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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

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.