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IoT-based continuous glucose monitoring system: A feasibility study

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Abstract

Health monitoring systems based on Internet-of-things (IoT) have been recently introduced to improve the quality of health care services. However, the number of advanced IoT-based continuous glucose monitoring systems is small and the existing systems have several limitations. In this paper we study feasibility of invasive and continuous glucose monitoring (CGM) system utilizing IoT based approach. We designed an IoT-based system architecture from a sensor device to a back-end system for presenting real-time glucose, body temperature and contextual data (i.e. environmental temperature) in graphical and human-readable forms to end-users such as patients and doctors. In addition, nRF communication protocol is customized for suiting to the glucose monitoring system and achieving a high level of energy efficiency. Furthermore, we investigate energy consumption of the sensor device and design energy harvesting units for the device. Finally, the work provides many advanced services at a gateway level such as a push notification service for notifying patient and doctors in case of abnormal situations (i.e. too low or too high glucose level). The results show that our system is able to achieve continuous glucose monitoring remotely in real-time. In addition, the results reveal that a high level of energy efficiency can be achieved by applying the customized nRF component, the power management unit and the energy harvesting unit altogether in the sensor device.

Keywords: Internet-of-Things, wearable, health monitoring, energy harvesting, energy efficient, power management, glucose monitoring

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1. Introduction

Internet of Things (IoT) can be viewed as a dynamic network where physical and virtual objects are interconnected together[1]. IoT encompassing advanced technologies such as wireless sensor networks (WSN), artificial intelligence, and cloud computing plays an important role in many domains comprising of robotics, logistics, transportation, and health-care. For instance, IoT-based systems for health-care consisting of sensing, WSN, smart gateways, and Cloud provide a way to remote and real-time e-health monitoring.

Advances in WSNs have created an innovative ground for e-health and wellness application development. Ambient assisted living, ambient intelligence, and smart homes are becoming increasingly popular[2]. These can be combined to other health solutions such as fitness and wellness, chronic disease management and diet or nutrition monitoring applications. The new initiatives tend to be integrated into the patient information ecosystem instead of being sepa-

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rated into monitoring and decision processes. There are potential benefits to ageing population, where elderly people could be monitored and treated at the comfort of their own homes.

Fully autonomous health monitoring wireless systems can have many useful applications. Among those applications is glucose level measurement for diabetics. Diabetes is a major health concern. According to a WHO report, the number of people with diabetes has exceeded 422 millions and in 2012, over 1.5 million people died because of diabetes. The WHO classified diabetes as a top ten causes of mortality. Diabetes has serious effects on the well-being of a person and the society. Unfortunately, there is still no known permanent cure for diabetes[3]. However, one solution to this problem is to continuously measure blood glucose levels and close the loop with appropriate insulin delivery. Statistics published by the UK Prospective Diabetes Group demonstrate that CGM can reduce the long term complications between 40 % and 75 %.[4]. Hence, CGM equipped with alarm systems can help patients to take corrective action(s) such as decisions on their diet, physical exercise and when to take medication.

Energy harvesters incorporated into wearable devices allow powering wireless sensor operated applications , thereby making them autonomously operated. This regime has many useful implications on patients and heath-care providers, specially for implanted sensors where battery changing could cause pain and discomfort. Cautious design of both low-power electronic circuitry and efficient energy harvesting scheme is pivotal to fully autonomous wearable systems.

In this paper, the presented work aims to study the feasibility of invasive and secure CGMS using IoT. The work is to design an IoT-based system architecture from a sensor device to a back-end system for presenting real-time glucose, body temperature and contextual data (i.e. environmental temperature) in graphical and text forms to end-users such as patient and doctor. Moreover, the work customizes the nRF communication protocol for suiting to the glucose monitoring system and achieving a high level of energy efficiency. Furthermore, we investigate energy consumption of a sensor device and design energy harvesting units for the device. Finally, we present a push notification service for notifying patient and doctors in case of abnormal situations such too low or too high glucose level. In summary, our main contributions in this paper are as follows:

- proposing continuous glucose monitoring IoT-based system
- designing an energy efficient sensor device using nRF protocol
- designing an energy harvesting unit for the sensor device to extend the sensor device's battery life

The remainder of the paper is organized as follows: In section 2 related works are presented. Section 3 presents the continuous glucose monitoring IoT-based system architecture. In section 4, an implementation of the glucose monitoring system is shown. In section 5, experimental results are discussed. Section 6 concludes the work.

2. Related works

Many research applications in glucose monitoring are not based on IoT-based architectures. Correspondingly, doctors or caregivers cannot monitor glucose levels of a patient remotely in real-time. Murakami et al.[5] present a CGM system in critical cardiac patients in the intensive care unit. The system is built by a disposable subcutaneous glucose sensor, a glucose client, and a server. The system collects glucose data four times per day and stores in a hospital information system. Doctors can use the bedside monitor to monitor the glucose data.

Ali et al.[6] propose a Bluetooth low energy (BLE) implantable glucose monitoring system. Glucose data collected from the system is transmitted via BLE to a PDA (smart-phone, or Ipad) which represents the received data in text forms for visualization. The system shows some achievements in reducing power consumption of an external power unit and an implantable unit.

Lucisano et al.[7] present a glucose monitoring in individuals with diabetes using long-term implanted sensor system and model. Glucose data is sent every two minutes to external receivers. The system shows its capability of continuous long-term glucose monitoring. In addition, the system proves that implanted sensors can be placed inside a human body for a long period time (i.e. 180 days) for managing diabetes and other diseases.

Menon et al.[8] propose a non-invasive blood glucose monitoring system using near-infrared (NIR). Glucose in blood is predicted based on the analysis of the variation in the received signal intensity obtained from a NIR sensor. The predicted glucose data is sent wirelessly to a remote computer for visualization.

Recently, some IoT-based applications for glucose monitoring have been built. However, those systems do not attentively consider energy efficiency of sensor nodes and the communication between sensor devices and a gateway. Rasyid et al.[9] propose a blood glucose level monitoring system based on wireless body area network for detecting diabetes. The system is built by using a glucometer sensor, Arduino Uno, and a Zigbee module. Doctor and caregiver can access to a web-page to monitor glucose levels of a patient remotely. However, the system is not energy efficient due to high power consumption of the Arduino Uno board and the Zigbee module.

Wang et al.[10] introduce a monitoring system for types 2 diabetes mellitus. The system is able to make decision on the statues of diabetes control and predict future glucose of an individual. Obtained glucose data can be monitored remotely by medical staffs via wide area networks.

Although these systems show their advantages in continuous glucose monitoring, there are still many limitations. For example, some systems do not consider real-time and remote monitoring while other systems do not pay attention on energy efficiency sensor devices/nodes. In addition, they are not able to inform to medical doctors in real-time in cases of emergency.

The main motivation of the paper is to provide an advanced IoT-based system for real-time and remote continuous monitoring glucose, contextual data, and body temperature. The differences between our work and others are energy efficient sensor devices integrated with an energy harvesting unit, a power management unit and an ultra low energy nRF wireless communication, together with dedicated gateways equipped with advanced services such as push notification for real-time notifying both doctor and patient in case of abnormality.

3. System architecture

In the furtherance of providing continuous glucose monitoring in real-time locally and remotely, the CGMS architecture shown in Fig .1 is based on an IoT architecture. The system includes three main components such as a portable sensor device, a gateway and a back-end system.

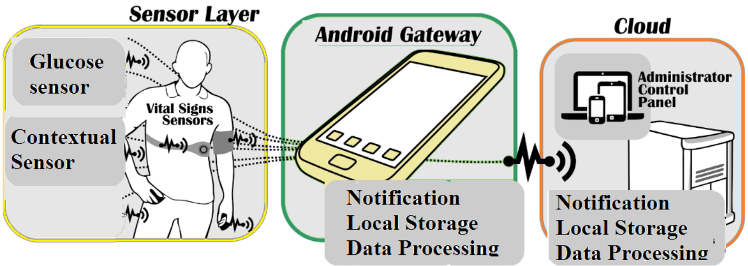


Fig. 1: Continuous Glucose Monitoring using IoT

3.1. Sensor device structure

The sensor device whose structure is shown in Fig .2 consists of primary component blocks such as sensors, a micro-controller, a wireless communication block, energy harvesting and management components. The micro-controller performs primary tasks of the device such as data acquisition and transmission. Therefore, it consumes a large part of the device's total power consumption. Reducing power consumption micro-controller can save a lot of power consumption of the device. The ultra low power micro-controller capable of operating with sleep modes is a suitable candidate for the target. In the device, the micro-controller receives glucose data from an implantable glucose sensor via a wireless inductive link receiver while it collects environmental and body temperature via data link wires such as UART, SPI or I2C. In the system, SPI is more preferable due to its lowest power consumption between these interfaces[11].

The nRF wireless communication block is responsible for transmitting data from the micro-controller to the gateway equipped with an nRF transceiver. The block includes a RF transceiver IC for the 2.4GHz ISM band and an embedded antenna. Due to 2Mbps supporting, nRF completely fulfills the requirements of transmission data rates in a CGM system. Transmission data rates of nRF can be configured for achieving some levels of energy efficiency. For example, instead of using 2Mbps, a data rate of 256kbps can be used for saving power when sending glucose, temperature, and contextual data. In addition, nRF is capable of both short and long range transmission from a few centimeters to a hundred of meters. Depending particular applications, the transmission range and transmission power can be configured. With a short range communication, nRF consumes lower energy.

In the sensor node, the energy harvesting unit and the power management unit described in the followings are two of the most important components because they directly impact on energy consumption and an operating duration of the sensor node.

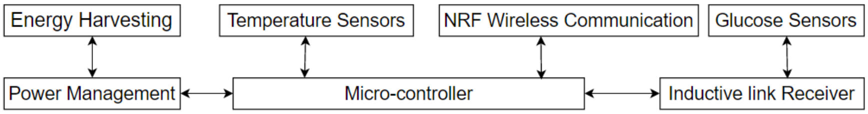


Fig. 2: Portable sensor device structure

3.1.1. Energy harvesting unit

The exponential advancements in WSNs, WBANs and the emerging field of IoT have opened the doors wide for numerous intelligent applications. Unfortunately, this development is not reflected at the battery capacity side. A major limitation of untethered nodes is a limited battery capacity which limits the operation time of the nodes. The finite lifetime of a node implies the nite lifetime of the applications or additional costs and complexity to regularly

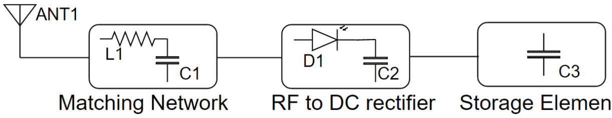


Fig. 3: RF energy harvesting system

change batteries. Nodes could possibly use large batteries for longer lifetimes, but will have to deal with increased size, weight and cost. Nodes may also opt to use low-power hardware like a low-power processor and radio, at the cost of lesser computation ability and lower transmission ranges. Several solution techniques have been proposed to maximize the lifetime of battery-powered sensor nodes. Some of these include energy-aware MAC protocols, power aware storage, routing and data dissemination protocols, duty-cycling strategies, adaptive sensing rate, tiered system architectures and redundant placement of nodes. While all the above techniques optimize and adapt energy usage to maximize the lifetime of a sensor node, the lifetime remains bounded and finite. The above techniques help prolong the application lifetime and/or the time interval between battery replacements but do not preclude energy related inhibitions[12].

Energy harvesting could be a solution to the above mentioned dilemma. Energy harvesting refers to harnessing energy from the environment or other energy sources (body heat, foot strike, finger strokes) and converting it to electrical energy. If the harvested energy source is large and periodically/continuously available, a sensor node can be powered perpetually. Energy sources can be broadly classified into the following two categories, (i) Ambient Energy Sources: Sources of energy from the surrounding environment, e.g., solar energy, wind energy and RF energy, and (ii) Human Power: Energy harvested from body movements of humans. Passive human power sources are those which are not user controllable. Some examples are blood pressure, body heat and breath. Active human power sources are those that are under user control, and the user exerts a specific force to generate the energy for harvesting, e.g., finger motion, paddling and walking. No single energy source is ideal for all applications. The choice depends on every applications requirements and constraints.

To power the glucose sensor node a combination of ambient and human powered sources is selected. Due to its ubiquitous availability RF energy is an adequate source for this application. Also, since the sensor is mounted on human body it makes sense to exploit this medium a source of energy. Through the use of a Thermoelectric Generator (TEG), thermal energy can be converted into electrical energy. The conversion process is based on the See-beck effect where electricity can be generated from the temperature gradient across two conductors connected together. In this paper the RF energy harvesting system is presented, thermal energy harvesting will be integrated into harvesting in future work.

The RF energy harvesting system illustrated in Fig. 3 is designed . A first step in designing the RF energy harvesting system is deciding on the frequencies at which power will be harvested. The wireless spectrum is full of signals with different frequencies and power levels, ranging from cellular standards, WLANs and TV signals. The criteria that control the selection of certain frequencies for the purpose of energy harvesting are wide deployment and power level. GSM 900/1800 and DTV signals cover most of the world. Thus it is almost guaranteed that GSM signals would be available wherever the harvesting system is placed. On the other hand, the power level of GSM signals can be very low reaching -102 dBm at receiver sensitivity, and transmitting power of DTV stations can be as high as 70 dBm[13]. Wi-Fi and Bluetooth signals abounds in urban environments, hence they can be exploited as well. A miniaturized printed elliptical nested fractal multiband antenna (PENF) was designed for this purpose in[13]. The proposed antenna covers GSM 900, 2.4 GHz Bluetooth/WLAN, 3.2 GHz (Radiolocation, 3G), 3.8 GHz (for LTE, 4G) and 5 GHz Wi-Fi bands. The antenna was designed and fabricated using FR4 substrate. The measured radiation patterns of PENF antenna in different planes verify the omni-directional feature of the proposed antenna. This feature is of interest in RF energy harvesting applications to receive the ambient signals from all directions.

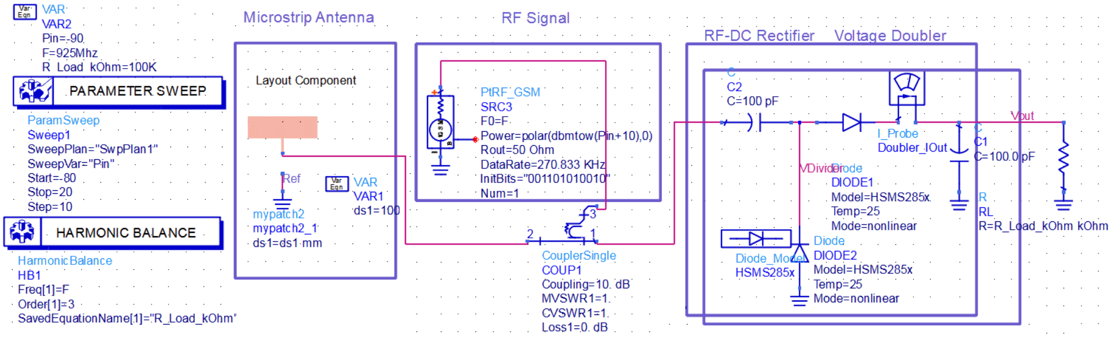


Fig. 4: RF-DC rectifier schematic and test bench

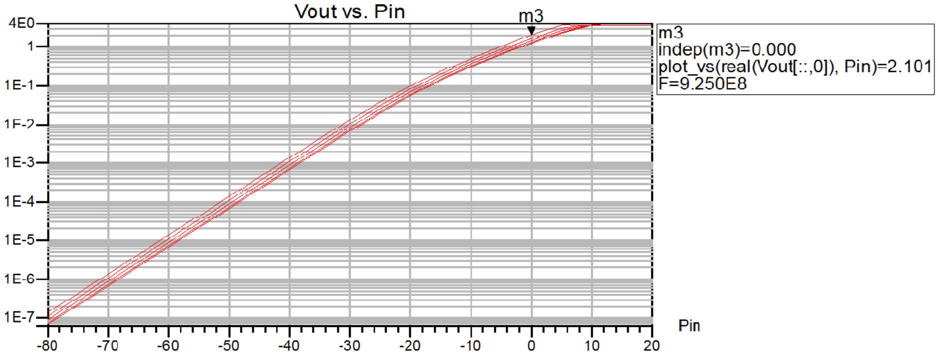


Fig. 5: Rectifier output voltage Vs. input power level

Due to their low forward voltage drop Schottky diodes are used in designing the rectifier and voltage doubler circuits. A Schottky diode is a rectifying metal semiconductor junction which is fabricated by depositing an n-type or p-type semiconductor material on a variety of metals. While the threshold voltage of a P-N diode is around 0.6 V to 0.7 V, Schottky diodes can achieve similar performance at lower threshold levels (0.2 V to 0.3 V). Fig. 4 illustrates the RF-DC rectifier schematic and test bench used in evaluating its performance. The rectifier unit itself shown at the right corner of Fig. 4 consists of a single unit voltage doubler constructed using a non-linear model for HSMS285 Schottky diode. Using a single patch antenna integrated into the schematic as a layout component is tested. At 925 MHz RF input signal, the corresponding output voltage for a wide range of input power levels is shown in Fig. 5. The sensor node constructed at this work requires 2 volts input for proper operation, the RF energy harvesting system designed was able to achieve this voltage at 0 dBm input power which corresponds to 1 mW.

3.1.2. power management unit

In battery powered wireless sensor network, the sensor goes to the idle status to prevent power draining. However, in case the sensor receives an incoming message (packet), the sensor should go from idle to active status. Duty-cycling is an efficient approach that reduces idle-mode power consumption[14]. There are three-types of duty cycling: (I) synchronous, (II) pseudo-synchronous and (III) asynchronous. The latter scheme has the lowest power dissipation.

A number of circuit techniques have been proposed to implement the wake-up unit. In [15], the author laid the foundation for radio-triggered wake-up circuit. The circuit consists of passive components (antenna, resistance, diode, capacitance and inductance). The circuit has low-sensitivity and may cause false wake-up.

The authors of[16] describe a dual source energy scavenging circuits for wireless sensor network. The power management system is composed of both a radio-triggered wake-up circuit and a voltage sensor. The latter pushes the sensor into a sleep-mode should the voltage level across the storage capacitor drops below a predefined voltage level. The wake-up circuit is implemented using a low-power Schmitt trigger circuit. The voltage sensor is implemented using a differential amplifier with positive feedback.

3.1.3. Proposed power management unit

The communication between the sensor and the gateway is quasi-unidirectional in which the information is relayed from the sensor towards the rest of the system. This unique characteristics makes the need for a radio-triggered wake-up circuit. However, the power management unit for the sensor needs to efficiently use the collected energy. To prevent an abrupt shutdown and to enable a better resource utilization, in case the power management unit descries insufficient amount of energy in the capacitor, drives the sensor into a deep-sleep mode and grants the energy scavenging unit enough time to charge the capacitor.

The core of the power management unit is the voltage sensor, which can be realized using the low-power Schmitt trigger circuit reported in [17]. Fig. 6 details the transistor level circuit for the PMU.

3.2. Gateway and back-end structure

Similar to conventional gateways in IoT systems, the proposed gateway collects data from wireless sensor devices and transmits the data to Cloud servers. The gateway performs its tasks by using a nRF transceiver and a wireless IP-based transceiver (i.e. Wifi, GPRS or 3G). The nRF transceiver, which is a plug-able component, is compatible with all types of smart devices (i.e. Android, Iphone, tablet). It is possible to use smart phones and fixed gateways as the system gateways. However, in this work, gateways based on smart-phones are more focused. The nRF transceiver consists of a micro-controller and a low power RF transceiver IC, and a FTDI component. The micro-controller and the nRF components are the same as the ones used in the sensor device. The FTDI chip is used for converting from an UART connection to an USB connection. All physical connections of an nRF component and a smart phone (Android) are shown in Fig.7.

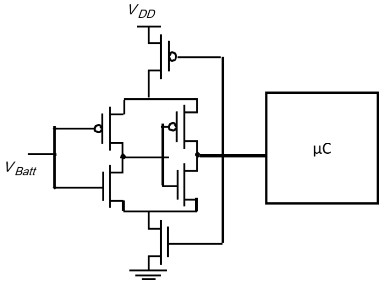


Fig. 6: Power Management unit using Schmitt triger circuit proposed in [17]

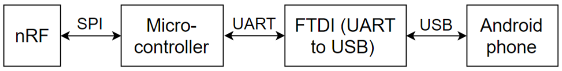


Fig. 7: Android gateway structure

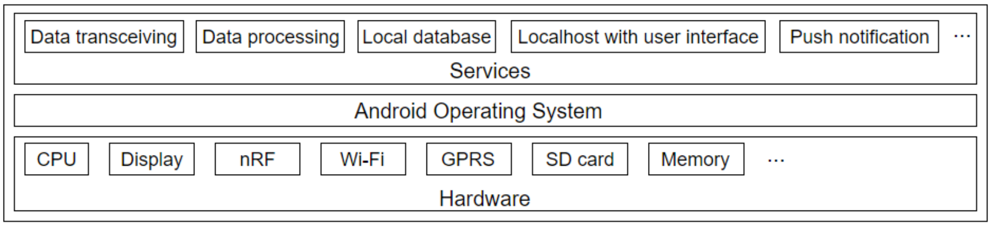


Fig. 8: Gateway operating structure

In addition to mentioned tasks, the gateway provides advanced services such as data processing, local database, local host with user interface and push notification shown in Fig.8. For example, the collected data might consist of noise and corrupted data. In order to provide a high quality of data, the noise and corrupted data must be filtered. In the gateway, the data processing unit not only performs filtering tasks but also run algorithms to process data such as decision making and categorization of diabetes statuses.

Local database in the gateway consists of an intact database and a real-time database. The intact database stores algorithms' information and configuration data while the real-time database is used for storing e-health and contextual data. Therefore, the intact database is only used for internal usage and managed by system administrators while the real-time database is regularly updated and synchronized with Cloud's database. Due to a small amount of collected data (i.e. 4-8 samples per 10 minutes), local database can store the data during a long period of time (i.e. several days) before getting full.

By supplying a local host with user interface, real-time data can be monitored directly from the gateway without requiring Cloud servers. In this case, this helps to eliminate an unnecessary latency of transmitting and receiving data to and from Cloud, respectively.

In the gateway, decision making and push notification services work together to provide real-time notifications to doctors or caregivers. For example, when a monitored glucose level is higher and lower than an acceptable level, the decision making service triggers the push notification to send messages for notifying a doctor in real-time. The back-end part comprises of Cloud and an user accessible terminal. Doctor can access real-time data in Cloud remotely via a web browser or a mobile application.

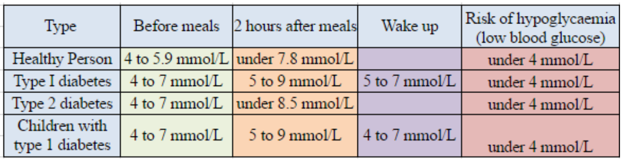
4. Implementation

With the purpose of evaluating feasibility of the CGM system using IoT, the entire system shown in Fig. 1 is implemented. First, the interaction of the biological tissue under investigation is studied. Since the glucose sensor will be subcutaneous, the electrical characteristics of the biological tissue i.e. skin will be evaluated from which the amount of power loss and absorption due to propagation through the biological tissue will be estimated.It is imperative to make sure that subjecting the human body to this continuous signals is within the safe specified measures. The guidelines for Electromagnetic Field exposure (EMF) are in terms of Specific Absorption Rate (SAR) and the equivalent plane wave power density (SW/m2). SAR is a measure of the rate of energy absorption per unit mass due to exposure to an RF source. SAR is normalized to mass and is defined as [18]:

$$SAR = (_{e}ffE_{r}ms^{2})/(W/Kg) \qquad (1)$$

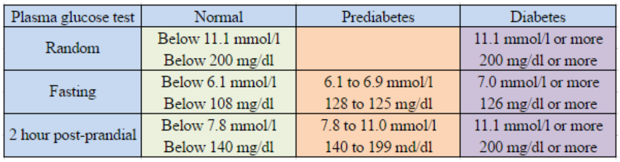
Where $_{e}ff$ is the effective conductivity of the biological material such as skin and is proportional to the frequency of the applied field, is the mass density which is approximately 1000 kg/m^{3} for most biological tissues,and $E_{r}ms$ is the root mean square value of the electric field E at the measurement point. As specified in [19] at an operating frequency

Table 1: Glucose levels



Type	Before meals	2 hours after meals	Wake up	Risk of hypoglycaemia (low blood glucose)
Healthy Person	4 to 5.9 mmol/L	under 7.8 mmol/L		under 4 mmol/L
Type I diabetes	4 to 7 mmol/L	5 to 9 mmol/L	5 to 7 mmol/L	under 4 mmol/L
Type 2 diabetes	4 to 7 mmol/L	under 8.5 mmol/L		under 4 mmol/L
Children with type 1 diabetes	4 to 7 mmol/L	5 to 9 mmol/L	4 to 7 mmol/L	under 4 mmol/L

Table 2: Blood glucose levels in diagnosing diabetes



Plasma glucose test	Normal	Prediabetes	Diabetes
Random	Below 11.1 mmol/l Below 200 mg/dl		11.1 mmol/l or more 200 mg/dl or more
Fasting	Below 6.1 mmol/l Below 108 mg/dl	6.1 to 6.9 mmol/l 128 to 125 mg/dl	7.0 mmol/l or more 126 mg/dl or more
2 hour post-prandial	Below 7.8 mmol/l Below 140 mg/dl	7.8 to 11.0 mmol/l 140 to 199 md/dl	11.1 mmol/l or more 200 mg/dl or more

of 2.4 GHz, the maximum E and S are 61 V/m and 10 W/m^2 respectively which are well below the targeted operation power of the wireless sensor node.

In the sensor device, an ATMega328P micro-controller is used because it can achieve a high level of energy efficiency. The micro-controller can run at 16Mhz. However, it needs to use an external oscillator and requires 5V power supply for running at this clock. In contrast, it merely uses 1Mhz internal oscillator and requires 2V power supply for operating at 1Mhz. On the grounds that the sensor device does not perform any heavy computation, 1MHz clock speed and 2V power supply are suitable. In the implementation, the sensor device is in a deep sleep mode in most of the time. It is waken up regularly i.e. for receiving incoming data from a glucose sensor and temperature sensors. Then, it wakes up a nRF component for transmitting the data to a gateway. After all, it goes back to the deep sleep mode.

The nRF24L01 IC is an ultra low power 2Mbps RF transceiver IC for the 2.4GHz ISM band. It is built-in with an advanced power management method. The nRF24L01 IC communicates with the micro-controller via a SPI interface. For the reason that it is no required a high transmission data rate to collect glucose, body temperature and environment temperature every 10 minutes, SPI with a data rate of 250kbps is applied in the implementation.

The gateway includes a nRF transceiver and a smart phone in which the nRF transceiver is connected to the phone via a USB port. In terms of the hardware implementation, the nRF transceiver is implemented by an ATMega328P micro-controller and a nRF24L01 IC. Similar to the micro-controller in the sensor device, the micro-controller of the nRF transceiver also run at 1Mhz. The micro-controller is supplied with 3.3V from the FTDI component which converts 5V from the phone's USB port to 3.3V. For saving power consumption, it is in a deep sleep mode in most of the time. It is only waken up by an interrupt for receiving incoming data from a sensor device and immediately forwarding to the smart phone. After completing these tasks, it goes back to a deep sleep node. When it is in a sleep mode, the nRF component is also in a sleep mode.

An Android app is built in the gateway for receiving data from the nRF component and performing other services. When data is available at one-end of the USB port, the app automatically reads the data and performs the data processing service. In addition, the app is capable of representing the processed data in text and graphical forms and triggering a push notification service.

The push notification service is implemented by a Google push notification API. When the mobile app detects abnormal situations (i.e. too low or too high glucose level), the push notification service in the gateway is triggered for sending notification messages to Cloud which then notifies doctors and an end-user wearing the sensor device.

Local database in gateways is implemented by MySQL database, and local storage (HD card). For example, the table of glucose levels based on the Australian and UK national diabetes service scheme and the global diabetes community[20]-[21] shown in TABLE .1-2 is stored MySQL tables.

The server is implemented by HTML5, Web-Socket and Node.js because they support real-time and streaming data. In addition, MySQL database for storing synchronized data and Javascipt for plotting graphical charts are utilized.

5. Experiments and Results

In order to verify the quality of data transmitted via nRF from a sensor node to a gateway, two sets of data including random and predefined data are used. The data collected at the sensor node and the received data at the gateway is compared in several cases such as the sensor node and the gateway in pockets, or the gateway in the environment less than 0 degree Celsius. In the experiments, the distance between the sensor node and the gateway is in a range of a few meters although in most of the cases, the distance is less than 1 meter. The results show that the sent and received data (i.e. environmental temperature and body temperature) is the same, and there is no lost during the transmission for all cases. In some cases when radio signals are blocked, the sensor node tries to send the data with a higher power. Fortunately, average power consumption of the sensor node does not vary dramatically due to a long interval (i.e. every 10 minutes) between transmission times. Power consumption of components and devices used in the implementation is shown in Table .3.

Table 3: Power consumption of nRF transceiver, sensor node and gateway

Device	Voltage supply (V)	Average Current (mA)
nRF transmitter (nRF + ATMEGA328P)	2	0.5
nRF receiver (nRF + ATMEGA328P + FTDI board)	5	5
Sensor node	2	1.4
gateway(Android phone without nRF receiver)	5	70
Android phone with nRF receiver	5	75

To the best of our knowledge, our sensor node consumes the least power than other sensor nodes existing in the market and proposed by other authors. Most of existing energy efficient sensor nodes for CGM consume more than 5mA while the proposed sensor node consume merely around 1.4mA. Table 3 shows that power consumption of the Android phone increases about 6.5% when attaching an nRF receiver prototype including nRF transceiver, ATMEGA328P and FTDI components. The power consumption can be reduced when the prototype is replaced by an entire circuit device. In this case, surplus components such as LEDs, and IO ports can be removed for saving power consumption. For testing functionality of the application in the gateway, several glucose values including low, medium and high glucose levels altogether with temperature values are sent from the sensor node to the gateway. The result shows that data is categorized and represented in text forms accurately. In addition, the push notification service operates accurately in real-xtime when abnormality (e.g. too high or too low glucose levels) is detected.

6. Conclusion

In this paper, we presented a real-time remote IoT-based continuous glucose monitoring system. The implemented IoT-based architecture is complete system starting from sensor node to a back-end server. Through the system, doctors and caregivers can easily monitor their patient anytime, anywhere via a browser or a smart-phone application. Sensor nodes of the system are able to obtain several types of data (i.e. glucose, body temperature, and environmental data) and transmit the data wirelessly to the gateway efficiently in term of energy consumption. In addition, the sensor node is integrated with the power management unit and the energy harvesting unit for extending operating duration of the sensor device. With the assistance of the customized nRF receiver, a patient's smart-phone becomes a gateway for receiving data from sensor nodes. In addition, the gateway with its application provides advanced services to users, such as a notification service. The result showed that it is feasible to remote monitor glucose continuously in real-time and the system can be made energy efficient.

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