Portable and Non-invasive Blood Glucose Monitoring over a Prolonged Period using Whispering Gallery Modes at 2.4 GHz

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Abstract

Invasive measurement of blood glucose is not approprate for everyone, particularly the patients with leukemia. Here, we demonstrate how the blood glucose can be non-invasively monitored over a prolonged period in the absence of any

expensive equipment. Method: A portable and non-invasive glucose sensor capable of monitoring blood glucose at real-time has been successfully constructed and tested in the absence of any vector network analyzer. Using vacuum suction, the sensor head of the proposed non-invasive glucose sensor forms a whispering gallery resonator out of a skin tissue on an arm during the measurement process. The architecture of the proposed glucose sensor is equipped with standard components, including a WIFI transmitter, an RSSI sensor and a microcontroller based computer display. Results: Using the proposed glucose sensor, a healthy volunteer has been his blood glucose levels monitored over 72 minutes after consuming a loaf of bread and a cup of cow milk. The measured blood glucose rose shortly after the meal until it peaked at 40 minutes and finally fell to the initial value at around 72 minutes. Conclusion: The overall results were in general consistent with the expected results. The proposed glucose sensor is expected to be instrumental for the individuals who dislike the traditional lancets.

Keywords: diabetics, blood glucose, Whispering Gallery modes, S-band, network analyzer, invasive blood glucose measurement, non-invasive measurement, Acuu-chek ™, RF/microwave, leaky

waves.

I. Introduction

Invasive measurement of blood glucose based on traditional lancets is not approprate for everyone, particularly for the patients with leukemia. There have been incidents of Hepatitis C virus (HCV) infection due to the use of a capillary blood glucose meter (CBGM) lancet [6]. There is certainly a demand for non-invasive blood glucose sensor for home diagnosis of diabetics although non-invasive blood glucose sensor is hard to find not only in the market but also in publised literature [3-5].

Non-invasive blood glucose monitoring at RF/microwave frequency is by far the most proven method of diagnosis [1-2]. Although the demand for non-invasive blood glucose sensor is high, design and construction of a reliable and accurate non-invasive blood glucose levels remain a challenge. The following reasons are:

1) At RF/microwave frequencies, the glucose sensor can act as a leaky wave antenna, which releases and absorbs leaky waves. The energy supposedly used for measurement at the receiving end of the sensor might have leaked as a radiations to the

surrounding, ending up with unstable and inaccurate blood glucose measurement.

2) The volume of blood to be measured is difficult to be ascertained because of the geometry and the non-invasive nature of a would-be non-invasive glucose sensor.

In this work, we show that all these technical issues as mentioned above are the things of the past. The non-invasive glucose sensor to be proposed is based purely whispering gallery waves, which is a form of non-radiating surface waves. When the surface waves dominate the propagation modes, the leaky waves will be suppressed.

The total volume of blood to be monitored or measured is fixed through the formation of a whispering gallery mode resonator out of the human skin. The accuracy of the proposed sensor has been verified in several clinical trials held in Vietnamese-German University.

II. Method of Solution

The proposed portable glucose sensor is capable of non-invasively monitoring blood glucose of a

period without any interruption.

The overall system architecture of the proposed portable glucose sensor is illustrated schematically in Fig. 2.1a. Fig. 2.1b shows the photograph of the overall system.

The heart of this portable glucose sensor was the sensor head as shown in Fig. 2.3b. The sensor head is basically a vacuum suction device partially wound by a Goubau line loop. The vacuum suction has one tuning knot which enables the air pressure inside the vacuum device to be reduced or adjusted. The reduced suction pressure allows the tissue bump to be formed out of a human arm. This tissue bump is used as a whispering gallery mode resonator.

One port of the Goubau line loop is fed with a microwave signal at 2.4 GHz, the signal The measured characteristic of this sensor head is shown in Fig. 2.3a. The measured characteristic of this sensor head has been verified by clinical trials in [1,2].

The sensor head as shown in Fig. 2.3b had two ports. As shown in Fig. 2.1a, port 1 is to be connected to the RF/microwave signal source and

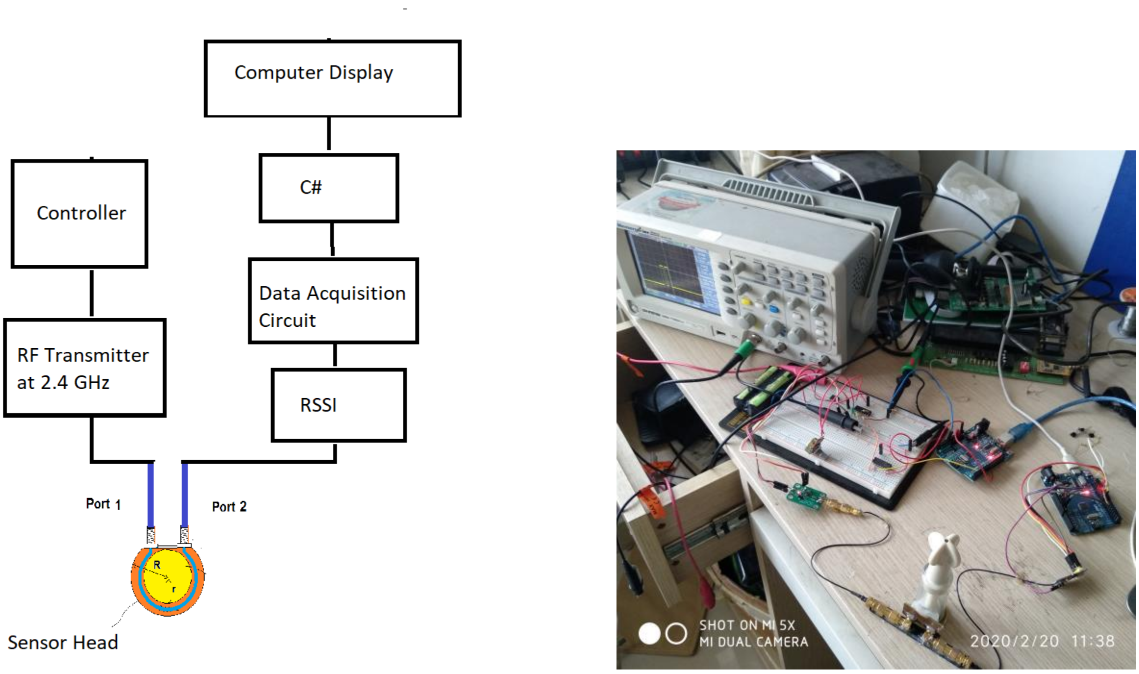
port 2 to be connected to the Radio Signal Strength indicator, i.e. RSSI device (port 2). The sensor head uses suction pressure to form a whispering gallery mode resonator out of the human skin tissue [1,2]. When the sensor head was placed on a human arm, as shown in Fig. 3.1, the tuning knot of the sensor head can be adjusted to create a vacuum inside the sensor head, which in turns created a tissue bump of a fixed volume. This tissue bump was considered as a whispering gallery mode resonator.

In this case the RF signal source to be fed to the sensor head was a RF/microwave transmitter as shown in Fig. 2.2. The RF/microwave transmitter originally had a built-in leaky wave antenna (see the circled part in Fig. 2.2). Since leaky modes introduce instability and uncertainty to the measurement process, the leaky antenna as was circled in Fig. 2.2 was removed from the WIFI circuit.

As illustrated in Fig. 2.1a, the RSSI device converts the power level of incoming signal from port 2 into a DC voltage. The DC voltage from the RSSI device was very small. It was acquired by the Acquisition circuit, which amplified the voltage using the built-in instrumentation amplifier. The

final voltage output from the Acquisition circuit was continuously read using another microcontroller program written in C#.

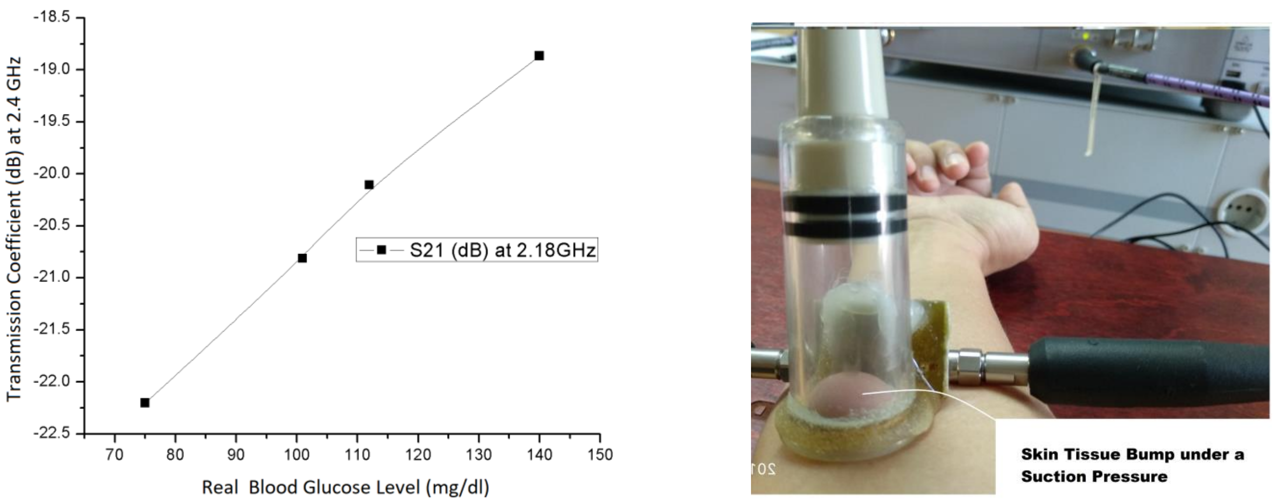
With the C# program, the microcontroller continusously converted the blood glucose as a received DC voltage and displayed in the computer.



(a) (b)

Fig. 2.1. The overall system architecture of the proposed portable glucose sensor. a) The schematic diagram; and b) The photograph illustrating the overall system.

Fig. 2.2. RF/microwave Transmitter generating an RF at 2.4 GHz.



(a) **(b)**

Fig. 2.3. Sensor head a) The measured characteristic of the sensor head at 2.18 GHz, which also works at 2.4 GHz [1,2]; b) The photograph of the sensor head.

III. Experimental Results

The volunteer was asked to use the proposed sensor to measure his blood glucose for one hour following consumption of a meal. The experimental setup is shown in Fig. 3.1.

The meal contains a loaf of bread and a cup of cow milk. The blood glucose rose and fell in a manner as predicted by conventional approach.

The initial blood glucose level of the volunteer was 70 mg/dl before meal. As shown in Fig. 3.2, the blood gluocose rose steadily until it reached 60 minutes.

As shown in Fig. 3.2, the blood glucose fell steadily after 60 minutes until it reached the original blood glucose level (i.e. 70 mg/dl)

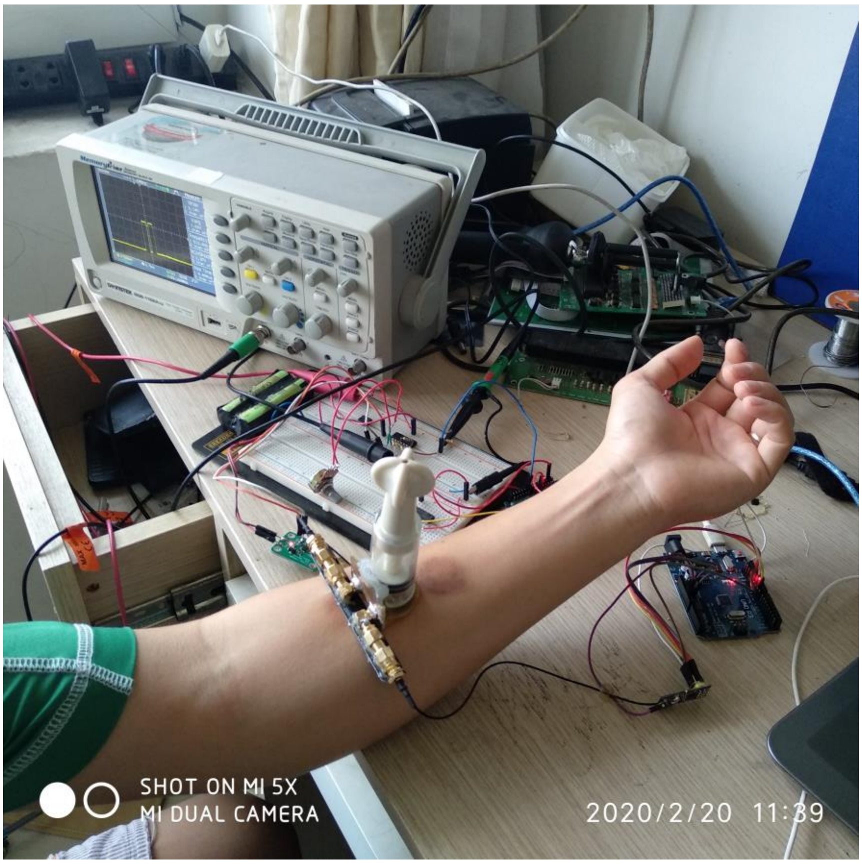


Fig. 3.1. Measurement setup using the proposed glucose sensor.

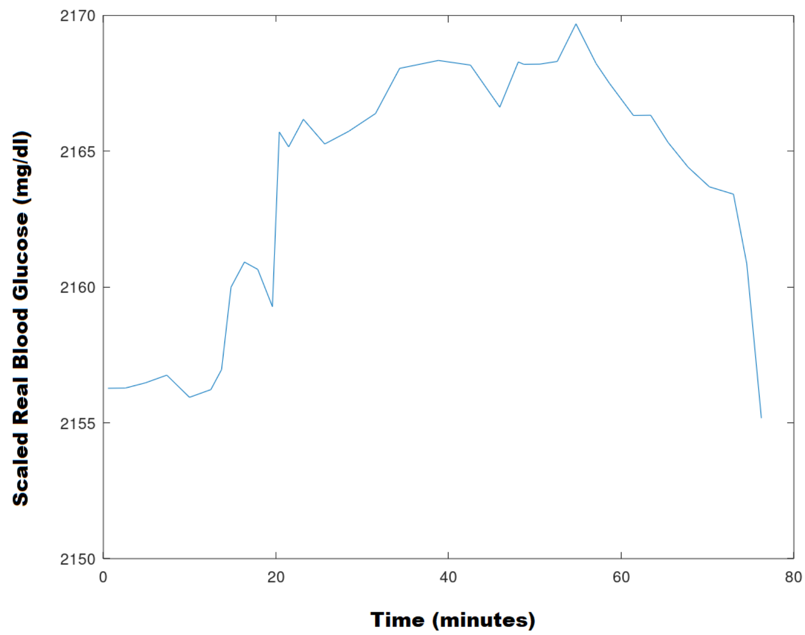


Fig. 3.2. Scaled blood glucose obtained by measured using the proposed sensor.

IV. Discussion

The overall system has proven functional as expected. As predicted, the blood glucose as measured by the proposed portable glucose sensor rose initially until it peaked at around 40 minutes from the start. The blood glucose finally fell to the initial value.

As Fig. 2.3a suggests, the transmission coefficient (i.e. S21) of the sensor head is almost proportional to the real blood glucose level. This characteristic was obtained from an in-vivo experiment when the operating frequency was around 2.18 GHz [2]. The accuracy of the sensor head already been proven by several experiments using the vector network

analyzer, which is an expensive piece of equipment [1,2]. The cost of a vector network analyzer is around US$70,000. Instead of using a vector network analyzer for monitoring blood glucose, we can simply use a Radio Signal Strength Indicator (RSSI) to measure the transmission coefficient provided that the antenna effect of the leaky wave radiation losses are minimal. Too much energy loss due to leaky wave radiation will end up with instablity and inaccuracy in measurement. To suppress the leaky radiation, the sensor head was based purely on whispering gallery modes, which were a kind of surface waves.

The proposed glucose sensor is expected to be highly instrumental for the people who cannot tolerate the pain due to the use of lancets.

The glucose over time plot as shown in Fig. 3.2 was not very smooth, in part because of the resolution problem of the RSSI sensor. The glucose over time can be further curve-fitted, depending on the applications.

V. Conclusion

We have constructed a non-invasive glucose sensor capable of monitoring blood glucose at real-time in

the absence of any vector network analyzer, which is an expensive equipment. The realized non-invasive glucose sensor is perfectly portable. The proposed sensor was based on a sensor head capable of forming a whispering gallery resonator out of a skin tissue on an arm using a vaccuum suction pressure. Instead of relying on a vector network analyzer, or any other expensive microwave equipment, the architecture of the proposed glucose sensor consists of a WIFI transmitter (a signal source generating an RF at 2.4 GHz), an RSSI sensor and a microcontroller based computer display. Using the proposed glucose sensor, the blood glucose of a healthy volunteer has been monitored over 72 minutes after the volunteer has eaten a meal containing a loaf of bread and a cup of cow milk. The measured blood glucose rose shortly after the meal until it peaked at 40 minutes. The blood glucose finally fell to the initial value at 72 minutes. The overall results were in general consistent with the results from some other research groups [6]. The proposed glucose sensor is expected to be instrumental for the individuals who cannot tolerate the pain following the use of traditional lancets.

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