A Portable Non-Invasive System for Detecting Blood Glucose Levels Using a Laser-Based Sensor

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Abstract

Diabetes is a long-term medical condition that impacts the way your body converts food into energy, it has the potential to lead to several severe health complications, such as heart disease, stroke, vision impairment, kidney issues, and nerve damage. Nevertheless, individuals with diabetes can lead extended and healthy lives with effective management. The goal of diabetes treatment is to keep your blood sugar levels within a healthy range. So Glucose measurement is an important part of diabetes management. It allows people with diabetes to track their blood sugar levels and make adjustments to their diet and medication as needed. Morning fasting blood glucose typically falls within the range of (70 mg/dL) to (110 mg/dL), while after a meal, blood glucose levels should ideally be below (140 mg/dL). In this proposed work an Arduino-based noninvasive glucose measurement device is proposed. Non-invasive glucose measurement devices do not require the user to prick their finger to draw blood. A Red Laser (RL) technique, is employed, this method surpasses the other invasive approach and non-invasive methods in terms of superiority. Since invasive techniques can be painful and expensive. This paper describes a new way to measure blood sugar levels without having to prick your finger. The method uses a red laser to shine light through the skin and measure how much the light is bent. The amount of bending tells the device how much sugar is in the blood. Numerous tests and experimental outcomes have been produced to demonstrate the exceptional accuracy of the proposed method.

Keywords: Blood glucose, Invasive Technique, Non-invasive Technique, Red laser.

نظام محمول (لايحتاج حقن داخل الجسم) لكشف مستويات السكر في الدم بأستخدام جهاز أستشعار يعتمد على الليزر

فاطمة أبراهيم ياسر ، زيد مصطفى خضير ، أحمد لطيف خدارحم

الخلاصة:

السكري هو حالة طبية طويلة الأمد تؤثر على الطريقة التي يحول بها جسمك الطعام إلى طاقة، ولديه القدرة على أن يؤدي إلى عدة مضاعفات صحية خطيرة، مثل أمراض القلب والسكتة الدماغية وتدهور الرؤية ومشاكل الكلى وأضرار الأعصاب. ومع ذلك، يمكن للأفراد الذين يعانون من مرض السكري أن يعيشوا حياة طويلة وصحية بفعالية إدارة المرض. هدف علاج السكري هو الحفاظ على مستويات السكر في الدم ضمن النطاق الصحيح. لذا فإن قياس الجلوكوز هو جزء مهم من إدارة السكري. إنه يسمح للأشخاص الذين يعانون من السكري بتتبع مستويات السكر في الدم وإجراء تعديلات على نظامهم الغذائي والدواء حسب الحاجة. مستوى الجلوكوز في الدم على مرأى من الصباح يجب أن يكون عادة ضمن النطاق من (٧٠ ملغ/ديسيلتر) إلى (١١٠ ملغ/ديسيلتر)، بينما بعد الوجبة، يجب أن تكون مستويات الجلوكوز في الدم في الأفضل أقل من (١٤٠ ملغ/ديسيلتر). في هذا العمل المقترح، يتم اقتراح جهاز قياس الجلوكوز اللاجراحي القائم على الأردوينو. لا تتطلب أجهزة قياس الجلوكوز غير الجراحية من المستخدم أن يخرق إصبعه لسحب الدم. يتم استخدام تقنية الليزر الأحمر

(RL)، وتتفوق هذه الطريقة على الطرق الأخرى الجراحية واللاجراحية من حيث التفوق. حيث يمكن أن تكون الطرق الجراحية مؤلمة ومكلفة. يصف هذا البحث طريقة جديدة لقياس مستويات السكر في الدم دون الحاجة إلى خرق الإصبع. تستخدم هذه الطريقة الليزر الأحمر لإشعال الضوء خلال الجلد وقياس مدى انحناء الضوء. كمية الانحناء تخبر الجهاز عن كمية السكر في الدم. تم إجراء العديد من الاختبارات والنتائج التجريبية لإثبات الدقة الاستثنائية للطريقة المقترحة.

1. Introduction

Diabetes is a metabolic disorder impacting countless individuals globally, marked by elevated levels of sugar in the bloodstream. (Hyperglycemia), which could result from problems with insulin production or insulin sensitivity. This can occur when the body either doesn't generate sufficient insulin or when the body's cells don't react appropriately to insulin. Insulin can define as a hormone that help body cells to use glucose for energy. A significant amount of prior research has focused on glucose detection in the past years, like aerometric introduced by both couto [1], Yang [2], spectrophotometric by Ukeda [3], Lepore and Xiao fluorometric methods [4], [5]. Nowdays invasive and non-invasive glucose measurement systems are utilized in glucose detection, each one have their own advantages and disadvantages. Invasive systems are generally were more accurate, but they are less convenient and painful. Non-invasive systems are more convenient and painless, but they are not yet widely commercially available. Table 1, shows a simple comparison between invasive and non-invasive glucose measurement systems.

Table (1): Invasive and Non-invasive comparison.

Characteristic	***Invasive***	***Non-Invasive***
Accuracy	*Accurate*	*Less accurate*
Convenience	*Less convenient (finger picking)*	*More convenient (no finger picking)*
Pain	*Painful*	*Painless*
Risk of infection	*Low risk of infection*	*No risk of infection*
Availability	*Commercially available*	*Not yet widely Commercially available*
Cost	*more expensive*	*less expensive*
FDA* approval	*approved*	*Not yet approved*

**FDA: Food and Drug Administration*

The best choice of glucose measurement system for a particular individual will depend on their individual needs and preferences. People who need the most accurate glucose measurements, such as people with type 1 diabetes, may prefer to use an invasive system. People who value convenience and painlessness may prefer to use a non-invasive system, even if it is less accurate. It is important to note that Arduino-based non-invasive glucose measurement devices are still in their early stages of development.

2. Literature Survey

Non-invasive methods encompass (near-infrared and Raman spectroscopy, polarimetry, light scattering, photoacoustic spectroscopy, polarization techniques, mid-infrared spectroscopy), and more. Which it is discussed in [6-11]. In near-infrared spectroscopy (NIR), absorption or emission data within the 0.7 to 2.5 µm spectral range are juxtaposed with established glucose data. In Raman spectroscopy, laser light is employed to stimulate emissions from energy level transitions in proximity to the excited state. Photoacoustic spectroscopy involves laser-driven excitation of fluids, producing an acoustic response and a spectrum as the laser's frequency is adjusted [12-14]. Red laser-Blood Glucose Monitoring (BGM) RL-BGM study are discussed by Haider Ali [15], it predominantly utilizes visible laser light to gauge blood glucose levels. A photodiode is employed to capture the transmitted signal through the finger, after which the optical energy is transformed into voltage levels. An LCD is utilized to exhibit both the voltage quantity and the blood glucose concentration. Shyqyri [16] This paper explores a non-invasive glucose measurement system based on spectroscopy for assessing glucose levels. The approach involves the utilization of near-infrared (NIR) transmission spectroscopy and encompasses both in vitro and in vivo experiments. In this method, NIR light is directed through the index finger to determine blood glucose concentration, with the refracted light being detected by a photodiode located at the opposite end. Zhang [17] discussion centered on a salivary glucose monitoring system that is non-invasive, dependable, user-friendly, fast, and capable of continuous personal use. It demonstrated exceptional clinical precision when compared to the UV Spectrophotometer. This method is based on the Lens-free Ultra-wide field Cell monitoring Array using Shadow images (LUCAS). [18], it primarily relies on the diffraction pattern of an individual cell, as opposed to the conventional optical microscope image, for characterization. Other latest studies that deal with blood glucose measurements are listed in Table 2.

Table (2): Recent related works.

Reference	***Year***	***Method***	***System***
[19]	*2015*	*Current Sensing*	*Invasive*
[20]	*2016*	*NIR*	*Non-invasive*
[21]	*2018*	*Laser Light*	*Non-invasive*
[22]	*2019*	*Laser Light*	*Non-invasive*
[23]	*2019*	*Pulse-oximeter*	*Non-invasive*
[24]	*2020*	*RL-BGM*	*Non-invasive*
[25]	*2020*	*Light-sensor*	*Non-invasive*
[26]	*2021*	*NI-BGM*	*Non-invasive*
[27]	*2022*	*Saliva*	*Non-invasive*
[28]	*2023*	*NIR*	*Non-invasive*

Arduino-based non-invasive glucose measurement devices are developing as many studies are concentrate on this field, these devices could become a valuable tool for people with diabetes. One challenge is that the accuracy of Arduino-based non-invasive glucose measurement devices is generally lower than that of traditional finger prick glucose meters. This is because these devices are measuring glucose levels through the skin, which is more difficult and less accurate than measuring glucose levels in blood.

3. Proposed Work

An innovative blood glucose monitoring system is suggested, which employs a sensor to continuously monitor the individual's blood sugar levels without the need for invasive procedures. The main advantage of this device is that it measures blood glucose levels without having to prick the skin. The results can be viewed on LCD screen. Noninvasive glucose monitoring could make blood glucose testing easier and more comfortable for millions of people. The system uses a Light dependent resistor (LDR) sensing system to detect blood glucose concentration. A 650 nm red light is transmitted through the finger, and the intensity of the light emerging from the opposite side is detected by a phototransistor. The glucose level in the individual is then presented based on the received light intensity. Light photons are characterized by two parameters: frequency and wavelength. The light spectrum encompasses ultraviolet to infrared radiation, and each type of radiation possesses a distinct energy and frequency range, with a wavelength that is inversely related to these ranges. When light interacts with biological tissue, it can do so in a number of ways, as shown in Fig. 1.

The transmittance value can be readily determined by analyzing the reflected light in relation to the incident light's intensity. Light intensity, denoted as "I," is linked to the light's wavelength, and the reflectivity of light is inversely linked to its absorption.

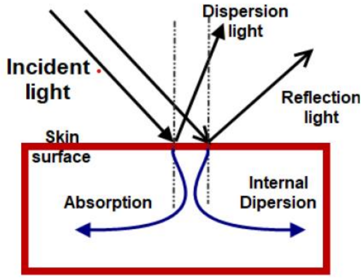

Figure (1): Interacting of Light with the outer layer of the skin [26].

In simpler terms, light interacts with biological tissue, and this interaction can result in light being reflected, transmitted, or absorbed by the tissue. The extent to which light is reflected, transmitted, or absorbed depends on both the wavelength of the light and the tissue's characteristics. There are two primary types of reflection: direct and diffuse. Direct reflection occurs when light bounces off the tissue's surface at the same angle as it initially struck. In contrast, diffuse reflection occurs when light scatters in various directions upon striking the tissue's surface. The transmittance value quantifies the amount of light that successfully passes through the tissue, calculated by dividing the transmitted light by the incident light, as illustrated in Fig. 2.

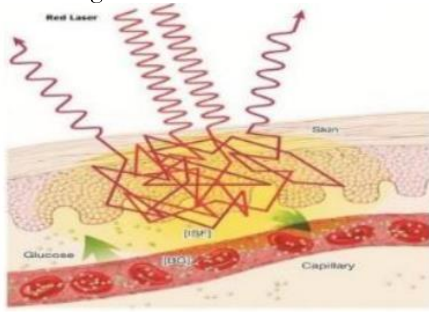

Figure (2): Absorbing Laser in Blood [29].

In this paper, the monitoring system design has two parts, Hardware Design and Software Design. The hardware design of the blood glucose monitoring system is considered first. Each component is briefly described. The Arduino UNO board is a microcontroller board that is used to control the other components of the system. Every component is elucidated, including the design process, as described later. Fig. 3 illustrates the block diagram of the blood glucose-measurement-monitoring system.

Arduino UNO: The Arduino UNO microcontroller functions as the central processing unit in the system, serving as the core for programming. It is a microcontroller board centered around the "ATMega328 chip, featuring 14 digital input pins, 6 analog output pins, a 16 MHz ceramic resonator, USB connectivity, a power jack, ICSP header, and a reset button". This board incorporates the necessary elements to support the microcontroller's operation when connected to a computer through a "USB cable".

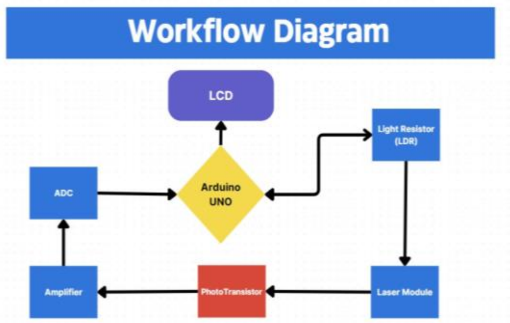

Figure (3): A diagram depicting the structure of a glucose monitoring system.

Power for the UNO can be supplied either via USB connection or an external power source, with automatic selection between the two. If an external "non-USB" power source is used, it can be provided by an Analog-to-Digital Converter (AC-to-DC) adapter "wall-wart" or a battery. A comprehensive list of all system components is listed in Table 3, and the proposed hardware system is illustrated in Fig. 4.

The procedure begins with the initialization of the devices, followed by positioning the finger over the light emitted by the laser source. A scanning process is then executed. If the ADC value falls below the threshold value, it is inferred that the finger is not in place. However, if the ADC value surpasses the threshold, the value is recorded, and the associated blood glucose level is shown on the display. The pin connections for the photo-resistor and phototransistor can be observed in Fig. 5.

Table (3): Components of the proposed work.

No.	Component	Details
1	LCD	16x2 LCD is employed for presenting instructions and displaying output. This screen can exhibit 16 characters in each of its two rows and is equipped with an (HD44780AOO) controller
2	ADC	Analog to digital conversation of signals. . The module have 16 bit with 4 channel
3	LDR	Photo-resistor, is a type of resistor that alters its resistance based on the strength of the incident light. These devices are constructed from semiconductor materials, becoming more conductive with increased light exposure, resulting in lower resistance
4	Phototransistor	Classified as an NPN junction transistor, its base region is sensitive to light. When illuminated, it generates an electric current, with the current's magnitude varying in response to the light's intensity
5	Amplifier	An LM 358 Op-amp with (8 pin DIP). This is "a dual op-amp integrated circuit" designed for low power consumption. It is engineered to function with a single power source across a broad range of supply voltages delivering a substantial gain of (100 dB)
6	Laser	Laser module of (6mm 5v and 650 nm)

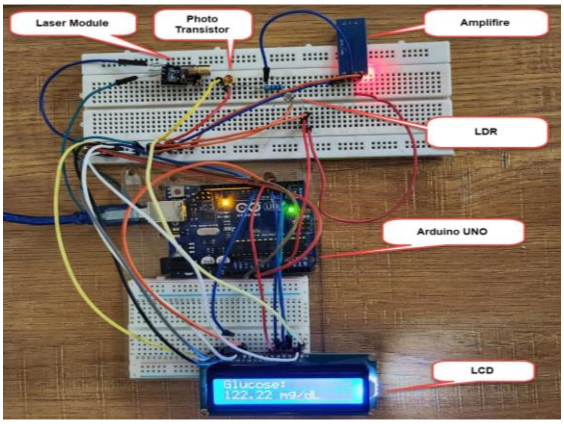

Figure (4): The proposed hardware system.

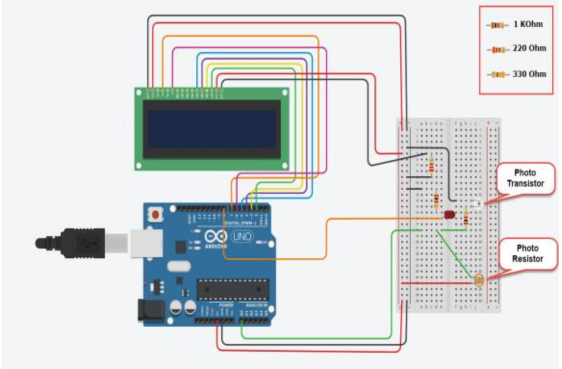

Figure (5): Pins connection of photo-resistor and photo-transistor.

Software: The program for (the digital-blood-glucose) is detailed in Fig. 6, it's performed by Arduino IDE programming to test the evaluation of the proposed system.

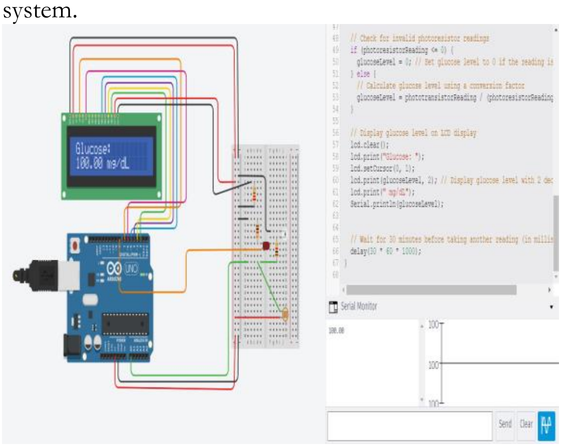

Figure (6): The software of the proposed system.

4. Results and discussions

The laser-based Arduino glucose-system was employed to measure blood glucose levels over a ten-day period. Random measurements were taken on different days to assess the device's effectiveness and sensitivity. As depicted in Fig. 7, it is evident that blood glucose levels during fasting are lower than those observed after consuming a meal. The glucose levels recorded using the non-invasive glucose monitor correlate well with those from an invasive glucose monitor, affirming the system's reliability.

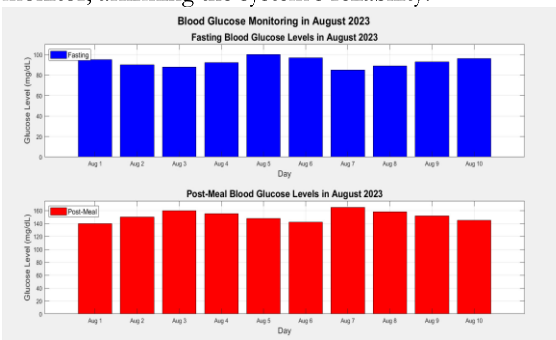

Figure (7): Blood glucose levels at fasting and post-meal.

5. Conclusion

The non-invasive system has the potential to transform how individuals manage their diabetes. It has the potential to simplify the process of checking blood sugar levels more frequently and accessing necessary care. The proposed non-invasive system offers a painless, comfortable, and infection-free way of measuring glucose levels. Moreover, it is more cost-effective and convenient compared to invasive methods, which are both time-consuming and expensive and cannot be used as regularly. This practical tool can be used easily in the comfort of one's home, at any location, and at any time. If patients or their caregivers opt to share this information with their healthcare providers, the continuous remote monitoring of glucose levels provides doctors with better insights into their patients' health. Although there may be some margin for error, the objective of developing a non-invasive blood glucose monitoring system has been attained. Ongoing advancements in technology will focus on minimizing these inaccuracies to yield more precise results.

6. Future Work

I. Improved Precision and Dependability: Subsequent research efforts should prioritize enhancing the precision and dependability of non-invasive blood glucose monitoring, which could necessitate enhancements to the sensor technology, reducing interference from external factors, and conducting extensive clinical trials to validate the device's performance across a diverse patient population

II. Miniaturization and Portability: Consider exploring ways to miniaturize the device, making it more portable and convenient for users. Smaller, wearable form factors can enhance the device's usability and encourage continuous monitoring.

III. Real time data receiving, CGM should be employed. The CGM stands for Continuous Glucose Monitoring, this method is needed to provide control and immediate intervention when necessary.

IV. Data Analysis and Machine Learning: Implementation of algorithms generated by ML in order to provide data analysis such as daily, weekly, and monthly trends of Glucose levels as well as providing future readings based on these trends and other data sheets in order needed to control any risk in the future.

V. Interoperability: Integration of the device with health applications such as Electronic Health Records (HER) in order to simplify the sharing of data with healthcare providers, allowing more informed decision-making and remote monitoring of the patient.

VI. Telemedicine Integration: In order to reduce clinic and hospitals visits of the patient, a Telemedicine platform should be employed. This would provide direct communication channel between patients and healthcare consultants, resulting in many advantages such as time saving and risk reduction.

VII. Regulatory Approval and Commercialization: Pursuing the required regulatory approvals (FDA approval) and corporations with medical device manufacturers to distribute the device to market legally.

VIII. Cost Reduction: Seeking for methods to reduce the manufacturing cost of the device, in order to become more accessible to all patients, especially those with limited budgets.

IX. Long-Term User Studies: Conduct long-term user studies to evaluate the device's efficiency in improving diabetes management, patient outcomes, and overall quality of life. Collect feedback from groups of users to make more improvement on the device.

X. Personalized Treatment Recommendations: Develop algorithms that can provide personalized treatment recommendations based on the collected glucose data, medication history, and individual patient characteristics.

XI. Security and Privacy: Strengthen the security measures for the GSM module and data transmission to ensure patient data privacy and protection from unauthorized access. Implement secure encryption and authentication protocols.

XII. GSM-Based Doctor Notifications: Implement a GSM module to enable the device to send SMS notifications to healthcare providers or designated doctors when glucose levels reach critical thresholds or when specific patterns are detected.

7. References

[1] C. M. C. M. Couto, A. N. Araújo, M. C. B. S. M. Montenegro, J. Rohwedder, I. Raimundo, and C. Pasquini, "Application of amperometric sol-gel biosensor to flow injection determination of glucose," Talanta, vol. 56, no. 6, pp. 997–1003, 2002, doi: 10.1016/S0039-9140(01)00587-2.

[2] Q. Yang, P. Atanasov, and E. Wilkins, "Development of needle-type glucose sensor with high selectivity," Sensors Actuators, B Chem., vol. 46 B46, no. 3, pp. 249–256, 1998, doi: 10.1016/s0925-4005(98)00126-9.

[3] H. Ukeda, Y. Fujita, M. Ohira, and M. Sawamura, "Immobilized Enzyme-Based Microtiter Plate Assay for Glucose in Foods," J. Agric. Food Chem., vol. 44, no. 12, pp. 3858–3863, 1996, doi: 10.1021/jf960261l.

[4] M. Lepore et al., "Glucose concentration determination by means of fluorescence emission spectra of soluble and insoluble glucose oxidase: Some useful indications for optical fibre-based sensors," J. Mol. Catal. B Enzym., vol. 31, no. 4–6, pp. 151–158, 2004, doi: 10.1016/j.molcatb.2004.07.008.

[5] X. J. Wu and M. M. F. Choi, "An optical glucose biosensor based on entrapped-glucose oxidase in silicate xerogel hybridised with hydroxyethyl carboxymethyl cellulose," Anal. Chim. Acta, vol. 514, no. 2, pp. 219–226, 2004, doi: 10.1016/j.aca.2004.03.052.

[6] O. S. Khalil, "Spectroscopic and clinical aspects of noninvasive glucose measurements," Clin. Chem., vol. 45, no. 2, pp. 165–177, 1999, doi: 10.1093/clinchem/45.2.165.

[7] L. N. Li, Q. B. Li, and G. J. Zhang, "A weak signal extraction method for human blood glucose noninvasive measurement using near infrared spectroscopy," J. Infrared, Millimeter, Terahertz Waves, vol. 30, no. 11, pp. 1191–1204, 2009, doi: 10.1007/s10762-009-9544-0.

[8] M. A. Arnold, L. Liu, and J. T. Olesberg,

"Selectivity assessment of noninvasive glucose measurements based on analysis of multivariate calibration vectors," J. Diabetes Sci. Technol., vol. 1, no. 4, pp. 454–462, 2007, doi: 10.1177/193229680700100402.

[9] C. Fischbacher, K. U. Jagemann, K. Danzer, U. A. Müller, L. Papenkordt, and J. Schüler, "Enhancing calibration models for non-invasive near-infrared spectroscopical blood glucose determination," Fresenius. J. Anal. Chem., vol. 359, no. 1, pp. 78–82, 1997, doi: 10.1007/s002160050539.

[10] A. W. S. Tarrant, "Optical measurements," Instrum. Ref. B. Third Ed., vol. 10, pp. 492–516, 2003, doi: 10.1016/B978-075067123-1/50025-9.

[11] K. V. Larin, M. S. Eledrisi, M. Motamedi, and R. O. Esenaliev, "Noninvasive blood glucose monitoring with optical coherence tomography: A pilot study in human subjects," Diabetes Care, vol. 25, no. 12, pp. 2263–2267, 2002, doi: 10.2337/diacare.25.12.2263.

[12] C. D. Malchoff, K. Shoukri, J. I. Landau, and J. M. Buchert, "A novel noninvasive blood glucose monitor," Diabetes Care, vol. 25, no. 12, pp. 2268–2275, 2002, doi: 10.2337/diacare.25.12.2268.

[13] S. F. Malin, T. L. Ruchti, T. B. Blank, S. N. Thennadil, and S. L. Monfre, "Noninvasive prediction of glucose by near-infrared diffuse reflectance spectroscopy," Clin. Chem., vol. 45, no. 9, pp. 1651–1658, 1999, doi: 10.1093/clinchem/45.9.1651.

[14] J. J. Burmeister and M. A. Arnold, "Evaluation of measurement sites for noninvasive blood glucose sensing with near-infrared transmission spectroscopy," Clin. Chem., vol. 45, no. 9, pp. 1621–1627, 1999, doi: 10.1093/clinchem/45.9.1621.

[15] H. Ali, F. Bensaali, and F. Jaber, "Novel Approach to Non-Invasive Blood Glucose Monitoring Based on Transmittance and Refraction of Visible Laser Light," IEEE Access, vol. 5, pp. 9163–9174, 2017, doi: 10.1109/ACCESS.2017.2707384.

[16] S. Haxha and J. Jhoja, "Optical Based Noninvasive Glucose Monitoring Sensor Prototype," IEEE Photonics J., vol. 8, no. 6, pp. 1–11, 2016, doi: 10.1109/JPHOT.2016.2616491.

[17] W. Zhang, Y. Du, and M. L. Wang, "Noninvasive glucose monitoring using saliva nano-biosensor," Sens. Bio-Sensing Res., vol. 4, pp. 23–29, 2015, doi: 10.1016/j.sbsr.2015.02.002.

[18] M. N. Mohd Zain, A. Musa, M. H. Hisham, A. R. Laili, and Z. M. Yusof, "Photon counting polarimetry measurement towards non-invasive biomedical glucose monitoring," Proc. ICP 2014 - 5th Int. Conf. Photonics 2014, no. September, pp. 156–158, 2015, doi: 10.1109/ICP.2014.7002364.

[19] A. S. A. El-hamid, A. E. Fetohi, R. S. Amin, and R. M. A. Hameed, "Design of Digital Blood Glucose Meter Based on Arduino UNO," IJournals All Rights Reserv., vol. 3, no. 8, p. 8, 2015, [Online]. Available: www.ijournals.in

[20] P. Narkhede, S. Dhalwar, and B. Karthikeyan, "NIR based non-invasive blood glucose measurement," Indian J. Sci. Technol., vol. 9, no. 41, 2016, doi: 10.17485/ijst/2016/v9i41/98996.

[21] B. Lakshmi Priya, S. Jayalakshmy, R. Bhuvaneshwar, and J. Kishore Kumar, "Non - Invasive Blood Glucose Monitoring based on Visible LASER Light," Proc. 3rd Int. Conf. Commun. Electron. Syst. ICCES 2018, no. October 2018, pp. 938–941, 2018, doi: 10.1109/CESYS.2018.8724048.

[22] T. W. Gamessa and D. Suman, "Non-invasive blood glucose monitoring using visible laser light," Res. J. Pharm. Technol., vol. 12, no. 2, pp. 831–840, 2019, doi: 10.5958/0974-360X.2019.00144.6.

[23] V. Apar and D. R. M. Autee, "Development of Portable Device for Measurement of Blood Glucose, Temperature and Pulse-Oximeter using Arduino," Int. Res. J. Eng. Technol., vol. 85, pp. 85–89, 2008, [Online]. Available: www.irjet.net

[24] M. J. Therese*, P. Dharanyadevi, Devi, and C. Kalaiarasy, "Detection of Blood Glucose Level in Humans using Non-Invasive Method-RL BGM," Int. J. Recent Technol. Eng., vol. 9, no. 1, pp. 304–309, 2020, doi: 10.35940/ijrte.f1209.059120.

[25] R. Ekawita, A. A. Nasution, E. Yuliza, N. Suardi, and S. Suwarsono, "Development of Non-Invasive Blood Glucose Level Monitoring System using Phone as a Patient Data Storage," J. Penelit. Fis. dan Apl., vol. 10, no. 2, p. 103, 2020, doi: 10.26740/jpfa.v10n2.p103-113.

[26] A. M. Tashtoush, "Non-invasive blood glucose measurement using laser technology (NIBGM)," Int. J. Comput. Digit. Syst., vol. 10, no. 1, pp. 297–307, 2021, doi: 10.12785/ijcds/100130.

[27] S. R. Z. Hamdani, M. Tahir, F. Akram, M. S. Orakzai, S. Amin, and Z. A. Khan, "Designing A Non-Invasive Testing Device for Infant Diabetes using Saliva," Pakistan J. Eng. Technol., vol. 5, no. 2, pp. 193–197, 2022, doi: 10.51846/vol5iss2pp193-197.

[28] G. S. Monisha, K. Kajendran, G. Nirmala, and D. R. Thirupurasundari, "A Smart Novel Approach of Blood Glucose Monitoring System using Arduino Board," Int. J. Intell. Syst. Appl. Eng., vol. 11, no. 2, pp. 495–502, 2023.

[29] N. Spegazzini et al., "Spectroscopic approach for dynamic bioanalyte tracking with minimal concentration information," Sci. Rep., vol. 4, pp. 1–7, 2014, doi: 10.1038/srep07013.