A study on Non-invasive blood glucose estimation - An approach using capacitance measurement technique

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Abstract—Continuous blood glucose monitoring can help and prevent hyperglycemia level in diabetic patients. In the present study we aimed to estimate the blood glucose concentration using cost effective non-invasive forearm capacitance measurement technique. This technique is based on the fact that glucose level affects the dielectric properties of blood and underlying tissue. Test procedures were performed on 10 healthy subjects with age ranging from 25 to 35 years in two phases using a designed parallel plate capacitor circuit. Forearm part act as a dielectric medium of parallel plate capacitor and 555 timer circuits is used to produce pulse waveform based on measured capacitance. In first phase, capacitance was measured after consumption of sucrose (table sugar). In second phase, capacitance was measured after consumption of artificial sweetener. A total of 25 trials were made during the whole testing process. We observed that as the blood glucose value increases, magnitude of measured capacitance value also decreases. Therefore the trend of measured capacitance obtained after sucrose consumption is similar to the trend which was already established in oral glucose tolerance (OGT) test. Hence our results are promising and show the potential of this technique in predicting in-vivo blood glucose concentration; however, further improvement of the accuracy of the device is needed by doing more trails.

Keywords—Blood Glucose estimation, Capacitance, Dielectric, Non-invasive technique

I. INTRODUCTION

Glucose is the main energy carrier of carbohydrate in human organism with recommended levels between 89 mg/dL and 125 mg/dL in whole or capillary blood [1]. World-wide 150 million people suffer from disturbances in the endocrine metabolic regulation called diabetes [2]. Approximately 10 % of the cases result from insulin deficiency (type 1), which often starts during childhood and requires the administration of this hormone usually many times a day. Insulin resistance (type 2) corresponds to 90 %, occurring more in people over 40 years old. Additional cases also are related to pregnancy, where 2% of women have gestational diabetes. Any kind of diabetes can be dangerous because long-term excess of glucose (hyperglycemia) can cause blindness, damage nerves and kidney (renal failure) or even increase the risk for heart diseases, stroke, and birth defects. On the other hand, low levels (hypoglycemia) can result in confusion, coma and even death [3]. Although diabetes can be treated with transplantation procedures, the limited number of donors, risks of immune suppression and complications in medical procedures are major disadvantages for such solution. Other approaches like bio-artificial pancreas have problems related to biocompatibility, stability of insulin secretion, and relatively short duration of operation [4]. Various methods for monitoring of the glycemia exist [5] and classified into three categories such as Invasive, Semi-invasive and Non-invasive. Fully invasive systems can be either bedside clinical devices or self-monitoring meters. Lancet systems are still standard techniques for home monitoring (6 – 7 % accuracy) reading glucose concentrations through electrochemical, colorimetric or optical disposable strips for finger-prick blood samples. Efforts have been done in order to reduce the level of invasiveness by decreasing blood sample volume to few micro-liters and measuring areas of the body less sensitive to pain than fingertips, such as the forearm, upper arm, or thigh [6]. Drawbacks of such system are lack of control during sleeping or manual activities, loss of episodes of hyper- or hypoglycemia, risks of infection, nerve damage and the discomfort of picking the finger several times a day, which leads often to non-compliance [7]. Minimally invasive measurements sample the interstitial fluid (ISF) with subcutaneous sensors [8]. Even in this method the discomfort causes difficulties to patient’s therapy, therefore research groups are working to develop non-invasive glucose control device [9]. Systems for non-invasive continuous monitoring of blood glucose are most promising. These systems provide more comprehensive information about the level of blood glucose in patients during the most dangerous periods. This provides a basis for selection of the most efficacious treatment tactics. Unfortunately, so far there are no reports or patents which show that such non-invasive methods have the same accuracy as invasive procedures [10]. Continuous monitoring could only be accomplished through direct measurement of body tissues such as skin, cornea, oral mucosa, tongue or tympanic membrane [11, 12,13]. Non-invasive glucose transducers should be capable to detect weak blood signals through intervening tissues (bone, fat, skin, etc.), and in addition separate information on glucose from that of other overlapping constituents of higher concentration (proteins, urea, uric acid, hemoglobin, water, etc). Sensors can measure either by a direct approach, based in the chemical structure of the glucose molecule, or indirectly by measuring blood sugar effects on
some secondary process such as temperature or pH changes [14,15].

Near infrared (NIR) spectroscopy, far infrared (FIR) spectroscopy, optical rotation of polarized light, which are major techniques for in-vivo blood glucose estimation, suffers from limitations such as relatively weak changes due to glucose imprinted to the signals registered, the limited resolution and the insufficient precision[16,17,18]. Although there are many methods of non-invasive blood glucose estimation which has patents but many of them still lag behind standard method due to above mentioned limitations. So our main objective of this study was to develop a cost effective forearm capacitance measurement technique for non-invasive blood glucose estimation continuously without much problem.

II. METHODOLOGY

a. Experimental Setup

The experimental setup primarily consists of a parallel plate capacitor, in which the forearm part acts as a dielectric medium. Two aluminium plates of equal dimensions were used as electrodes and placed near left wrist. The parallel plate capacitor thus formed is connected to 555 timer circuit in astable mode as in figure 1.

![Figure 1: Experimental Setup](image)

This multivibrator produces pulse train waveform with on \((T_{ON})\) and off time \((T_{OFF})\) governed by following relations.

\[
T_{ON} = C \left( R_A + R_B \right) \ln 2 \tag{1}
\]

\[
T_{OFF} = C R_B \ln 2 \tag{2}
\]

From off-time (low time) of pulse train waveform, the value of forearm capacitance ‘C’ can be found out, since \(R_A\) and \(R_B\) are fixed.

This study was carried out in 2 phases namely:
1. After consumption of sucrose (table sugar)
2. After consumption of Artificial-Sweetener

b. Test Procedure

All measurements were made in left forearm near wrist while subject was in relaxed position in order to standardize the test procedure. Traditionally wrist part was used to measure pulse where changes in blood flow can be identified easily, so forearm part is used for measurement. Time period for each individual measurement was fixed as 90 seconds, since beyond that time; rate of change of capacitance was not significant as observed in oscilloscope and also approximately after 100 seconds sweating starts. Sweating should be strictly avoided since there is a considerable change in resistance while sweating, which might affect the results. Test subjects were tested in random and at random time on a particular day. Amount of sucrose to be consumed orally was fixed as 7 gram. Since artificial sweetener has sweetness many times as that of sucrose and has adverse side effects, so amount of artificial sweetener to be consumed orally was restricted to 0.04 gram.

III. RESULT

a. After Consumption of Sucrose

Capacitance value for test subjects decreases after sucrose consumption. After water consumption, it was observed that capacitance value increased due to neutralization property of water. From the above graph it is clear that capacitance value of forearm is inversely related to blood glucose level. Although capacitance value for each test subject is different even when same test procedure is followed, but similar trend can be observed in all test subjects. Since each subject has different body metabolism at each time instant, so does the difference in capacitance value.

The test was repeated for a subject for 100 minutes. And the result obtained (figure 4) was similar to the expected curve as established in oral glucose tolerance test [19].

![Figure 2: Capacitance variation with time after consumption of sucrose](image)

![Figure 3: Oral glucose tolerance test curves](image)
Figure 3 and 4 follow the same pattern, so capacitance measurement is essentially a suitable technique for predicting blood glucose level. Repeatability of the instrument was tested for 3 trials and the same pattern was obtained as shown in Figure 5.

b. After Consumption of Artificial Sweetener

From the plot, it was observed that the pattern obtained was different from that of sucrose consumption. In Figure 6, it is seen that the capacitance value remains the same even after consumption of artificial sweetener. This again validates the fact that artificial sweetener does not increase the blood glucose content. Repeating the same experiment on a test subject confirms the same pattern.

IV. DISCUSSION AND CONCLUSION

At present, there are no commercially available non-invasive glucose monitors and many improvements are still needed in order to have the same precision as standard methods with blood samples. In this study, an attempt has been made to non-invasively measure blood glucose level using capacitance measurement in forearm. Although exact value of glucose concentration was not predicted in this preliminary study, it can be predicted after further analysis of the trend in capacitance observed. From Figure 4 it is clear that capacitance measured reaches the initial value approximately 100 minutes after sucrose consumption. So, capacitance measurement is a direct measure of blood glucose. It is well known that skin parameters such as thickness of individual layers or moisture content of stratum corneum can vary considerably between different subjects [20]. So, knowledge about influences of these parameters on
measurement is required. Also fat thickness at forearm varies for different people, so individual calibration may require for this method.

Finally, a deeper study of stability is still required, which should be done in parallel with improving sensitivity of the technique. Also this process was carried over with oscilloscope for preliminary study, but can also be connected to LCD display via microcontroller for direct display of capacitance value.

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References

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