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Nonlinear transfer function's approach to non-invasive glucose measurement

Abstract

In this paper a non-invasive glucose sensor Fast Fourier Transform (FFT) base is suggested using the relatively new concept of nonlinear transfer function. From the conceptual idea to the electronic schematic circuit, showing some in-vivo measurements, this paper opens the discussion for a new idea improving the necessity of demanding for a reliably portable non-invasive glucose sensor, moreover being of low cost.

Keywords: non-invasive; glucose level; FFT, nonlinear transfer function

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Introduction

Diabetes mellitus is a pathological condition that renders the blood glucose concentration level variable during the day (see for instance).¹ It is well known that a poor regulation of blood glucose concentration leads severe complications such as cardiovascular diseases, damage of blood vessels; stroke, etc (see the survey and the references therein).² For this reason a correct in-vivo measurement of glucose concentration is of vital importance being classified according to: invasive, minimally invasive, non-invasive. As it is clear, a portable non-invasive device is always desirable to alleviate the patient pain with several measurements a day. However, the development of a non-invasive device is a long story open problem (see for instance).³ Among the non-invasive techniques, the use of Near Infrared Spectroscopy (NIRS) appeared very promising (see).² However, using NIR leads the great unsolved calibration for drawback different patients, even with the advantages of high reflective signals compared to mid-range and skin penetration of about 100 mm (see for instance)⁴ and the use of FFT. To overcome this drawback, this paper proposes replacing static FFT models using a novel technique: nonlinear transfer functions FFT based point of view (see for instance for a detail on nonlinear transfer functions).⁵

In field glucose measurement: in-vivo data capturing using arduino nano

The problem of model calibration along with the short periods of validity appears in all the modeling using static models and NIR (see).² To overcome this issue to account for patient variability, a dynamical model: Pulses in an infrared diode-Glucose concentration is proposed. Assuming the glucose's level as a dynamical system's output, the block diagram depicted in Figure 1 can be described. The complete survey² described that blood glucose concentration can be more effectively detected in the range of 1408nm to 2326 nm. However, lower wavelength can be used to detect glucose concentrations as well (see for instance).⁶ The clear advantage is the low cost of 980nm infrared diodes that can be used to implement NIR detection. Moreover, the available literature makes use of NIR through skin tissue (see for instance),⁷ this technique needs a complex and complicated hardware. To overcome this issue some papers describe the use of reflecting NIR (see for instance),⁸ in this paper, NIR is used taking measurements of the infrared rays returning after shocking the

skin tissue (Figure 2). It turns out that the returning infrared ray must be used to extract glucose concentration. To this end, a cheap NIR commercial receptor is used and converted to digital (A/D) with a 10 bit low cost Arduino Nano platform.

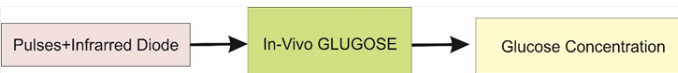


Figure 1 Schematic block diagram.

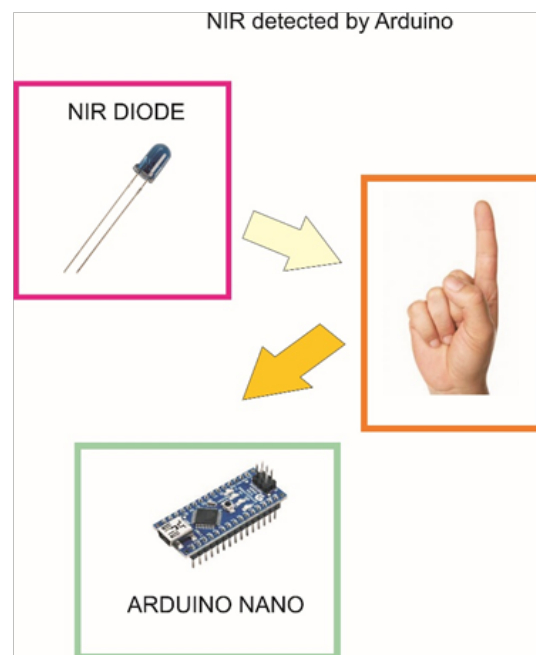


Figure 2 Returning infrared's energy and Arduino Nano.

Measurement's format and matlab GUI

Once the data is captured by Arduino's internal flash memory (a set of 500 points are taken), the data is sent to Matlab via RS232-USB.

This application allows saving data to hard disk, so as many patient samples as required can be taken and then analyzed off-line (Figure 3).

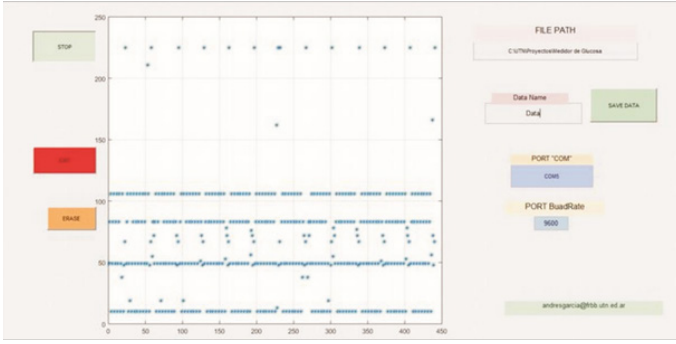


Figure 3 Matlab's GUI collecting Arduino's measurements.

Post-processing using FFT: non-linear transfer's function approach

Besides the NIR diode's returned energy, a salient property inspired by Bode's linear system theorem (see for instance⁹ toward the implementation of a real non-invasive glucose sensor, FFT it is proposed to represent the data (500 points) with a further nonlinear transfer function identification (see for instance⁵ for further details on nonlinear transfer functions). Figure 4 depicts these ideas allowing two possibilities:

- I. Nonlinear transfer function identification.
- II. Minimal second order transfer function with minimum error.

First possibility attempts to extract a truly optimal transfer function that represents the system: *Pulse Width Modulated (PWM)-Glucose Concentration*, whereas the second one aims to provide a simple, yet effective, representation with minimum amount of parameters inspired in the classical linear control literature and the low frequency effect observed in Figure 6:

$$G(j \cdot \omega) = \underset{\theta \in \mathbb{R}^N}{\operatorname{argmin}} \sum_{i=1}^M \left[G(\theta, \omega_i) - Y_i \right]^2 \quad \text{Truly}$$

optimal transfer function (1)

$$G(j \cdot \omega) = \underset{\{a_1, a_2, a_3\}}{\operatorname{argmin}} \sum_{i=1}^M \left[\frac{a_1}{\omega_i^2 + 2 \cdot a_2 \cdot \omega_i + a_3} - Y_i \right]^2$$

Second order (minimal parameter) estimation (2)

Where $G(\cdot)$ is a given universal form, Y_i are power spectral density from FFT using the Arduino data (Figure 4), M is the number of points taken by Arduino, ω_i are the FFT frequencies estimated with the internal latency for the analog to digital (A/D) conversion considering the PWM frequency of 1KHz and $\theta \in \mathbb{R}^N$ the set of N parameters to be identified. Mathematical models (1) and (2) are depicted in Figure 5: This is an ongoing project; however, to give a flavor's overall idea, two real measurements are shown in Figure 6 taken from two different patients. These measurements suggest the glucose's concentration could be related to the power spectral density of the FFT. The continuous decreasing behavior in Figure 6 inspires a further simplification in model (2):

$$G(j \cdot \omega) = \underset{\{a_1, a_2, a_3\}}{\operatorname{argmin}} \sum_{i=1}^M \left[\frac{a_1}{\omega_i + a_2} - Y_i \right]^2$$

Clearly one of the best ways to identify parameters $\{a_1, a_2\}$ is the well-known Laguerre's basis method (one simple pole with multiple data, see for instance.¹⁰



Figure 4 Data-FFT conversion plus nonlinear transfer function.

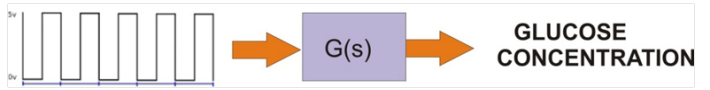


Figure 5 Block diagram.

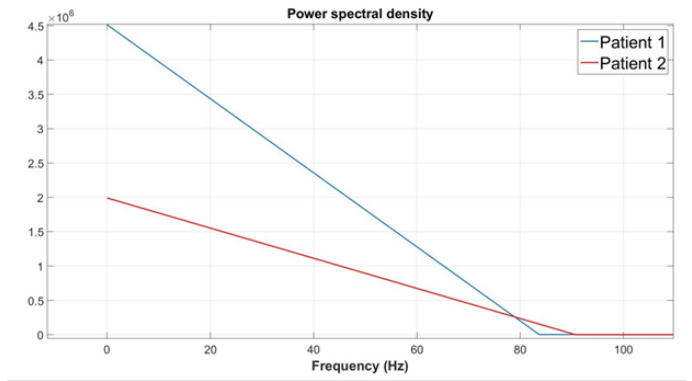


Figure 6 Data-FFT conversion plus nonlinear transfer function.

Micro-power solution using atmel attiny 85

Once the nonlinear transfer function is identified, the parameters of these transfer functions are programmed in a microcontroller to provide a real portable glucose instrument. The transfer's function pole in previous section as long as an FFT algorithm is programmed on-board in a microcontroller Attiny85, so the DC level $G(0)$ must be estimated to provide an indication of the glucose concentration in real time according to the conclusions in previous section (Figure 7). An estimation of the autonomy using a CR2032 battery can be envisioned:

$$\begin{aligned} \text{Energy}(CR2032) &= 375mWh \Rightarrow PWM(1KHz) @ 2 \text{ secs (aprox)} \text{ with } 0.25 \text{ Duty} \Rightarrow 11125 \text{ samples} \\ \text{Energy(per measurement)} &= 120mW \cdot \text{sec} \end{aligned}$$

With at least five measurements a day, this is more than two years' autonomy with a single battery. Moreover, if any harvesting method is added: body heat, vibration walking, etc, the autonomy can be increased using optimal control as depicted for instance.^{11,12}

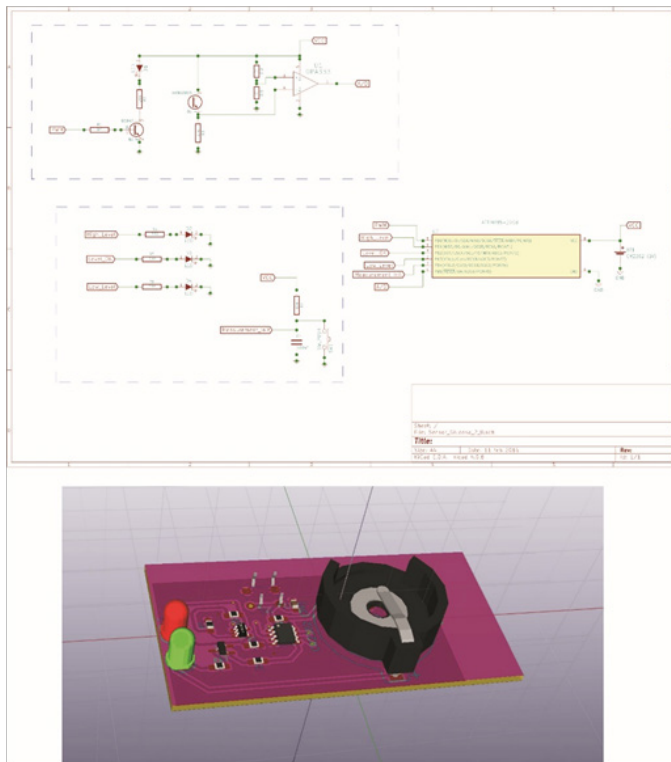


Figure 7 3-D schematic with Attiny 85 and on-board battery CR2032.

Conclusion

The problem of a portable instrument with low cost able to provide a confident estimation of the blood glucose concentration was identified. After a short review of the available results, a new mathematical model based on nonlinear transfer functions and FFT was presented. This is an on-going project, so a flavor of the possible glucose-transfer function was depicted with the DC value $G(0)$. A real prototype was presented using Atmel's microcontroller Attiny85 with on-board FFT and real-time indication with three indications: normal, low and high glucose levels. As a future work, exhaust measurements will validate these ideas using the electronic prototype presented.

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Conflict of interest

Authors declare that there is no conflict of interest.

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