Chapter 38
D-CARE: A Non-invasive Glucose Measuring Technique for Monitoring Diabetes Patients

Md. Mahbub Alam, Swapnil Saha, Proshib Saha, Fernaz Narin Nur, Nazmun Nessa Moon, Asif Karim and Sami Azam

1 Introduction

Diabetes is one kind of disease of the pancreas, which is responsible for producing a hormone called insulin. Diabetes happens when the pancreas gland is no longer able to produce insulin or the body cannot properly utilize the insulin delivered by the pancreas, resulting in the high level of blood glucose in the bloodstream. However, the human body needs some glucose as it provides the necessary energy for the body to work. The prevalence of diabetes was about 8% in 2011, which will probably rise to 10% by 2030. The alarming fact is, 80% of diabetic people are from low-income or middle-income countries. In Bangladesh about 10%, in China 9% and in

Md. M. Alam · S. Saha · P. Saha · F. N. Nur (✉) · N. N. Moon
Department of Computer Science and Engineering, Daffodil International University, Dhaka, Bangladesh
e-mail: narin@daffodilvarsity.edu.bd

Md. M. Alam
e-mail: mahbub15-5237@diu.edu.bd

S. Saha
e-mail: swapnil15-4939@diu.edu.bd

P. Saha
e-mail: proshib15-5041@diu.edu.bd

N. N. Moon
e-mail: moon@daffodilvarsity.edu.bd

A. Karim · S. Azam
College of Engineering, IT and Environment, Charles Darwin University, Casuarina, NT, Australia
e-mail: asif.karim@cdu.edu.au

S. Azam
e-mail: sami.azam@cdu.edu.au

© Springer Nature Singapore Pte Ltd. 2020

M. S. Uddin and J. C. Bansal (eds.), *Proceedings of International Joint Conference on Computational Intelligence*, Algorithms for Intelligent Systems, https://doi.org/10.1007/978-981-13-7564-4_38

India 8% of the population are affected by the disease [1]. Deaths occurring from diabetes mellitus in Bangladesh has reached to 40,142, which is nearly 5.09% of total deaths according to WHO [2]. As the statistics show, diabetes is a key reason for deaths in Bangladesh in recent years.Statistics shows that the prevalence of diabetes in Bangladesh has increased from 5% (2001–2005) to 9% (2006–2010). Such rate will rise up to 13% by 2030 according to the International Diabetes Federation [1, 3].

One worrying stat is that the diabetes-affected infants and aged people are less cautious about their condition than the adults and middle-aged people. Supposedly, the middle-aged people are more cautious about their condition, and it is seen that they are capable of understanding their medical conditions better than the aged people and the younger ones. Non-invasive method for blood glucose monitoring is becoming more of interest to researchers as it has become a must for constant monitoring of glucose level in blood. In this paper, a design has been presented to monitor blood glucose level using *Near-Infrared (NIR)* light source, which is of 940 nm wavelength [4–7]. The intensity of light passed through the finger is used to calculate the blood glucose level. Arm, finger and earlobe; these three different probes were used to calculate the blood glucose using 940 nm NIR LED. The data obtained from the sensor through the microcontroller subsequently is sent to a web server and also to an observer (any relative/someone taking care of the patient), in case, the level of glucose in bloodstream becomes too low or too high. That way, a person can always be aware of any impending danger if such condition does arrive. This system can be used to continuously monitor the blood glucose level and notify the patient accordingly to take necessary measures for an initial treatment; e.g. if the patient's blood level is critically low, the system will advise the patient to consume some kind of desert or any sweet stuff. However to determine the exact level of insulin dose required, the sugar level in bloodstream needs to be determined by an invasive method.

2 Related Works

Through an in-depth literature review, some research initiatives based on the above-mentioned method have been identified, where the main objective has been to measure the glucose level and the proper insulin dose. The widely used method to calculate glucose level in the bloodstream is an invasive technique that is painful, high-priced and may cause the outbreak of infectious diseases. Besides, the invasive technique results in damaged finger tissues in case of frequent application. As an alternative, the non-invasive approach may be used, which helps frequent check-ups and relieves ache and discomfort caused by common finger pricks [4, 8–15]. Daarani and Kavithamani [4] have proposed a non-invasive method of glucose level measurement with a NIR sensor. The method displays the measured value in LCD display and also sends out to the Android application, as well as stores data via Bluetooth. Buda and Addi [8] have proposed a system, where they have developed a non-invasive blood glucose monitoring device to observe glucose concentration in blood. The device shows the glucose level and the proper insulin dose, resembling the body mass index (BMI) of the user. The work projected a 4–16% accuracy in glucose detection. Rahmat et al. [9] have proposed IoT-based non-invasive glucose monitoring technique where the researchers have put fingertip into *Near-Infrared (NIR) LED* to calculate blood glucose level and the concentration measure of glucose in the blood. They displayed glucose reading on the LCD display and showed it to the patient's family and the doctor via SMS and Android application for monitoring patients remotely. The system demonstrated results with an approximate accuracy of 88.89%. Based on seven assessments, the work had average 7.20% error of glucose reading in comparison to their proposed method with invasive method. Saleh et al. [10] have designed a non-invasive system to measure the blood glucose level. They showed 17% accuracy by implementing a notch filter. Yadav et al. [11] have introduced the glucose sensor based on the principle of NIR LED. In their work, the 940 nm spectrum continuous wave has been used to explore different concentration of glucose for experimentation. The authors had experimented on the human forearm and overlooked the reflectance spectra of blood. Bobade and Patil [12] have described a non-invasive blood glucose level detection method for diabetic and non-diabetic peoples. Near-Infrared (NIR) sensor for the measurement of blood glucose has been used in their proposed method. The measured glucose level is further transfused to the smart Android app for exploration and storage of the data. Narkhede et al. [13] have introduced the method for non-invasive glucose estimation using the near-infrared-based optical technique. The structured method comprises of LED emitting signals with the wavelength of 940 nm. Hotmartua et al. [14] have developed near-infrared sensor-based non-invasive earlobe testing method for detecting the blood glucose. In their research work, two approaches had been devised to generate a formula for the estimation of blood glucose concentration with a maximum error rate of 30%. Lawand et al. [15] have designed a compact framework for non-invasive blood glucose measurement. They tested and found the valid results by using statistical techniques. The outcome showed that there is a correlation between voltage intensity level due to the pulsatile nature of blood and blood glucose level. Menon et al. [16] have put forward a non-invasive voltage intensive blood glucose monitoring. Near-infrared sensor has again been used for the proposed method and after obtaining result, it is communicated with a smartphone through Bluetooth.

3 Methodology and System Architecture

3.1 Block Diagram of Proposed Work

From Fig. 1 it is seen that Glucose level is measured by *Photodiode* and *Near Infrared (NIR) Sensor*. NIR with 800–1700 nm wavelength is suitable for measuring continuous glucose level. Once NIR sensor transmits continuous wave, a photodiode with

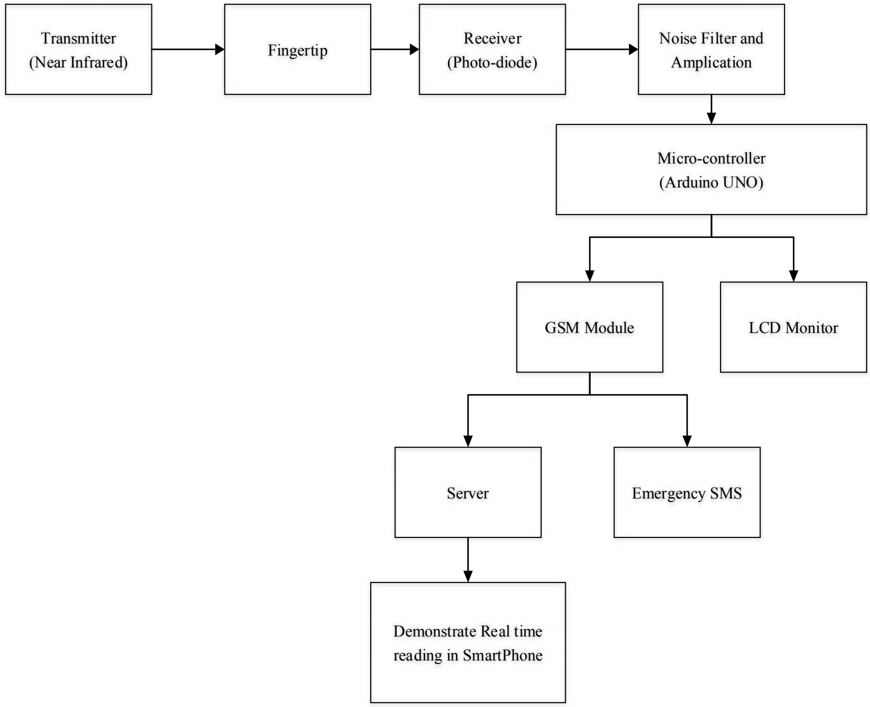


Fig. 1 Proposed block diagram of non-invasive blood glucose monitoring system

1550 nm wavelength receives these waves. After noise filtration and amplification, these wave signals are converted into a suitable voltage value and the microcontroller converts these voltage value to an equivalent glucose value. This glucose value is displayed to the patient with a LCD monitor. The Microcontroller also sends this value to a server using a GSM module (SIM808). Observer can observe this glucose level obtained from the patient by using a smartphone. In critical situation, emergency SMS is also sent to an observer (Fig. 1).

3.2 Architecture of System

The proposed system works on a diabetes patient, and simultaneously aids the patient's carer or observer. Patient's fingertip is placed between the glucose measuring sensors that measure glucose value through the aid of microcontroller. The patient can see his glucose reading in the LCD display and observer can monitor the patient's glucose condition through a smartphone. The observer also gets notified with SMS when the patient's glucose level reaches at a worrying level (Fig. 2).

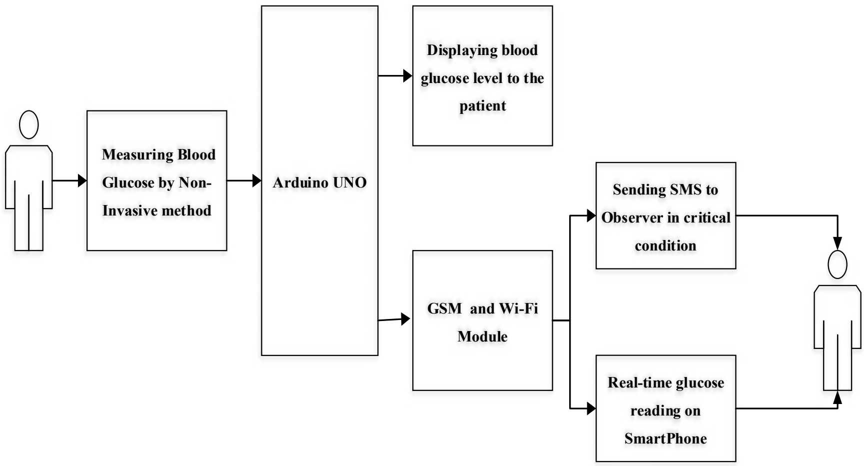


Fig. 2 Architecture of the proposed system

3.3 Flowchart of the Proposed System

Figure 3 illustrates the flowchart of the proposed system. First, NIR sensor is powered up. Now to measure blood glucose, the patient's finger has to be placed between the NIR sensor and photodiode sensor. NIR sensor generates optical wave to the photodiode and attenuated light wave, which is then measured and converted into a signal by the photodiode sensor.

In the subsequent steps, noise frequency of the signal from NIR is reduced through noise filtering procedure and the signal is amplified through amplification procedure in order to expand the weak signal. After the conversion of signal into electrical current value, Arduino converts this current value into a relative glucose value.

The obtained glucose value is then compared using some predefined conditions, and according to the conditions, the derived glucose value is displayed in an LCD monitor with categorized level such as *dangerously low, low, normal, high and very high*. When blood glucose value is less than or equal 50 mg/DL, then this will be categorized as *dangerously low*. An SMS will be sent to the observer to check on the patient whether he or she has sought medical attention. If blood glucose is between 51 and 70 mg/DL, then it will be categorized as *low*. An SMS will also be sent to the observer at this time to provide some sugar\dessert to the patient as soon as possible. If the blood glucose is between 71 and 179 mg/DL, then it is considered as normal. If the value ranges between 180 and 237 mg/DL, then it is taken as high. And if the blood glucose value is more than 237 mg/DL, then it will be categorized as very high level, and this time also an SMS will be sent to the observer to advise the patient to visit a healthcare profession as soon as possible. All glucose readings are stored in a database before a monitoring cycle completes.

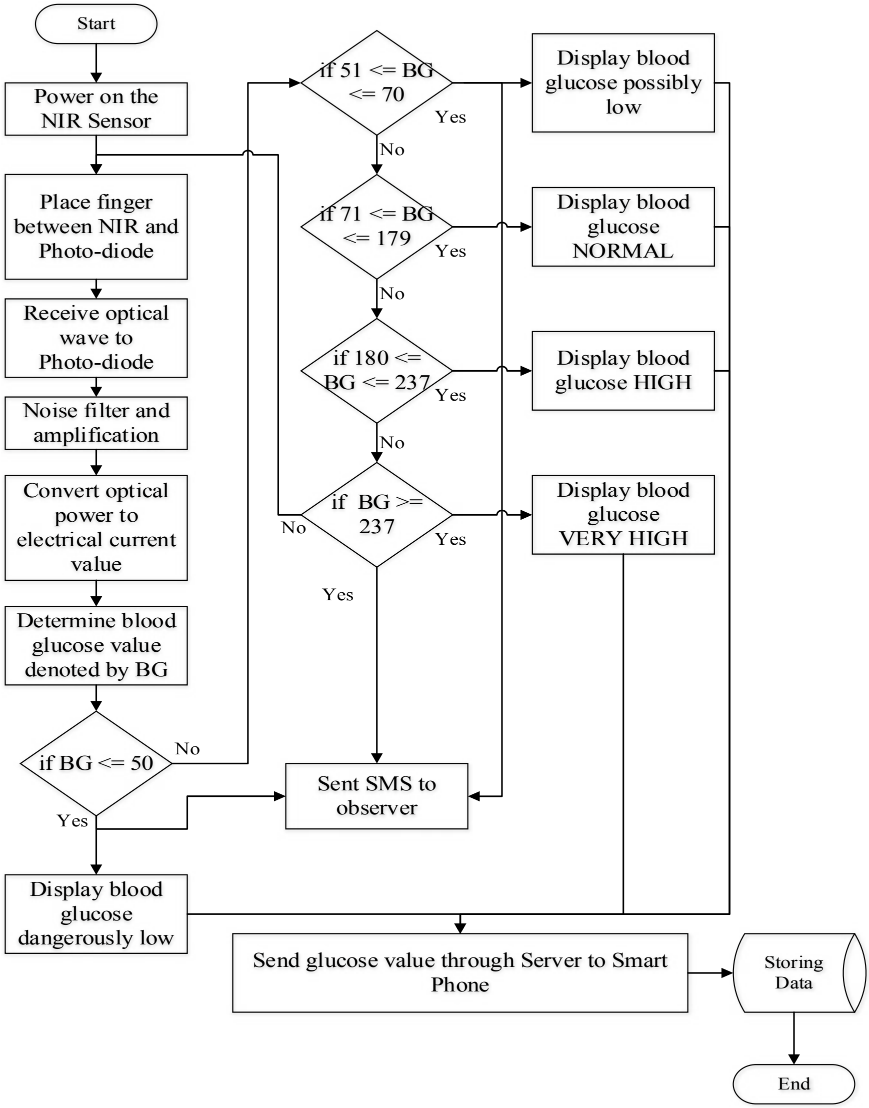


Fig. 3 Flowchart of working procedure of the proposed system

4 System Design

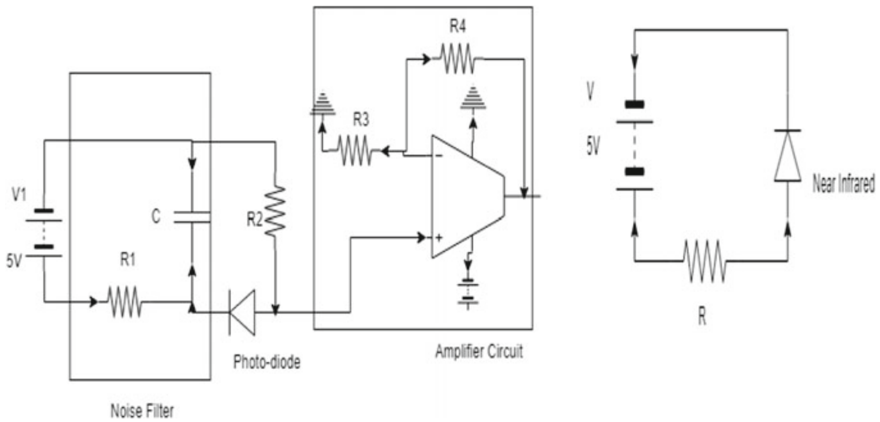
The system has been designed in two units:

4.1 *Blood Glucose Measuring Unit*

In blood glucose measuring unit, there are two circuits as shown in (Fig. 4a) (Receiver Circuit) and (Fig. 4b) (Transmitter Circuit). The transmitter circuit consists of a noise filter, a photodiode (1550 nm) and an operational amplifier (lm358); and receiver circuit consists of a near-infrared device (800–1700 nm). The transmitter transmits continuous wave thread light through the finger, and the receiver receives this attenuated light. First, the noise frequency of this light is reduced by noise filtering components, and then, it has been amplified to expand the weak signal. After that, the intended signal is converted into an electric current value. Arduino converts the electric current value into a relative glucose value.

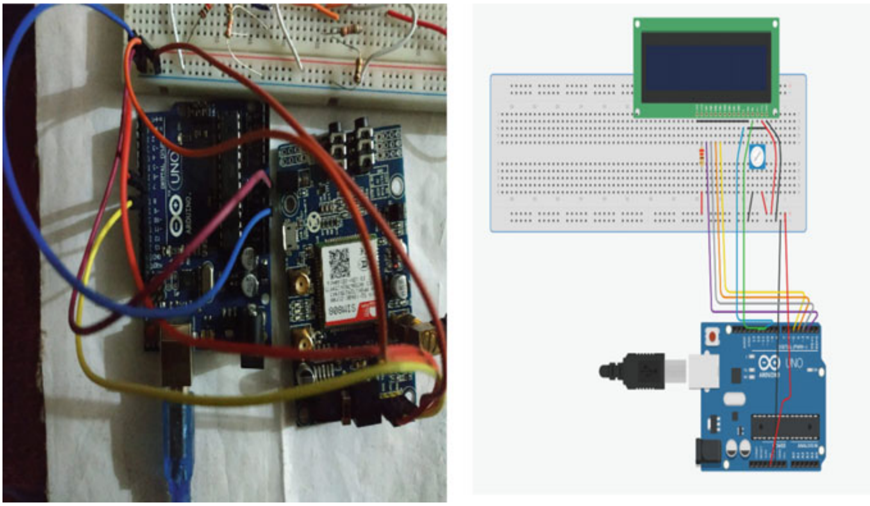
4.2 *Monitoring Unit*

Glucose value will be displayed in an LCD display for the patient (Fig. 5b) shows LCD circuit diagram); also, the value will be displayed through a smartphone application to an observer (Fig. 5a) shows GSM module circuit diagram). GSM module SIM808 v3.2 has GSM and GPRS shield. GPRS refers to General Packet Radio Ser-



(a) Receiver circuit (b) Transmitter Circuit

Fig. 4 Schematic diagram for measuring blood glucose



(a) GSM module (SIM808) circuit (b) LCD display circuit

Fig. 5 Circuit diagram for monitoring unit

vice that can be connected to the internet. Microcontroller sends the obtained value to the server using simple GET method. The Android application fetches these values from that server. When the patient's glucose value is critical, then an emergency SMS is also sent to the observer's cellular number through SIM808 GSM shield.

5 Result

From the receiver sensor, the intended signal is then converted into a voltage value and sent to microcontroller. The following equation is used to calculate the glucose value in bloodstream from the voltage obtained from the sensors:

$$y = 1398.7 * x - 2361.2 \tag{1}$$

In this equation, x is the value of obtained voltage in volt and y is the glucose value (mg/DL) [9].

Blood glucose levels have been tested by both traditional methods and with this system. Table 1 shows the comparison between the obtained test results for 20 individuals. On an average, the developed system gives almost 94.32% accuracy compared to traditional methods. From the table, the percentage error of each test of our proposed method compared to invasive method is not more than 8.56% based on the test of 20 individuals. If the percentage error for the glucose reading is within 20%, it is considered as clinically accurate [4, 9].

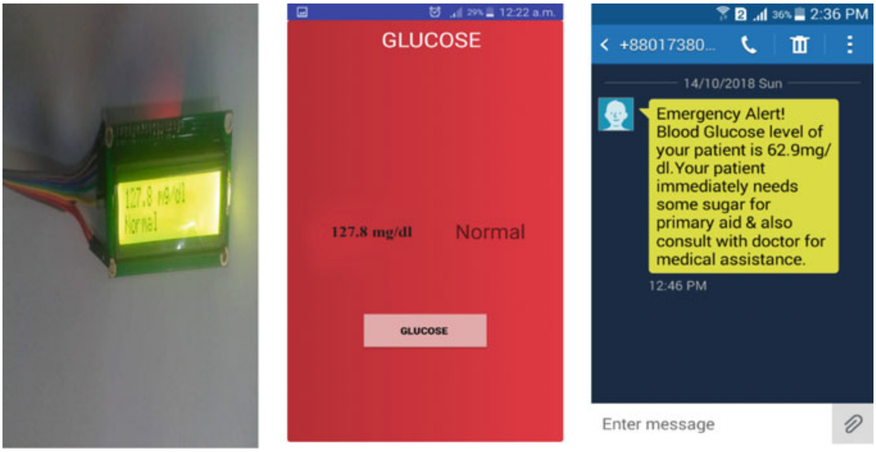
Table 1 Comparison between traditional method and our proposed system

Number of persons	Glucose level measurements		Percentage error (%)
	Traditional method (mg/dl)	D-care method (mg/dl)	
1	128.7	119.25	7.34
2	119.3	113.50	4.86
3	138.0	127.82	7.33
4	143.2	135.97	5.04
5	135.0	127.80	5.33
6	152.0	140.60	7.50
7	149.8	140.30	6.30
8	130.9	119.70	8.56
9	134.3	125.50	6.55
10	125.8	117.90	6.20
11	131.0	120.20	8.24
12	127.0	133.50	5.11
13	155.0	147.70	4.70
14	80.0	84.2	5.25
15	90.3	87.1	3.54
16	122.1	128.3	5.07
17	160.7	153.4	4.54
18	200.2	207.8	3.80
19	170.5	164.7	3.40
20	129.6	123.3	4.90

In the following table, the Percentage error is provided. The following equation is used to calculate the Percentage error:

$$Percentage\, error = \frac{D - care\, method\, value - Traditional\, method\, value}{Traditional\, method\, value} * 100\% \quad (2)$$

Figure 6a shows the glucose value in LCD that will be shown to the patient and Fig. 6b demonstrates the value in a smartphone for the observer. The developed system also transmits an emergency message when the patient's condition is critical. Figure 6c shows the emergency messaging alert. For the demonstration purpose, the glucose value has been manually entered to show the emergency message to the observer.



(a) LCD display (b) Mobile application (c) Send SMS to observer

Fig. 6 Result illustration

6 Conclusion

The IoT-based non-invasive method using Near-Infrared (NIR) is becoming a very useful option for constant glucose monitoring. As it is not painful and there is no risk for infection unlike the traditional invasive methods, more people are willing to utilize the framework. IoT has been an integral part for a number of different sectors, ranging from health care to building smart homes [17]. This proposed work can act as a multidimensional health monitoring system as it is capable of combining the monitoring functionality with feature such as notifying relevant information to the patient and the observer. The constant remote collection of the patient's glucose readings will also help any doctor to take a decision based on the patient's health, if the patient or the observer decides to discuss the obtained information with the doctor.

The obtained result might contain some errors. The system will be further developed to counter such errors and also to output more accurate value. Adding features such as diet plan for diabetes patient based on their glucose level is also another consideration for future development.

References

1. Akter S, Rahman MM, Abe SK, Sultana P (2014) Prevalence of diabetes and prediabetes and their risk factors among Bangladeshi adults: a nationwide survey. Bull World Health Organ 92(3):204–213A
2. Bangladesh: Diabetes Mellitus. https://www.worldlifeexpectancy.com/bangladesh-Diabetes-mellitus. Last Accessed 10 Oct 2018
3. Nur FN, Moon NN (2012) Health care system based on Cloud Computing. Asian Trans Comput 2(5):9–11
4. Daarani P, Kavithamani A (2017) Blood glucose level monitoring by noninvasive method using near infrared sensor. Int J Latest Trends Eng Technol 141–147
5. Saifuzzaman M, Khan AH, Moon NN, Nur FN (2017) Smart security for an organization based on IoT. Int J Comput Appl (0975 – 8887) 165(10)
6. Saifuzzaman M, Moon NN, Nur FN (2017) IoT based street lighting and traffic management system. In: Region 10 humanitarian technology conference. IEEE R10HTC, BUET, Dhaka, Bangladesh
7. Yadav J, Rani A, Singh V, Murari BM (2015) Comparative study of different measurement sites using NIR based non-invasive glucose measurement system. In: 4th International conference on eco-friendly computing and communication systems (ICECCS). Procedia computer science, vol 70. Elsevier, pp 469–475
8. Buda RA, Addi MM (2014) A portable non-invasive blood glucose monitoring device. In: Conference on Biomedical Engineering and Sciences (IECBES). IEEE
9. Rahmat MAA, Su ELM, Addi MM, Yeong CF (2017) GluQo: IoT-based non-invasive blood glucose monitoring. J Telecommun Electron Comput Eng 9(3–9):71–75
10. Saleh G, Alkaabi F, Al-Hajhouj N, Al-Towailib F, Al-Hamza S (2018) Design of noninvasive glucose meter using near infrared technique. J Med Eng Technol 42(2):140–147
11. Yadav J, Rani A, Singh V, Murari BM (2014) Near-infrared LED based noninvasive blood glucose sensor. In: International conference on signal processing and integrated networks (SPIN), Noida, India
12. Bobade CD, Patil Dr. MS (2016) Non-invasive monitoring of glucose level in blood using near-infrared spectroscopy. Int J Recent Trends Eng Res (IJRTER) 2(6),2455–1457
13. Narkhede P, Dhalwar S, Karthikeyan B (2016) NIR based non-invasive blood glucose measurement. Indian J Sci Technol 9(41):98996
14. Hotmartua R, Pangestu PW, Zakaria H, Irawan YS (2015) Noninvasive blood glucose detection using near infrared sensor. In: International conference on electrical engineering and informatics (ICEEI), Denpasar, Bali, Indonesia
15. Lawand K, Parihar M, Patil SN (2015) Design and development of infrared led based non invasive blood glucometer. In: Annual IEEE India conference (INDICON). IEEE, New Delhi, India
16. Menon KAU, Hemachandran D, Kunnath AT (2013) Voltage intensity based non-invasive blood glucose monitoring. In: Fourth international conference on computing, communications and networking technologies (ICCCNT). IEEE, Tiruchengode, India
17. Gai A, Azam S, Shanmugam B, Jonkman M, Boer FD (2018) Categorisation of security threats for smart home appliances. In: International conference on computer communication and informatics. IEEE (In Press)