ORIGINAL ARTICLE

A Real Time IOT Enhanced Glucose Monitoring System (EGMS) for Diabetes Patients

Caleb Akanbi[1,]*, and Seun Akintola[2]

[1]*Dept. of Information and Communication Technology. Osun State University, Osogbo, Osun State*

[2]*Dept. of Electrical and Electronic Engineering, Osun State University, Osogbo, Osun State*

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*Corresponding author: akanbico@uniosun.edu.ng

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Abstract: Blood glucose meter (BGM) plays a very important role in diabetes management by providing opportunity for the diabetes patients to monitor blood glucose levels from homes. The major limitation of the existing BGM is the inability to keep track of result records obtained over a long period of time due to the manufacturer threshold setup and limited memory space of the device. To provide solution, this paper presents an Internet of things (IOT) enhanced BGM system. The system design consists of Arduino Uno, INA219 Biosensor, Test Strip and Ethernet module. The software platform for this design was implemented using C Programming Language and Arduino 1.6.4 which logs test results from BGM into a remote database on the Google sheet online. Finally, appropriate testing and performance evaluation for ten patients was carried using voltage level and Blood Flow-rate metrics. The result obtained showed that this proposed system performed very well for various categories of patients.

Keywords: Arduino, Diabetes, Glucose,IoT and Healthcare application.

Introduction

Diabetes Mellitus is a chronic condition associated with an unusually high glucose (sugar) level in the blood which is a major health concern. It is commonly known as diabetes. Diabetes is widely categorized into two types: insulin-dependent diabolical diabetes (IDDM) or Type I and non-insulin-dependent diabetes (NIDDM) or Type II (IDDM). Type II diabetes represents 80% to 90% of the diabetes population as the most common account. NIDDM is less severe than IDDM in adults usually more than 35 years of age [1, 2]. Heart and kidney diseases and amputation at low extremities are just a few of the many health complications that may arise from this deadly condition. According to the World Health Organization (WHO) report, some 382 billion adults are living with diabetes in 2013. Diabetes patients were more than 422 million and more than 1.5 million deaths in 2012 which list them among the top 10 mortalities [1]

So, blood glucose levels need to be monitored continuously in patients so that they can keep the disease under control. Two major approaches have been identified to monitor the Blood Glucose Level [3]; Medical Laboratory Test (MLT) and Blood Glucose Meter (BGM) methods [3]. MLT is carried out in the hospital or Private Clinics with adequate facilities. However, the accuracy of the results obtained depend on the experts, functionality of the machines, and adequate interpretations [4]. BGM which is very handy and portable requires little technical know how and can be used at home, workplace and at any time of the day with the results obtained instantly. So, several diabetes patients have BGM monitoring devices at home for regular measurement to keep the situation under control. Once the measurement is on the high side, the patients quickly contact the medical expert for solutions [5, 6].

The major limitation of the existing BGM is the inability to keep track of results (records) obtained over several days or months. As new readings are taking, some previous ones are automatically deleted due to the manufacturer threshold setup and the limited memory space of the devices. As a result of this, Doctors or Caregivers cannot remotely monitor patient's glucose levels, particularly on real times basis. It is not scientific enough to conclude on a single or few test records or results obtained. The best practice in getting accurate result is to have a record of test results of patients over a period of time such as weekly, monthly or even yearly.

To provide solution to the limitation above, this paper presents an Internet of things (IOT) enhanced BGM. The approach adopted in this research work presents an enhanced technology for capturing an array of regular patient blood glucose test strip results obtained from BGM and regularly transmitting them to a cloud-based server for storage and better analysis on weekly or monthly bases for further medical procedures.

Literature Review

IoT can be viewed as a dynamic network where physical and virtual objects are interconnected together [7]. It encompasses advanced technologies such as wireless sensor networks (WSN), artificial intelligence, and cloud computing to plays an important role in many domains comprising of robotics, logistics, transportation, and health-care. In particular, IoT-based systems for health-care consisting of sensors, WSN, smart gateways, and cloud based server to provide remote and real-time e-health monitoring [8, 9, 10, 11]

IoT architecture offers specific object identification, sensor and connection capability as the basis for the development of independent cooperative services and applications. Utilizing the power of wireless adhoc [12],sensor networks[13], latest technologies like fog computing and smart devices [1]. Between 1991 and 2000, small meters appeared in the health sector. Glucose was one of the most commonly measured analytes in clinical units, primary care and patients for monitoring home, because systems based on dry reactant test strips and/or easy-to-use reflectance meters and biosensors were available.

However, an important setback in the blood glucose system of the first generation was operating-dependent steps that enabled misleading results to be obtained that adversely affected treatment [13]. These problems were mainly in the production of adequate blood volume, inaccuracies in the timing and blood removal of the test strip, inexact wiping technique, miscoding and calibration errors, maintenance deficiencies and quality control procedures. In view of these concerns, many companies developed systems that removed these operator-dependent steps or minimized them.

[14] proposed a Cloud based system for the diagnosis of diabetes mellitus using K-means clustering algorithm. This proposed cloud architecture uses Hadoop big data framework couple with machine learning clustering technique to handle the challenges of mining useful information from the huge healthcare dataset. This system predicts the event of diabetes under different conditions and furthermore compares which of the two clustering techniques (k-means and hierarchical clustering algorithm) used gives better result based on performance, runtime and quality. The gender, age and family is among other features of the dataset are explored. The outcome shows that, more people within the age bracket of 45–64 are diagnosed with diabetes similarly, hypertension and work nature also contribute significantly in affecting the people.

An IoT based system for Diabetic Retinopathy diagnosis was introduced by [15]. The proposed methodology estimates glucose level in the blood through sensors on diabetic patients. Internet of Things (IoT) platform suggest a workable solution to Diabetic Retinopathy in order to save patient from vision loss based on sensor's reading,. The body sensor safely move data with IoT platform to the mobile apps so as to collaborate with each other. This platform continuously collect large amount of data from the sensor and IoT device and store it securely in the database.

[16] proposed a remote IoT-based system for real-time constant glucose monitoring. With this system, healthcare providers; doctors and caregivers using their smart phone and web browser can observe their patient whenever and at any place. Nodes of the sensor obtain many types of data (for example blood glucose level, body temperature and other environment data) and send the data remotely to the gateway efficiently in term of energy consumption. With the help of the adapted RF receiver, smart phone of patients' provides a platform for data reception from sensor hubs. Not only that, the gateway couple with its application also provides advanced services to users, such as a notification service. The outcome demonstrated that it is possible to remotely monitor glucose constantly and continuously also, the system can be made to be energy efficient.

[17] proposed a system for diabetes and cardiovascular ailment diagnosis using advanced conceptual diagnosis method, smart data mining and IoT (SMDIoT) based system. When IoT and data mining are hybridized with some other emerging computing techniques, this is supposed to give a more effective and economical solution to diabetic and cardio patients. The bio-sensors of the proposed system will help with getting the present and exact status of the concerned patients, if there should be a crisis, the needed medical help can be given [18]. Sufficient support of Chabot, granular computing, context entity search, semantic analysis and the hybrid framework of data mining and IoT are where the innovation lies. The system performs to be more

functioning and cost-effective answer for diabetes and cardio patients.

[19] revealed that cloud computing technology could be employed in order to predict and diagnose several ailments such as diabetes using fuzzy neural classifier by processing massive data from IoT devices used in healthcare environment. This method is utilized for the diabetes ailments and the related medical information is generated by utilizing the UCI Repository dataset and the medical sensors for predicting the people who are severely affected with diabetes. A new classification algorithm called “Fuzzy Rule based Neural Classifier” for diagnosing the disease and the severity was also proposed. The experimental results demonstrated that the performance of the proposed work outperforms the existing systems for disease prediction.

[20] proposed Internet of Things (IoT) based system for checking and identifying people affected with stroke. Sensors (Arduino Mega microcontroller, Pressure sensor, Heartbeat sensor, Sugar sensor) are used to collect patients’ health parameters which are transformed into scale and sent to cloud for storage, these parameters are then analyzed using machine learning classification algorithm. The prediction system receives the critical data, sees this input as test data and use it to predict whether the patient is having high risk of stroke or not. A notification email and short message service is sent to notify the healthcare provider if there is any modification in the vital signs. At whatever point the serious condition occurs, the chances of occurrence of the disease was predicted by the system which allows doctor to take necessary action. Machine learning classification algorithm was used to analysed the patients’ health parameters.

[21] explained that for a series that used glucose oxidase or GDH catalyzed reactions, Bayer branded its glucometers as Ascensia. Autodisks were used rather than streaks by the Ascensia Breeze (2003) and a 2-2 μL autocalibration sample. Ascensia Breeze II (2007) only needed 1μL of sample with a fast response and a more sophisticated data administration system [22].

[23] presents a non-invasive measurement of blood glucose based on near infra-red (NIR) optical technique. This has an advantage of the relief from the pain due to finger puncturing in invasive methods. The non-invasive method monitoring glucose reduces the challenges faced in glucose measurement thus reduces the cost of healthcare. An example of this method is the IR spectroscopy which is popular, but method with a reliable result has not been established yet.

A system of monitoring of type 2 diabetes mellitus is introduced by [24]. The system can determine the status of diabetes control and predict future glucose for a person. Medical personnel can remotely monitor the glucose data obtained from a wide range of networks. [25] Critical cardiac patients have a CGM system in the Intensive Care Unit. For the system, the device includes a single, subcutaneous glucose sensor, a glucose client and a server. The system collects and stores glucose data in a hospital information system four times a day. Doctors may use a bedside monitor to monitor the glucose data.

[7] proposed the Bluetooth low-energy (BLE) implantable glucose monitoring system. The system collects glucose via BLE, which represents the data received for visualization in the text form, to the PDA (SmartPhone or Ipad).

Although previous studies showed their advantages in continuous glucose monitoring, they do not have capacity of storing the test result data over a long period of time. The main motivation of the paper is to provide an enhanced IoT-based system for real-time and remote continuous monitoring glucose contextual data for several months.

Methodology

System Design

This study presents an amperometrical method -an electrochemical diagnostic border, which uses glucose oxidation enzymes, for measuring blood glucose (BGM). The enzyme becomes active catalytically when a blood sample is applied, and electrons transmitted to the electrode biosensor by the mediator. The electric signal is transformed to Arduino UNO via INA219 and displayed with the LCD module.

Fig. 1 presents the system conceptual design comprising five major modules: Sensors, Arduino and Ethernet modules, the cloud server, the Android Application and the data base.

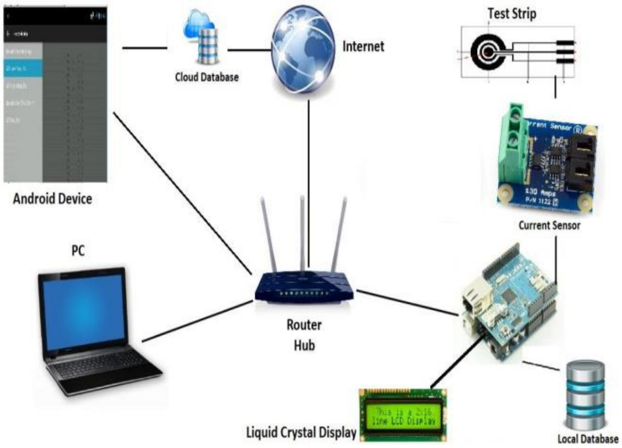

Fig 1. Proposed IOT Enhanced Glucose Monitoring System.

The circuit diagram is shown in Figure 2. The glucose sensor (test strip) is an electrochemical strip that oxidizes enzymes with glucose. The blood sample transfers the electrons to the electrode when the enzyme is catalytically active. A test strip then generates a few but significant amounts of current from the working electrode (WE) to the counter electrode (CE) during contact with blood. Each time a drop of blood is applied to electrodes, the amount of current that flows depends on the blood glucose level. However, with an analog input from an Arduino a current sensor (INA219) is so small and almost unmeasurable when it first interfaces the test strip as an amplifier. INA219 is a power monitor with an I2C interface and a high-sided shunt.

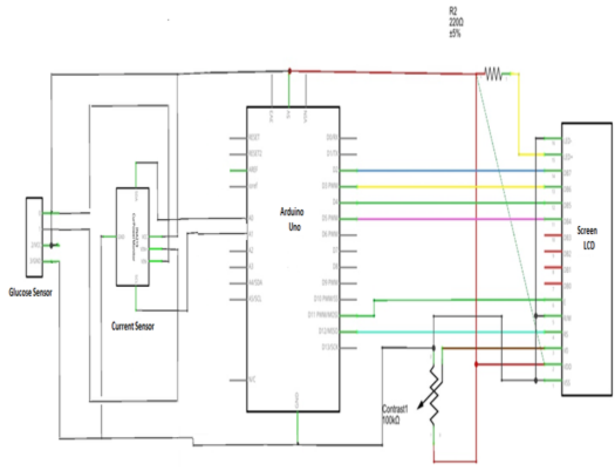

Fig 2. Proposed IOT Enhanced Glucose Monitoring System.

With its programmable conversion time and filtering, the INA219 monitors the down sizing and supply voltage. The combination with an internal multiplier, a programmable calibration value allows for direct read-up in amperes. An additional register of multiplicators which calculates watts power. 16 programmable addresses are provided on the I2C interface. On buses can vary between 0 and 26 V, the INA219 senses over shunts.

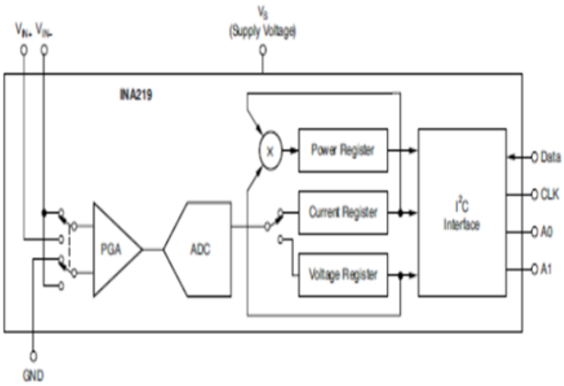

Fig 3. Current sensor pin connection INA219

The unit uses one single supply from+ 3V until + 5.5V with a maximum current of 1mA. INA219 works between + 125 ° C and-40 ° C. The INA219 current sensing pin connection is given in Figure 3.

Amplified output signal from the current sensor is in turn passed into the analog input of the Arduino. The Arduino board which has an AMD microcontroller, processes the input signal using Analog Digital Controller (ADC) feature of the controller. The Arduino is serially connected to the display unit which is mainly made of the Liquid Crystal Display LCD. The result of each test taken is first displayed on the LCD. The metrics and formula for calculating and converting to digital value of the input (eAG) is expressed in equation (1) and (2) as.

$$A1C\ (mmol/L) = (2.59 + average\_blood\_glucose) / 1.59 \quad (1)$$

$$eAG\ (mmol/l) = 28.7 \times A1C - 46.7 \quad (2)$$

Where A1C *is* the percentage of all hemoglobin that is glaciated and eAG is the estimated average glucose.

After the computation by the microcontroller, the result is first stored into a temp database, displayed on the LCD screen of the system. Later on, the Arduino checks for internet connectivity by pinging an address through the Ethernet module interfaced with it. After successful connection to the internet, the Arduino sends the data measure and the time of measurement to a remote server which in turn logs it into a remote database designed for this purpose. To finally present the result intelligently to the user for smart view, an android device collects data already stored on the Google sheet online and then sent and stored to the app on request.

Design Implementation:

The microcontroller Arduino UNO is the brain of the system for programming. Using USB or external power supply, the UNO is connected automatically the source of power . Either an AC-to-DC adapter (wall-wart) or a battery supplied with external (NON-USB) power. In this prototype system, temporary connections were made using jumper wires and minimal soldering. The Arduino contains a 256 kb memory to hold data temporarily as long as the power is on and an EEPROM to store data temporarily even after OFF power has been switched. This function of the Arduino board micro-controller is accessed and used until there is an internet connection to each test result in the Arduino memory. The results are sent to the on-line server by first verifying the Internet connection and availability of the remote server via http. By pinging the public IP and calling the server's web address, the result and other test parameters, such as the time of test, meal time etc are sent to the remote server.

The server end results are then saved in a SQL database for this purpose. The database has only one table containing every entry detail. In the table, the columns indicate: SNO (for serial no.), test result, test time, AML (for meals), and test int (for tests). The data records in the database are accessed via a call to the getrecs.php script on the server on any mobile device running this application. On request, a query such as' SELECT* FROM's' records' WHERE' test time' <' 10-06-2018' is running. The output from the database containing all records is then returned to the Android device, which is waiting for the server to respond. This results are displayed immediately on the app and stored on the Android device in an Android local SQL database for easy access even if there is no internet connection until record updates or log-syncs to the online server are necessary.

As shown in Figure 4, for easy carriage, a small, smoothly plastic case was used for insertion of LCD, cables and strip holder and the Arduino UNO components.

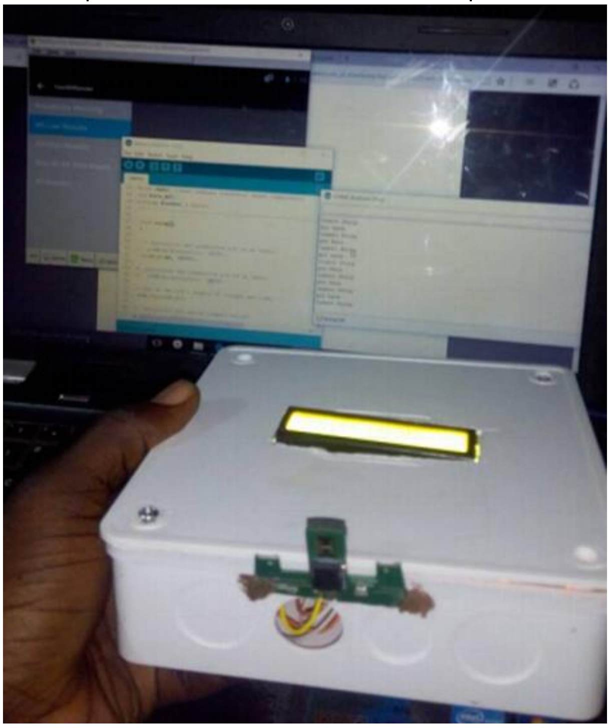

Fig 4. Proposed System Implementation Package.

System Testing and Performance Evaluation

System Testing

Testing of this system starts with the system setup where required constants are specified. It noteworthy that the glucose measurements before and after meal slightly varies irrespective of the actual level of blood glucose. This is because the food intake increases the level of blood glucose immediately after meal, which could thereby give misleading results. This is therefore taken care of by system. User is therefore always prompted to indicate if the current measurement is taken before or after meal.

The system was programmed with a loop class where the Arduino continuously checks if a new test strip has been inserted. In a small opening on the frontage of the instrument, the test strips are inserted (the strip form is designed to prevent incorrect insertion). The band's electrochemistry is the key to the glucose sensor's operation. The strip is inserted into the outer portion of the device with the following three electrodes: WE, RE, CE which stand for Working Electrodes, Reference Electrodes and Counter Electrodes respectively.

Once the Arduino detects the test strip, the current flows through the working electrode to the current sensor and then to the analog port of the Arduino. Also, in this work, the analog value received at the analog port of the Arduino is scaled based on available information online. This is however inaccurate but the result is linearly proportional to the level of glucose in the blood tested.

Finally, this result is displayed on the LCD and sent to the Google script for populating our database of results. The android application is designed to continuously check for any new result from cloud, as soon as a new measurement is pushed to the cloud, it is immediately available for download and use by the mobile device. However, an additional feature of refresh to immediately download updated records from the cloud. The system was also connected to the laptop for serial monitoring of the activities and to fine tune the result. The test was conducted on six different patients for a period of 9 days. The result obtained is as expressed in figure 5. The results obtained were based on the random tests performed on some patients before and after meals.

Performance Evaluation

Fig 5: Result of Glucose level Test Conducted

To carry out performance evaluation for this study, two major metrics are considered, these are voltage level(v) obtained and Blood Flowrate (mg/dL). Blood samples of 10 Patients between age of 12 and 60 were tested on this developed system. The results obtained are represented in Table 1 and figure 6. From the analysis, the voltage level for children between ages of 10 to 18yrs, the voltage level started decreasing from 18ys to 30 yrs.

Above age of 30yrs to 52 yrs., the voltage level start increasing again. The higher the level of voltage level, the better the glucose content in the body for this age range. Therefore, glucose content is higher in adult between ages of 18 to 30yrs. Once the ages is more than 52yrs, the voltage level start decreasing.

PATIENT	AGE (YEARS)	VOLTAGE LEVELS (V)
1	12	0.987
2	18	0.990
3	23	0.765
4	29	0.729
5	34	0.860
6	39	0.867
7	44	0.874
8	52	0.879
9	60	0.758
10	77	0.679

Table1: Performance Analysis of Glucose Level Based on Voltage Level

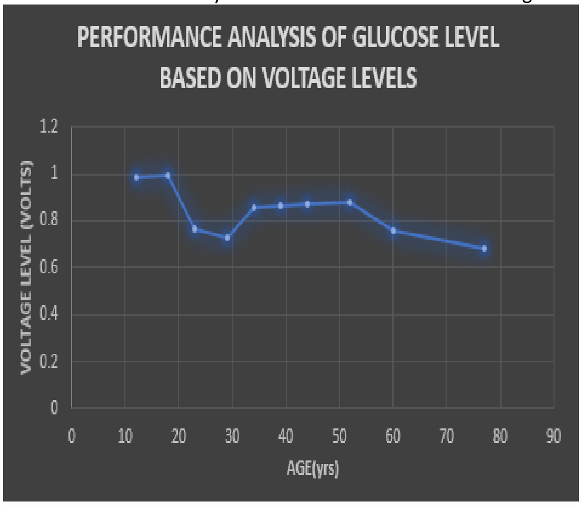

Fig 6: Performance Analysis of Glucose Level B ased on Voltage Level

The glucose content is identical in ages above 30yrs to 52yrs and started reducing above 52yrs. Glucose content is negligible in small children under ages of 18 yrs.

Table 2 and figure 7 showed the result of Blood Flowrate (mg/dL) for the ten patients in the proposed system. Based on the analysis, the higher the blood flow rate in human body, the better the glucose content. There is higher blood flow rate from 80mg/dl to 93mg/dl for ages from 29 to 52 yrs. Blood flow rate reduces from age of 52yrs. therefore, higher glucose content is abnormal in human body above age of 52yrs.

PATIENT	AGE (YEARS)	Blood Flowrate (mg/dL)
1	12	84
2	18	86
3	23	81
4	29	79
5	34	85
6	39	87
7	44	91
8	52	93
9	60	52
10	77	46

Table 2: Performance Analysis of Glucose Monitoring based on Blood Flow-rate

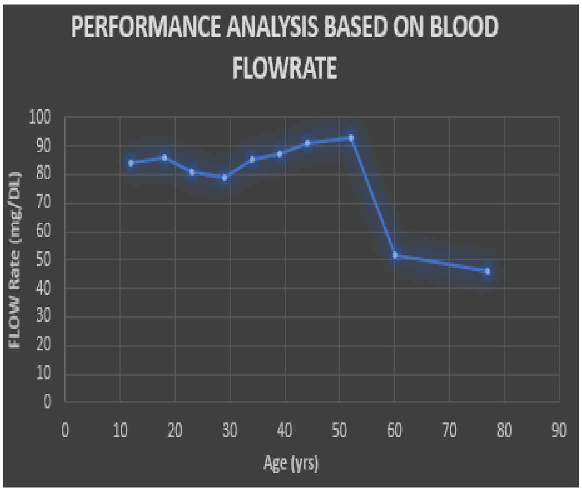

Fig 6: Performance Analysis of Glucose Monitoring based on Blood Flow-rate

Conclusion

The Arduino Uno-based system was used in this research to determine the approximate glucose concentration in the blood by using its hardware and software features. To monitor blood glucose levels, we used Biosensor. The software platform for this design was implemented using C Programming Language and Arduino 1.6.4. In this research work, we use test strips, which interact with the elements on the strip that cause a reaction and generate the electric when a drop of blood is placed on the test strip. The current is transmitted to INA219 and converted to voltage.

This voltage is sent to Arduino for further processing and LCD displays to make the result visible which logs test results from BGM into a remote database on the Google sheet online. As a recommendation for further research or development in this field, a design consideration could be made for patient who wants to avoid the pain of getting blood; a system could be designed to analyse and measure the ketone level of the patient's urine. This prototype design could be taken to the industry for mass production in the market as an alternative to the existing glucose meter.

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