DESIGN A NON-INVASIVE BLOOD GLUCOSE MONITOR USING INFRARED SPECTRUM

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ABSTRACT

The incidence of Type 2 Diabetes mellitus (T2DM) is progressively escalating, and the increasing susceptibility to this ailment in India underscores the considerable health obstacle it presents to individuals and families in the country. According to International Diabetic Federation, 537 million adults are currently living with diabetes, and this will further increase to more than 700 million by 2045. T2DM is not cured, it can only be controlled with medication and/or insulin therapy. T2DM patients regularly monitor their blood glucose by glucometer, which is invasive and painful method, required blood sample and also it is cost effective for low-income group of family. In this context, our study was aimed to design a non-invasive blood glucose measuring instrument. Blood glucose monitoring was divided into invasive and non-invasive method of 10 nondiabetic persons and 10 diabetic persons. In invasive blood glucose measurement was done by glucometer and also HbA1c measured by semi-auto analyzer. Non-invasive blood glucose monitoring was performed using our own designed non-invasive glucometer using infrared (IR) of 960 nm wave length, photo diode, operational amplifier (OPAMP), and light-emitting diode (LED). From the invasive method mean blood glucose and HbA1c for nondiabetic persons are 96.20±1.24, 4.86±0.12 and for diabetic persons are 225.20±2.75, 9.41±0.38 respectively. Our own designed non-invasive glucose sensor identified only hypo and hyperglycemia when IR passed through fingertip. It has been concluded that non-invasive blood glucose sensor sensed here only qualitative manner but required more specified for quantitative measurement.

KEYWORDS: T2DM, Blood Glucose, Glucometer, Infrared, Hyperglycemia, Non-Invasive

INTRODUCTION

Diabetes presents a significant global health challenge, placing a substantial burden on public health and socioeconomic advancement on a global scale. Its prevalence is on the upswing in both developed and developing countries, primarily as a result of the adoption of Western lifestyles[1]. Type 2 diabetes, a chronic metabolic disorder resulting from beta-cell dysfunction and insulin resistance, is at the forefront of this health crisis [2]. Individuals diagnosed with Type 2 diabetes mellitus (T2DM) face various short-term and long-term comorbidities [3]. Our prior research has highlighted the financial strain experienced by low-income families with a member suffering from diabetes mellitus. Remarkably, approximately a quarter of their monthly income is allocated to purchasing medication and conducting blood glucose tests for the diabetic family member[4]. Meanwhile, individuals with Type 1 diabetes are encouraged to take responsibility for their health by diligently managing their glucose levels[5]. For those using insulin or other medications that affect blood sugar, or those with concurrent medical conditions, transitioning to diabetes treatment plans is crucial[6]. Maintaining blood sugar levels within the range of 70 mg/dl to 180 mg/dl is considered ideal for overall health. Hypoglycemia, characterized by blood sugar levels dropping below 70 mg/dl, poses a significant short-term risk. Conversely, hyperglycemia, where blood sugar levels exceed 200 mg/dl, has lasting adverse effects on bodily functions. Numerous studies have consistently linked intensive care with frequent glycemic self-monitoring to a substantial delay in the onset or progression of complications. Patients often utilize invasive handheld glucose biosensors, which require regular blood samples obtained by needling the patient's finger multiple times a day using a lancet, a practice that can discourage consistent monitoring[7]. There are two primary approaches to glucose monitoring: partly invasive and non-invasive methods. The partly invasive technique involves placing a sensor under the skin to measure glucose concentration, while non-invasive methods rely on wearable devices to detect glucose levels on the spot [8]. Needle-type glucose sensors have also emerged, providing subcutaneous tissue glucose readings without the need for blood withdrawal. These devices enable patients to monitor their glucose levels during physical activity and alert them to hypoglycemia through an audible alarm[9]. In comparison to traditional methods, biosensors offer improved specificity, detection limits, and response speed[10]. Recent advancements in glucose measurement technology have spurred the development and commercialization of integrated glucose monitoring devices. However, many of these devices still rely on invasive monitoring techniques, involving painful finger pricks to collect blood samples. Consequently, there is a pressing need for the development of accurate, non-invasive blood glucose meters that enhance the convenience and comfort of individuals with diabetes[6]. Despite these technological advancements, a significant portion of individuals with diabetes continue to struggle with blood sugar control, leading to potentially severe consequences. This underscores the importance of regularly assessing blood sugar levels using invasive methods, which involve collecting blood samples through finger pricking—a procedure that remains uncomfortable and discouraging for many patients[11]. The main aim of this study was to present and discuss the updated advances and developments in the 'model of non-invasive blood glucose monitoring device' [6].

MATERIALS AND METHODS

Selection of subject

We were selected 10 pre-diagnosed with T2DM (aged from 40 to 50 years) patients and another 10 persons unknown for T2DM (aged from 40 to 50 years), Midnapur town, Paschim Medinipur, West Bengal, India. The study was carried out according to the declaration of Helsinki and all procedures were approved by the Institution Human Ethics Committee (IHEC) of Raja Narendra Lal Khan Women's College (Autonomous)[4].

Invasive measurement of fasting blood glucose (FBG) and glycosylated hemoglobin (HbA1c)

FBG was measured by glucometer and HbA1c was estimated by standard kit method using the semiauto analyzer[12].

Non-invasive measurement of blood glucose

For non-invasive blood glucose monitoring, we have used our own designed sensor using IR light source of 960 nm wave length, photo diode, OPAMP, red LED and green LED (figure 2), after giving the input, at a certain level the output of one OPAMP is sensed else another of comparator circuit. Red LED was sensed when voltage(v1) decrease, otherwise green LED was sensed when high voltage(v2) passed through it.

Statistical analysis

Mean ± standard error (SE) of FBG and HbA1c have analyzed by a student two tail 't' test using the origin statistics package [13].

RESULTS

From the invasive method mean FBG for nondiabetic persons are 96.20±1.24 (Table 1), and for diabetic persons are 225.20±2.75 (Table 1). HbA1c for nondiabetic persons are 4.86±0.12 (Table 1) and for diabetic persons are 9.41±0.38 (Table 1). FBG and HbA1c was significantly ($P < 0.001$) higher in diabetic person than nondiabetic persons. The non-invasive glucose sensor was placed on a fingertip of diabetic and nondiabetic patient where IR of 960 nm wave length of light passed to a photo diode (figure 2). It measured the changing absorbance of the wave length. High blood glucose and HbA1c absorbed more IR light and diode generated less current which passes through OPAMP-A and then this current converted into voltage and this voltage when passes through comparator circuit, it sensed red LED. When IR light passed through fingertip of nondiabetic person, IR light less absorbed than diabatic person and diode generated more current which passes through OPAMP-A and then this current converted into voltage and this voltage when passes through comparator circuit, it sensed green LED.

DISCUSSION

Numerous blood glucose meters are currently available in the market. However, these glucometers come with a price tag exceeding 1000 rupees and require test strips, each costing around 30 rupees per test. Furthermore, commercially available blood glucose meters typically demonstrate an accuracy rate of 85-90% [14]. Extensive research consistently highlights the benefits of regular blood sugar level monitoring, showing a correlation between such monitoring, lowered blood sugar levels, and improved overall quality of life. Interestingly, the frequency of blood sugar testing exhibits a negative correlation with actual blood sugar levels[15]. Non-invasive blood glucose monitoring, as the term suggests, entails measuring blood glucose levels in humans without causing harm to their tissues [16]. These methods can be broadly categorized into optical, microwave, and electrochemical techniques[17]. For individuals with diabetes who rely on regular insulin injections to maintain blood sugar balance, frequent and regular blood glucose monitoring is of paramount importance[18]. Therefore, the development of innovative, painless, and stress-free non-invasive blood glucose monitoring technologies and precise closed-loop drug delivery systems has the potential to directly benefit millions of patients by eliminating the need for painful blood draws[19]. Numerous non-invasive techniques are employed to ascertain and determine glucose levels in the human body. An example of such a method is the Gluco Watch sensor, which utilizes iontophoresis to measure glucose levels by extracting interstitial fluid through the skin via an electric current[20]. It's worth noting that this sensor was withdrawn from the market due to reported skin irritation in several patients[21]. As technology continues to advance and new data coding and verification techniques emerge, non-invasive blood glucose meters are gradually entering the market, promising increased accuracy and reduced errors and interference compared to invasive blood glucose meters[22]. Consequently, there's a growing need to examine the similarities and differences between Invasive and Non-Invasive Blood Glucose Meters[23]. Non-invasive blood glucose meters enable the measurement of glucose levels within seconds, without causing stress, pain, blood withdrawals, or finger pricks. Currently, various non-invasive blood glucose monitoring techniques are undergoing evaluation[24]. Blood glucose monitors must deliver precise results, particularly at levels crucial for clinical care, while remaining practical and cost-effective[25]. Recent developments have opened up the possibility of continuous glucose monitoring[26]. In the field of science, numerous devices are being developed to measure blood glucose levels, with a particular focus on using infrared (IR) light sources. Influenced by this reason, we are also using IR light source to make a 'Model of blood glucose meter'[27]. The flowchart of developed 'Model of blood glucose meter' is shown in figure 1. The flowchart at figure 1 of proposed model is consisting of IR source (wavelength λ=960nm), sample (skin), infrared receiver (photo diode), OPAMP-A, comparator circuit (OPAMP-B and OPAMP-C), red LED (for T2DM) and green LED (for NT2DM). Based on this we designed a 'model of non-invasive blood glucose monitoring device'. The circuit configuration of our proposed model is shown in figure 2, which works as follows.

To produced it initially a beam of monochromatic light of wave length 960 nm (IR spectra) falls on human skin (sample like finger) with a fixed wave length λ and after being reflected from the skin beam becomes of wave length λ' (shifting of wavelength), the beam received by an IR receiver (say photo diode) and convert it to corresponding current[28]. Next scaled related voltage to be introduced as input of a OPAMP comparator (consist of OPAMP-B, OPAMP-C and LED) for a reference voltage[29]. After giving the input, at a certain level the output of one OPAMP is sensed else another, by which we can detect whether a person is diagnosed with T2DM or NT2DM[30]. So, for diabetic patient due to high blood glucose and HbA1c absorbed more IR light and diode generated less current which passes through OPAMP-A and then this current converted into voltage say v1 and this voltage when passes through comparator circuit, it sensed red LED. For nondiabetic person, IR light less absorbed than diabatic person and diode generated more current which passes through OPAMP-A and then this current converted into voltage say v2 and this voltage when passes through comparator circuit, it sensed green LED. Here R1, R2, R3 and R4 are resistances[31].

CONCLUSION

Using IR of 960 nm wave length through the human finger and then convert the shifting wave length into current with the help of diode and then convert that current into voltage with the help of OPAMP and send that voltage through the comparator circuit which consists of OPAMP and LED, then we can easily classify high blood glucose and low blood glucose persons at very low or no cost. Our own designed non-invasive glucose sensor identified only hypo and hyperglycemia when IR passed through fingertip. It has been concluded that non-invasive blood glucose sensor sensed here only qualitative manner but required more specified for quantitative measurement.

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Disclosure of conflict of interest

No conflict of interest.

Statement of ethical approval

The present research work was approved by Institutional Human Ethical Committee of Belda College, Belda, District-Paschim Medinipur, West Bengal, India (Approval No. BC/IHEC/01/2020 dated 11.10.2020).

Statement of informed consent

Informed consent was obtained from all individual participants, included in the study.

REFERENCES

1. Aljunid SM, Aung YN, Ismail A, Abdul Rashid SA, Nur AM, Cheah J, et al. Economic burden of hypoglycemia for type II diabetes mellitus patients in Malaysia. PLoS One. 2019;14(10): e0211248. doi: 10.1371/journal.pone.0211248.
2. Butt MD, Ong SC, Wahab MU, Rasool MF, Saleem F, Hashmi A, et al. Cost of illness analysis of type 2 diabetes mellitus: the findings from a lower-middle income country. International Journal of Environmental Research and Public Health. 2022;19(19):12611. doi: 10.3390/ijerph191912611.
3. Sefah IA, Okotah A, Afriyie DK, Amponsah SK. Adherence to oral hypoglycemic drugs among type 2 diabetic patients in a resource-poor setting. International Journal of Applied and Basic Medical Research. 2020 ;10(2):102-9. DOI: 10.4103/ijabmr.IJABMR_270_19.
4. Pal P, Bhowmik S, Pyne S, Mandal M, Das K, Kumar S. The socio-economic burden of expenditure for diabetes mellitus treatment: A cross sectional study. International Journal of Science and Research Archive. 2022;7(1):427-33. dio: 10.30574/ijsra.2022.7.1.0204.
5. Ganasegeran K, Hor CP, Jamil MF, Loh HC, Noor JM, Hamid Naet et al. A systematic review of the economic burden of type 2 diabetes in Malaysia. International journal of environmental research and public health. 2020 ;17(16):5723. doi: 10.3390/ijerph17165723.
6. Gamessa TW, Suman D, Tadesse ZK. Blood glucose monitoring techniques: recent advances, challenges and future perspectives. International Journal of Advanced Technology and Engineering Exploration. 2018 ;5(46):335-44. doi:10.19101/IJATEE.2018.546008.
7. Demitri N, Zoubir AM. Measuring blood glucose concentrations in photometric glucometers requiring very small sample volumes. IEEE Transactions on Biomedical Engineering. 2016;64(1):28-39. doi: 10.1109/TBME.2016.2530021. Epub2016.
8. Alsunaidi B, Althobaiti M, Tamal M, Albaker W, Al-Naib I. A review of non-invasive optical systems for continuous blood glucose monitoring. Sensors. 2021;21(20):6820. doi: 10.3390/s21206820.
9. Shichiri M, Asakawa N, Yamasaki Y, Kawamori R, Abe H. Telemetry glucose monitoring device with needle-type glucose sensor: a useful tool for blood glucose monitoring in diabetic individuals. Diabetes Care. 1986;9(3):298-301.doi.org/10.2337/diacare.9.3.298.
10. Mujawar TH, Kasbe MS, Mule SS, Deshmukh LP. Development of wireless gas sensing system for home safety. International Journal of Engineering Sciences & Emerging Technologies. 2016;8:213-21. https://www.researchgate.net/publication/299847299_MICROCONTROLLER_BASED_BLOOD_GLUCOSE_METER_DESIGN_AND_DEVELOPMENT.
11. Valero M, Pola P, Falaiye O, Ingram KH, Zhao L, Shahriar H, et al. Development of a noninvasive blood glucose monitoring system prototype: Pilot study. JMIR formative research. 2022 ;6(8):e38664.doi: 10.2196/38664.
12. Bhowmick S, Giri D, Mandal M, Pyne S, Pal P, Das S, et al. Protective Effect of Arjunakwatha and Arjunasheeta in Paracetamol-induced Kidney Injury in Rat Model. International Journal of Pharmaceutical Investigation. 2023 1(1).doi: https://doi.org/10.5530/223097131728.
13. Pal P, Bhowmik S, Pyne S, Mandal M, Das K, Kumar S. The socio-economic burden of expenditure for diabetes mellitus treatment: A cross sectional study. International Journal of Science and Research Archive. 2022;7(1): 427-33.doi: 10.26420/intjnutrsci.2021.1060.
14. Baghelani M, Abbasi Z, Daneshmand M, Light PE. Non-invasive

continuous-time glucose monitoring system using a chipless printable sensor based on split ring microwave resonators. Scientific Reports. 2020 ;10(1):12980. doi.org/10.1038/s41598-020-69547-1.
15. Smyth BJ, Polaski RS, Safer A, Boettcher FA, Konrad-Martin D, Gratton MA. Point-of-Care Glucose and Lipid Profile Measures Using a Human Point-of-Care Device in Mouse Models of Type 2 Diabetes Mellitus, Aging, and Alzheimer Disease. Journal of the American Association for Laboratory Animal Science. 2021 ;60(6): 609-15.doi:10.30802/AALAS-JAALAS-21-000011
16. Yao J, Wang H, Yan J, Shao D, Sun Q, Yin X. Understanding the profiles of blood glucose monitoring among patients with type 2 diabetes mellitus: a cross-sectional study in Shandong, China. Patient preference and adherence. 2021:399-409. doi: 10.2147/PPA.S292086.
17. Chouhan S, Kallianpur S, Prabhu KT, Tijare M, Kasetty S, Gupta S. Candidal prevalence in diabetics and its species identification. International Journal of Applied and Basic Medical Research. 2019 Jan 1;9(1):49-54. DOI: 10.4103/ijabmr.IJABMR_259_18.
18. Thomas A, Shenoy MT, Shenoy KT, George N. Glucometers for Patients with Type 2 Diabetes Mellitus: Are they helpful?. International Journal of Medical Students. 2021 ;9(2):140-4.doi.org/10.5195/ijms.2021.786.
19. Mahajan R. Distinguishing Viral and Bacterial Infections Made Easy Through the Food and Drug Administration Approved Technology-Assisted Diagnosis. International Journal of Applied and Basic Medical Research. 2021 ;11(4):205. DOI: 10.4103/ijabmr.ijabmr_662_21.
20. Raghavendra GB, Bhat SG. Glucometer as a chairside device to assess blood glucose in periodontal patients. Journal of the international clinical dental research organization. 2010 ;2(3):130-5. doi: 10.4103/2231-0754.95286.
21. Al Zubaer A, Islam MA, Rahman MH, Hossain MA, Mondal SK. IoT Based Infrared Remote Controlled AC Fan Regulator. International Journal of Trend in Scientific Research and Development (IJTSRD). 2020 ;4(6):2456-6470. www.ijtsrd.com/papers/ijtsrd33484.pdf.
22. Arslan M, Kazi U, Rabb A, Saleem F. Accuracy, interferences and their prevention in using portable Gluco-meters. Isra Medical Journal. 2018 ;10(4).http://www.imj.com.pk/wp-content/uploads/2018/09/16-RA-30-12-17.pdf
23. Bamgboje D, Christoulakis I, Smanis I, Chavan G, Shah R, Malekzadeh M, et al. Continuous non-invasive glucose monitoring via contact lenses: Current approaches and future perspectives. Biosensors. 2021 ;11(6):189. doi: 10.3390/bios11060189. PMID: 34207533.
24. Beardsall K. Measurement of glucose levels in the newborn. Early human development. 2010 ;86(5): 263-7. doi: 10.1016/j.earlhumdev.2010.05.005. Epub2010.
25. Shah JH, Bhalodiya DK, Rawal AP, Nikam TS. Long-term results of transcatheter closure of large patent ductus arteriosus with severe pulmonary arterial hypertension in pediatric patients. International Journal of Applied and Basic Medical Research. 2020 ;10(1):3-7. DOI: 10.4103/ijabmr.IJABMR_192_19.
26. Tang L, Chang SJ, Chen CJ, Liu JT. Non-invasive blood glucose monitoring technology: a review. Sensors. 2020 ;20(23): 6925. doi: 10.3390/s20236925.
27. Nkono BL, Rouamba A, Omokolo JG, Tcheudi BT, Tigui BA, Dzeufiet PD et al. Antidiabetic and antiradical effects of garcinia kola seeds in dexamethasone-induced hyperglycemic rats. International Journal of Applied and Basic Medical Research. 2022 ;12(3):203-10. DOI: 10.4103/ijabmr.ijabmr_199_22.
28. Khan M, Agarwal M, Usman K, Mishra P. Prevalence of Self-care Practices among Type 2 Diabetes Mellitus Patients and its Effect on Glycemic Control: A Cross-sectional Study in Secondary and Tertiary Health-care Centers in Lucknow. International Journal of Applied and Basic Medical Research. 2023 ;13(4):246-54. DOI: 10.4103/ijabmr.ijabmr_212_23.
29. Hina A, Saadeh W. Noninvasive blood glucose monitoring systems using near-infrared technology—a review. Sensors. 2022 ;22(13): 4855.doi: 10.3390/s22134855.
30. So CF, Choi KS, Wong TK, Chung JW. Recent advances in noninvasive glucose monitoring. Medical devices: evidence and research. 2012:45-52. doi: 10.2147/MDER.S28134. Epub 2012 Jun 29.
31. Ismail A, Suddin LS, Sulong S, Ahmed Z, Kamaruddin NA, Sukor N. Economic burden of managing Type 2 diabetes mellitus: Analysis from a Teaching Hospital in Malaysia. Indian journal of public health. 2017;61(4):243-7. doi: 10.4103/ijph.IJPH_24_16. PMID: 29219128.

Class	Blood glucose level (mg/dl) (Mean ± SE)	HbA1C (g/dl) (Mean ± SE)
T2DM	225.20±2.75*	9.41±0.38*
NT2DM	96.20±1.24	4.86±0.12

Table 1: Blood glucose level of 10 T2DM and 10 NT2DM patients. Data (Mean± Standard error) were analyzed by student 't' test at the level of α0.001.

T2DM - type 2 diabetes mellitus, * p<0.001, NT2DM - non-type 2 diabetes mellitus.

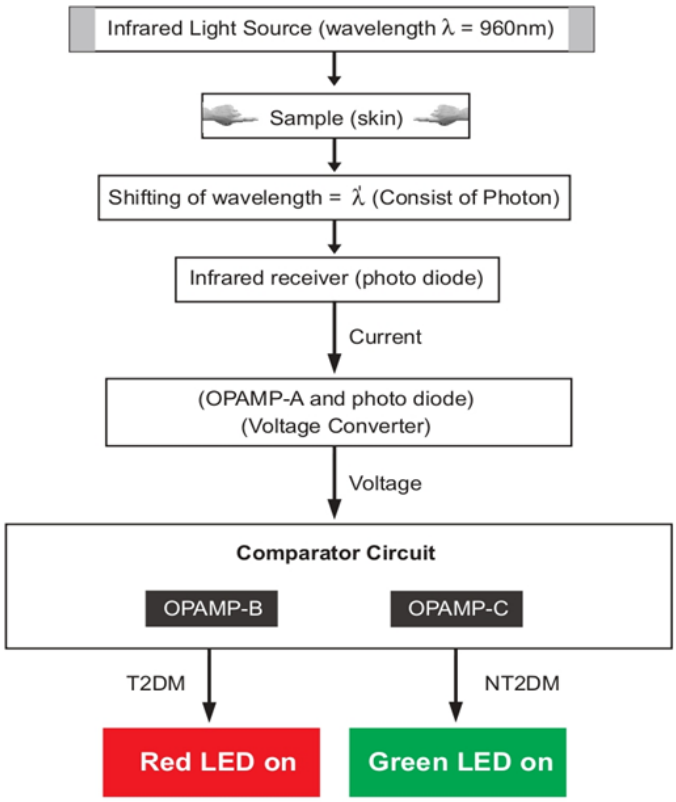

Figure 1: The flowchart of 'model of blood glucose meter'. T2DM - type 2 diabetes mellitus, NT2DM - non-type 2 diabetes mellitus, OPAM - operational amplifier, LED - light-emitting diode.

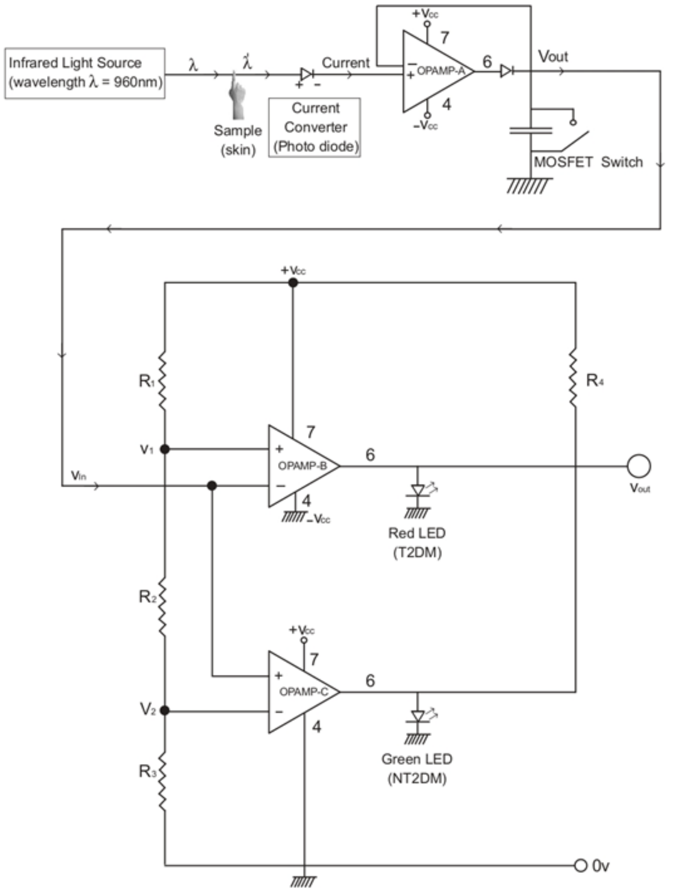

Figure 2: The circuit configuration of 'model of blood glucose meter'.

T2DM - type 2 diabetes mellitus, NT2DM - non-type 2 diabetes mellitus, OPAM - operational amplifier, LED - light-emitting diode.