on this, a real effort is needed to create innovative products based on research in producing non-invasive, wearable blood sugar level monitoring technology at affordable prices to detect the risk of increasing blood sugar so that the prevalence and complications of Diabetes can be controlled.

The current condition in Indonesia is that blood sugar testing instruments are still invasive, and the price is relatively high so that only some people can afford to buy them for home use. Meanwhile, for people with Diabetes who do not have blood sugar testing devices, they must come to health services (hospitals, public health center, and private clinics) and to Integrated Service Center for non-communicable diseases to check their blood sugar, which often has many obstacles in utilizing the facilities either because of the distance, costs, or time. A non-invasive, affordable blood sugar identification tool at an affordable price allows people with Diabetes to independently control their sugar levels. The independence of managing blood sugar levels is a form of family and community empowerment that is very influential on government efforts in controlling prevalence and preventing complications due to DM [7], [8].

Various portable blood sugar testing devices have been marketed, especially invasive blood sugar testing devices using blood samples taken from capillary vessels that still cause discomfort, pain and can even cause the risk of infection [9]. Besides using disposable test strips, the price is still quite high [10][11]. So that it is necessary to innovate a convenient and painless blood sugar measuring device that is a non-invasive blood sugar measuring device.

Measurement of blood sugar by non-invasive techniques is carried out using the light propagation method on the human body, especially in the subcutaneous tissue. Light is fired with various sources, including near-infrared (NIR) spectroscopy, mid-infrared spectroscopy, fluorescence, Raman spectroscopy, and thermal infrared [12] [13][14].

The development of non-invasive blood sugar measuring devices using NIR has advantages, including clear water in the NIR tape, relatively inexpensive materials needed, directly proportional signal intensity to the concentration of the analytic, relatively fast sample preparation time. It can adapt to disruptors such as glass and materials made of plastic [15].

Generally, non-invasive blood sugar testing uses the index finger [16][17][18] since it is easy to use. However, the installation of the sensor on the index finger sometimes interferes with activities. Meanwhile, the testing conducted by Priyoti [19] showed that the testing using different fingers resulted in dissimilar test results. Even though the range was not stated, it would affect the accuracy of non-invasive blood sugar testing. Another testing was carried out by Manurung by only using the thumb [20].

The purpose of this study is to determine the degree of sensitivity of the NIR LED sensor on the thumb to the little finger to the reading of light reflections coming out of body tissues. Then, it will be identified how much the density of light compared with the body's position and amount of blood sugar.

Methods and Material

The study used correlation analysis design with based on the Micro Controller Unit (MCU) d1 Wemos mini is built to process how strong each finger absorbs light to determine how much influence each finger has on the sensitivity of the light emitted by the NIR LED. The sample in this study consisted of 15 respondents with characteristics ranging in age from 20 to 44 years old. The following inclusion criteria were applied: the person must be in good physical and mental health and must sign an informed consent form as part of the agreement for the study. The exclusion criteria are the person who are in a coma and have mental disorders. Measurements were carried out five times with a voltage source of 3.3 volts for each participant. Data were collected by attaching a non-invasive blood sugar measuring kit to each respondent, namely the NIR Led sensor at the fingertips, then the data processor was used as a wristband. Then, the measurement was left for about 1-3 minutes until it was stable then the data appeared in the display on the record. In this case, the measurements were repeated for 5 time.

This research was approved by the Ethics Committee of the Ministry of Health Polytechnic of Tasikmalaya with number of 2021/KEPK/PE/VI/00134. Its implementation met the required ethical principles, such as respondents explained the purpose of the study, signed the consent sheets to engage in research, maintaining the confidentiality of respondents to create an atmosphere as comfortable as possible during the data collection. Data collection was carried out from March until April 2021 at the electrical laboratory of the electrical engineering department of the University of Siliwangi. Data analysis was carried out through linear regression to see the change in voltage with invasive testing value

Photodiode Spectroscopy – NIR led. Photodiode Spectroscopy NIR led using near-infrared light was employed to measure the light intensity levels at the reception and the transmission, continued by analysis to obtain the blood sugar levels. The following Figure 1 shows how Spectroscopy works by firing light on human body skin tissue.
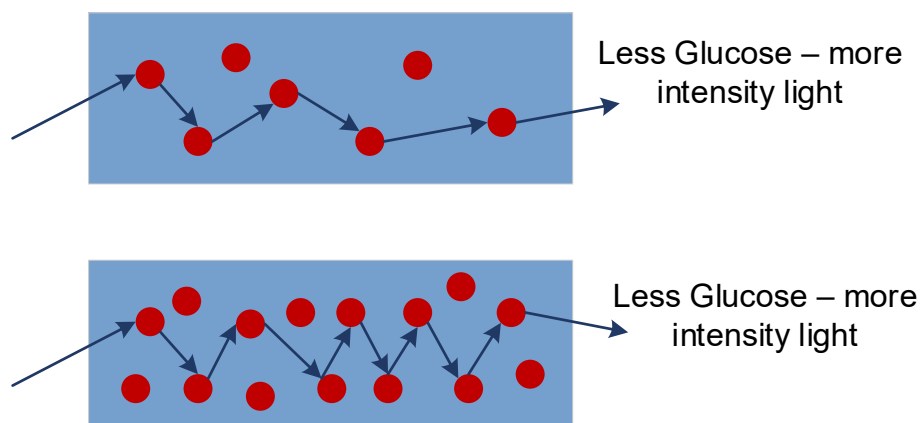

Fig. 1. The difference in light reflection with different sugar levels [13]

Fig. 1 shows that the skin tissue with normal blood sugar levels will absorb light by blood molecules and less reflection than blood containing high sugar levels. Rays coming out of the skin tissue will experience differences in density due to absorption and reflection in the skin tissue. To produce good rays, Near Infrared LEDs were used. The rays was fired with a specific wavelength ranging between 780 - 2500 nm [11]. Then, on the receiving side, there was a photodiode that received the density of light, which was then converted into a voltage; the voltage difference was analogous to the difference in blood sugar levels.

Light shooting can be done in several ways. Chua [21] used eight (8) pairs of red, orange, blue, green, white, and ultraviolet 1450 nm LEDs to measure blood sugar concentrations from 0 to 720 mg/dL, and the results showed a rising trend in blood sugar levels. While the use of near-infrared LEDs used by Yadav [22] with 940 nm NIR LEDs in vitro obtained quite good results, there are still positions and interference errors that must be filtered out. Another test was carried out by Robiah [23] with 1200 nm infrared with non-invasive blood monitoring equipment.

Non-Invasive Blood Sugar Test Kits. The main component of the test kit is a near infrared LED with a wavelength of 1550 nm. This Near infrared LED sensor was paired with a photodiode to determine the reflected light through a skin tissue clamped to the fingertips. Fig. 2 shows how to install a non-led and photodiode on a fingertip.

The signal obtained from the photodiode will be sorted through a lower filter circuit. This filtering was performed to suppress the noise in the photodiode signal. The signal from the LPF (Low Pass Filter) that will be passed is a signal below 1590 Hz. This signal will be amplified by the LM 358 op-amp IC (integrated Circuit) so that it is sufficient to be processed by the MCU.
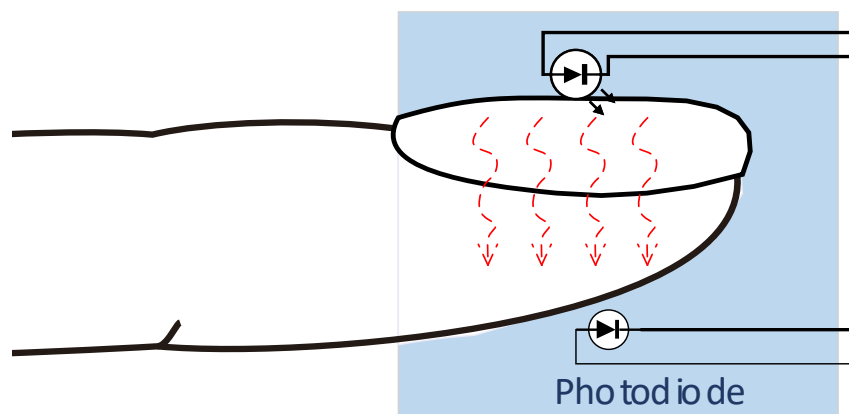

Fig. 2 Installation of LED NIR sensor probes and photodiodes

The amplified signal from the op-amp Circuit was processed in the Microcontroller Unit through an analog input. This signal was then enumerated using an analog to digital converter Analog to Digital Converter ADC[20]. The MCU used is D1 mini Wemos which has a 10-bit analog to digital converter [24].

Wemos processed the value of the enumeration results. Furthermore, it was displayed on the Liquid Crystal Display LCD. Any changes in the photodiode input will be visible. A rechargeable lithium-polymer battery powers the kit. This battery power enables the kit to be used, while not plugged into a home wall outlet. Block diagram of the non-invasive blood test kit can be seen in Fig. 3.
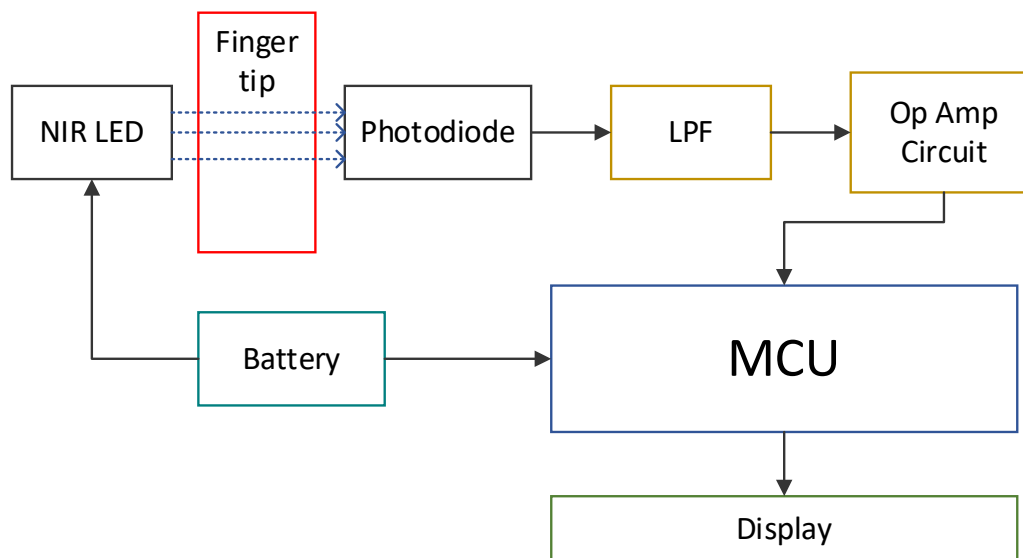
Fig. 3 Block Diagram of a Non-Invasive Blood Sugar Measurement System

Test and Result

The test was performed by placing the finger on a modified oximeter equipped with a 1550 nm LED NIR with a photodiode and testing the finger position from the thumb to the little finger, as shown in Fig. 4. This kit can be used as an armband, is easy to use, and can be carried anywhere. As a comparison, the test was performed using the invasive blood sugar test (brand: Autocheck).
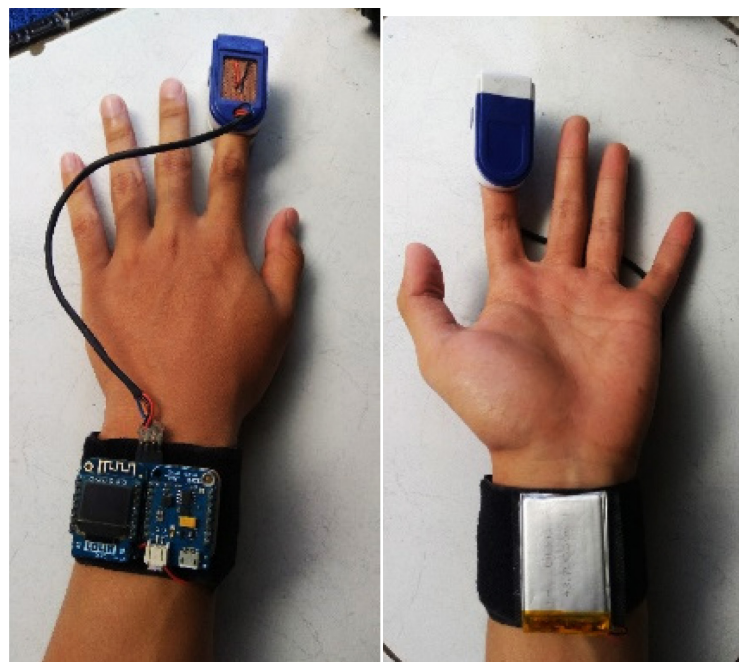

Fig. 4. Laying of the NIR LED sensor and photodiode on the finger

Table 1 displays the test results. The limitation of the number of participants in this research was due to the current pandemic situation that hindered the volunteers' involvement. This research had more respondents than the research carried out by Saputra [16] that only had five respondents with the same method, Linear regression or [25] with 10 volunteers to study hyperventilation in patients.

Table 1 Comparison of accuracy testing of LED NIR position with invasive blood sugar test values

No.	Finger (volt)					Invasive Blood Sugar Test (mg/dl)
	Pinkie finger	Ring finger	Middle finger	Index finger	Thumb	
1	0.2604	0.2481	0.2469	0.3223	0.2307	69
2	0.2411	0.2224	0.2243	0.2778	0.2211	74
3	0.2301	0.2172	0.2017	0.2585	0.2211	75
4	0.1766	0.1399	0.1341	0.2095	0.1470	79
5	0.2243	0.2114	0.2082	0.2494	0.2050	80
6	0.1921	0.1856	0.1824	0.2900	0.1785	85
7	0.1811	0.1727	0.1727	0.1760	0.1592	85
8	0.1792	0.1663	0.1624	0.1798	0.1508	87
9	0.2140	0.1927	0.1914	0.2185	0.1985	93
10	0.1669	0.1470	0.1431	0.1231	0.1811	94
11	0.1876	0.1798	0.1721	0.1985	0.1508	105
12	0.1502	0.1347	0.1366	0.1624	0.1250	105
13	0.1463	0.1238	0.1173	0.1714	0.1115	107
14	0.1714	0.1644	0.1528	0.1985	0.1270	116
15	0.1753	0.1463	0.1173	0.1695	0.1205	118
Correlation	-0.736512	-0.69653	-0.7527	-0.67109	-0.82708	1

The test results of 15 respondents with different blood sugar levels and age conditions found that the voltage received by the photodiode on the index finger was higher than the other fingers. The most significant difference between the average voltage difference between the index finger and thumb is about 0.1537 volts, then between the index finger with the middle finger of 0.1513 volts, index fingers with ring fingers of 0.1454 volts, and index fingers with the little finger of 0.0206 volts. The dimensions of the index finger are almost the same as the middle finger and ring finger, but the difference between the two is quite significant. This condition is inversely proportional to the little finger, which has smaller dimensions. These conditions indicate that the stress due to the finger received by the photodiode does not correlate with accuracy. Pearson correlation test results show the most positive relationship found in the thumb to changes in blood sugar levels, while the index finger has the smallest correlation. This can be caused by the width of the thumb section so that the consistency of the light supplied by the NIR LED can be maintained when passing under the skin tissue.

To find out the distribution of lighting results to the invasive test results, scatter mapping was carried out as shown in Fig. 5.

Fig. 5 shows the linear regression[26] of each finger against invasive blood sugar testing. The linear regression results show that the thumb has a linear tendency with R^2 of 0.6987, the largest compared to other fingers; even the index finger has R^2 of 0.5826, which have approximately the same value with ring finger.
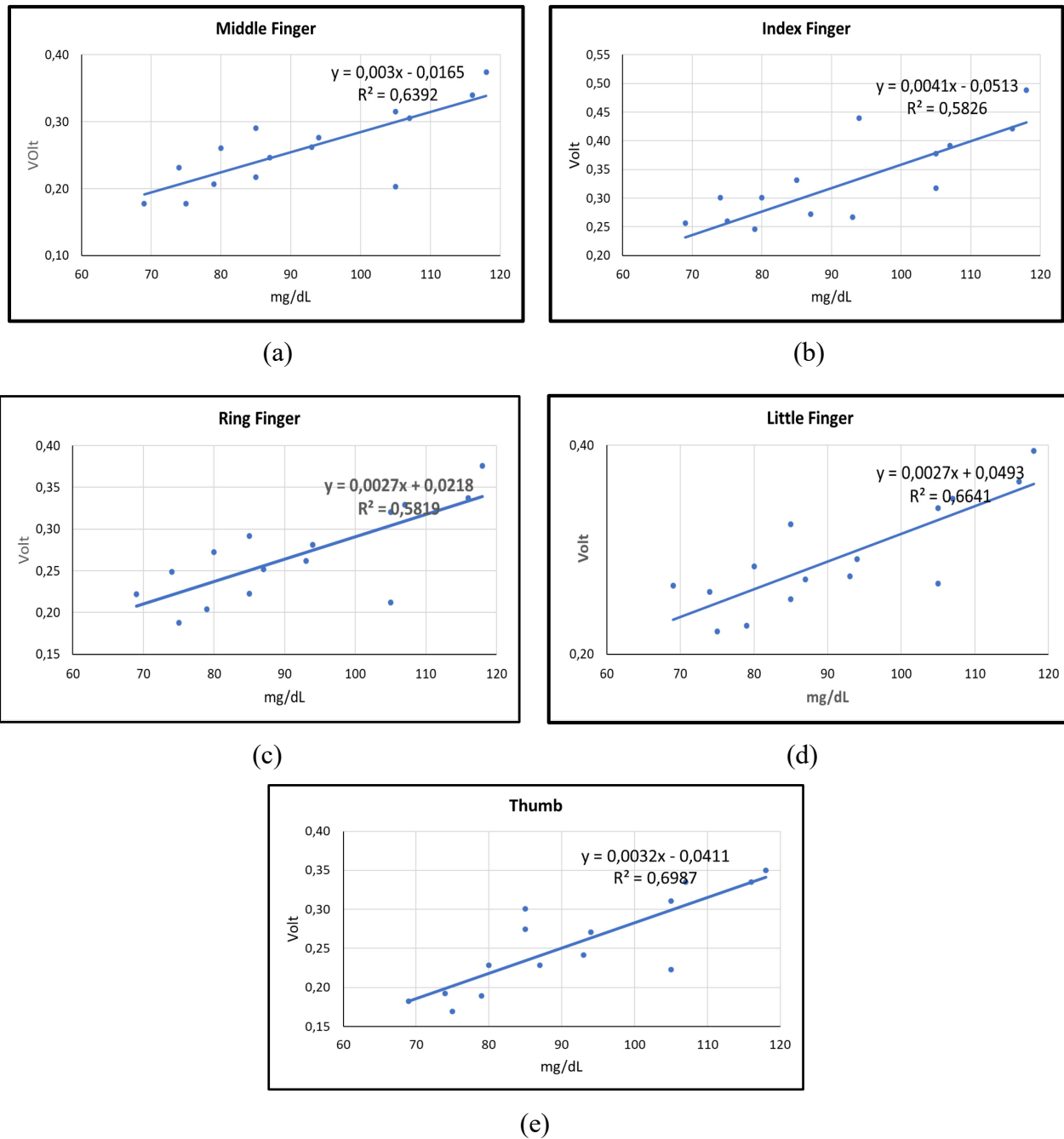
Fig. 5. Comparison graph of invasive measuring devices with NIR LEDs on each finger
(a) ring finger (b) little finger (c) middle finger (d) index finger (e) thumb

Discussion

Testing of blood sugar using a non-invasive method was also carried out by muhamaduyasic [27] using a red laser beam with a wavelength of 650 nm resulting in the same approach as the research conducted, namely linear regression. Similarly, Javid [28] did the non-invasive method using NIR LED with testing on glucose solution using linear regression.

The limitation of this study that obtaining Near Infrared with wavelengths varying from 750 to 2500 nm is an obstacle so testing is limited to NIR LEDs with a wavelength of 1550 nm thus limiting the measurement accuracy. The implication is that the results of this study can be recommended to use the thumb as an alternative to the placement of the NIR LED sensor to measure blood sugar levels non-invasively in DM patients.

From the two results above, it can be seen that the thumb is a finger that has sensitivity and consistency in its ability to conduct light waves and can respond to differences in blood sugar well; this is due to the cross-sectional area of the thumb larger than the other fingers so that all the tissue can absorb the scattered light under the skin. It is in accordance with the research carried out by Priyoti [19] stating that the width of fingers can affect radiation transmission. According to this research result, it is suggested to use the thumb to increase the accuracy of blood sugar reading since it has the greatest sensitivity.

Conclusion

This study has succeeded in identifying the degree of sensitivity of the NIR Led on the fingertips. The sensitivity of the non-invasive blood sugar sensor type NIR LED with a wavelength of 1550 nm has been carried out on different samples, both blood sugar, and age. The results obtained variations in the density of light received by the photodiode, converted into a voltage.

The most significant tension is received by the index finger and the smallest by the thumb. However, the most significant correlation test was found on the thumb, so the biggest R^2 is on the thumb with the linear regression test. This significant correlation is possible because the surface dimension of the thumb is higher than that of the other fingers so that the consistency of absorption is greater and more comprehensive, which results in the thumb being more sensitive than the other fingers. Therefore, thumb is an alternative for sugar data collection with non-invasive methods. Furthermore, the next research is expected to be able to carry out the algorithm to increase the correlation between the ADC reading and blood sugar.

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