Energy Harvesting Based Glucose Sensor

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Abstract. Blood glucose self-monitoring plays an essential role in the life of diabetic people. A regular control helps diabetic persons to avoid acute complications, e.g. hypoglycaemic coma, and can reduce the risk of long-term consequences of diabetes. The implementation and usage of wireless technologies, e.g. NFC, in smartphones are a big step forward for diabetes home monitoring. Near Field Communication (NFC) is a wireless technology which allows the transmission of data and energy over short distances. The transmitted energy can be used for energy harvesting and in conjunction with low power electronic smart sensor solution reduced in size, weight and costs can be realized. We developed a smart glucose meter based on an amperometric measurement. The prototype is powered by the NFC interface of a smartphone. A user friendly mobile app completes the smart sensor system. The measured blood glucose is visualized on the smartphone and is stored in a diary automatically.

Keywords: Near Field Communication · NFC · Diabetes mellitus
Glucometer · Blood glucose self-monitoring · Mobile diagnostics

1 Introduction

Diabetes mellitus is a group of metabolic diseases whose main symptom is hyperglycemia, an increased blood glucose concentration. Diabetes is one of the most common metabolic disorders worldwide. According to the IDF Diabetes Atlas 2015 [1], around 415 million people worldwide suffer from diabetes mellitus. An unhealthy lifestyle, lack of exercise, hyper caloric nutrition and obesity favour diabetes. Over the last years the number of diabetics has grown rapidly.

There are four main types of diabetes in which type I and type II diabetes are the most common representatives. Type I diabetes is characterized by the impaired production of insulin of beta cells in the islets of Langerhans in the pancreas [2,4]. This leads to an absolute insulin deficiency. Type I diabetes affects about 5% to 10% of the diabetes patients worldwide and is most frequently diagnosed in children and in young adults [3,4].

Type II diabetes is the most prevalent form of diabetes mellitus [4]. Type II diabetes mellitus is characterized by insulin resistance of the tissue and by the

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reduced insulin secretion (relatively insulin deficiency) [2]. Diabetes has acute and chronic effects on the patients' health. Acute complications can include hypoglycaemic and hyperglycaemic coma, ketoacidosis, fainting or death [4]. Chronic effects result from persistently high blood glucose concentrations; damage the retina, kidneys, nerves and circulatory system (micro- and macrovascular consequences) [2,4].

Blood glucose self-monitoring plays a crucial role in the life of diabetics. By controlling the blood glucose concentration help diabetic person to avoid acute hypoglycemic risks and can drastically reduce the likelihood of chronic effects [4]. A regular control of the blood glucose concentration helps patients to manage their disease successfully. In addition this increases the quality of life and the patient safety of diabetics. Furthermore, a good controlled blood glucose level will reduce the costs for the health care system. To maintain the health of type I diabetics they need to monitor their blood glucose concentration 5–6 times a day [4].

Nowadays smartphones are an integral part of our everyday life. The number of smartphone users is already quite high and is still increasing annually. The implementation and usage of the smartphones' wireless capabilities (e.g. Bluetooth, NFC) present a considerable progress for the blood glucose meters. In the case of NFC connectivity, the meter can be powered directly by the smartphone without an additional power source like a battery. Furthermore, size, weight and costs of the resulting device can be minimized.

2 Methods

2.1 Glucose Measurement

The most common glucose measurements are based on amperometric or photometric methods. Blood glucose meters based on amperometric measurement are currently state of the art [3]. The basic concept is that an immobilized enzyme, glucose oxidase (GOx) or glucose dehydrogenase (GDH), catalyzes the oxidation of glucose and uses one of three cofactors: PQQ, FAD, NAD. These two enzymes differ in redox potential, cofactors, turnover rate and selectivity for glucose [3,4]. Depending on the electron transfer mechanism; glucose biosensors were divided into different generations:

First generation glucose biosensors use the presence of oxygen to detect the concentration of hydrogen peroxide. Hydrogen peroxide is oxidized at a platinum electrode at an electrode potential of 0.7 V vs. Ag/AgCl electrode [5].

Second generation glucose biosensors use mediators to carry the electrons between the redox center and the electrode surface [6]. This biosensor does not require oxygen unlike the GOx method. Furthermore this biosensor results in faster electron transfer rates and the use of mediators reduce the required redox potential.

Third generation glucose biosensors do not require a regent [3]. The electron is transferred directly from glucose via the active side of the enzyme [3].

This type of biosensor is mainly used in continuous glucose measurement. Figure 1 shows the different glucose biosensor generations.

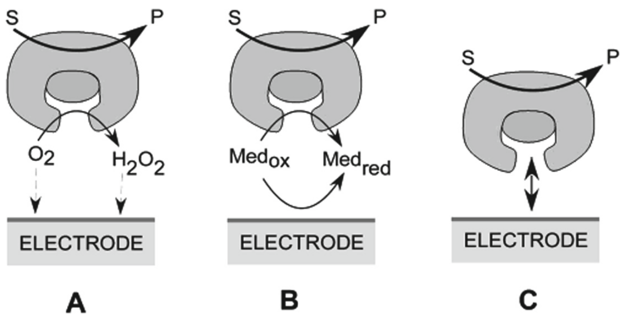

Fig. 1. Different glucose biosensors types: **A** first generation glucose biosensor, **B** second generation of glucose biosensor, **C** third generation of glucose biosensor [6]

2.2 Chronoamperometry

Chronoamperometry (CA) is an electrochemical technique to determine an analyte quantitatively in which a potential step is applied on the working electrode [7]. The resulting current from faradaic process occurring at the electrode is monitored as a function of time. The faradaic current is described in the Cottrell equation (1):

$$i = nFA\sqrt{\frac{D}{\pi t}}c_0 \tag{1}$$

where,

i = current in A
n = n the number of transferred electrons
F = Faraday constant, 96.485 C mol^{-1}
A = area of the electrode in cm^2
c_0 = initial concentration of the analyte in mol cm^{-3}
D = diffusion coefficient in cm^2 s^{-1}
t = time in s

When an adequate amount of blood is applied on the test strip and the required redox potential is applied on the working electrode, a cascade of redox reaction takes place on the test strip [3]. The resulting current from the electrochemical reaction on the blood glucose test strip is direct proportional to the glucose concentration [3].

2.3 Near Field Communication

Near field communication (NFC) is wireless technology to transmit data and energy over short distances [8]. NFC is a future-oriented and upcoming technology well known in payment and access control. It also provides different application in the sensing and personal health monitoring area. NFC is based on RFID (Radio Frequency Identification) and uses inductive coupling between two devices (Fig. 2), like an air transformer. NFC operates at a frequency of 13.56 MHz and supports data rates of 106, 212 or 424 kbit/s [8].

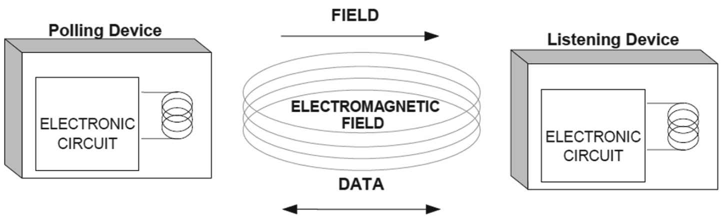

Fig. 2. NFC system [9]

A NFC system consists of an initiator (polling device or reader) and a target (listening device or transponder). Initiators actively generate an RF field that can power a passive target by using energy harvesting. NFC-enabled devices support three modes of operation: card emulation, peer-to-peer, and reader/writer. Peer-to-peer mode enables two active NFC-enabled devices to communicate with each other to exchange data [10]. In card emulation mode, the NFC-enabled device communicates with an external reader like a traditional contactless smart card [10]. Reader/writer mode enables NFC-enabled devices to read data stored on NFC tags [10]. The communication protocol is based on the ISO/IEC 18092 NFC IP-1, JIS X 6319-4 and ISO/IEC 14443 contactless smart card standards [8,10].

3 Results

3.1 NFC-Glucometer

The developed NFC-Glucometer is based on a multi-chip solution, containing NFC-frontend, low power microcontroller and measurement unit to measure blood glucose quantitatively (Fig. 3).

The NFC-frontend is an ISO/IEC 14443 (NFC-A) NFC forum tag type 2 with a dual access EEPROM. The NFC-frontend uses the transmitted energy for energy harvesting to power the electronics of the entire passive sensor tag.

The required redox potential of approximately 185 mV is supplied by a DAC of the low power microcontroller. A transimpedance amplifier (TIA) converts the resulting current to an equivalent voltage. This voltage is measured with an ADC of the low power microcontroller.

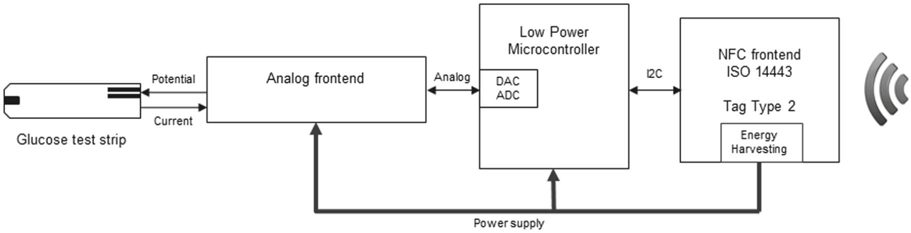

Fig. 3. NFC-Glucometer: Hardware architecture

The current NFC-Glucometer prototype is powered by the NFC interface of a smartphone. A user friendly and intuitive mobile app completes the smart glucose meter. The measured blood glucose concentration is visualized on the display and is stored in a diary automatically.

In contrast to a common glucose meter our NFC glucose sensor system take advantage of the versatile functionality of the smartphone. Therefore, only the blood glucose measurement is performed by the NFC-Glucometer. Data processing tasks, displaying the measured blood glucose concentration and data storage are performed by the NFC-enabled smartphone (Fig. 4).

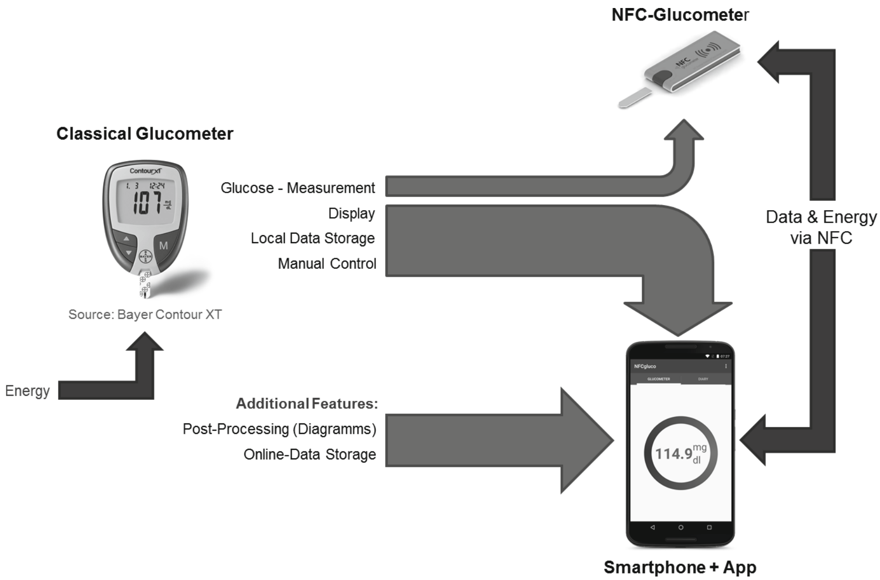

Fig. 4. Comparison of common blood glucose meter and NFC-Glucometer system

4 Discussion

According of the importance of blood glucose self-monitoring, the implementation of NFC in smartphones and the advantage of the versatile functionality of the smartphones present a considerable progress of diabetes home monitoring. The transmitted energy of the NFC field can be used for energy harvesting and allows to supply low power electronics. Therefore, size, weight and costs of the resulting device can be minimized. These smart sensor solutions enables the opportunity to measure diagnostic relevant parameters, e.g. blood glucose level, blood pressure, as well as therapeutic relevant parameters, e.g. medication compliance, time stamps of measurement, food intake, exercises and mood very easily and fast. The measured data can be stored local on the mobile device or on-line. Physician and patient itself have the opportunity to use the additional information to adjust the treatment, e.g. insulin treatment. An automatic diary function can reduce the risk of recording the measured blood glucose concentration incorrectly. Furthermore, a regular control of the blood glucose concentration can avoid acute complications, e.g. hypoglycaemic coma, and can reduce the risk of long-term consequences of diabetes. Finally this leads to an increased quality of life and patient safety of the diabetic persons.

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