Non-Invasive Estimation of Glucose using Fixed Wavelength Visible Light Sources

Marlon Sequeira andDr. G.M.Naik

Electronic Department,Goa University,Taleigao,Goa,India

Abstract

In view of aiding the frequent monitoring of glucose for people having diabetes mellitus we need to develop methods which are cheap, portable and less intimidating to the patient as compared to the traditional methods. We propose a system which non-invasively predicts the glucose concentrations using visible fixed wavelength electromagnetic radiation. To achieve this, we use a probe housing consisting of visible LEDs and a silicon detector. The laboratory samples consisting of varying glucose concentration is placed between the probe. The detected signal by the silicon detector will be sent to the Analog Front End (AFE) which will handle the signal conditioning of the incoming signal. The absorbance will be calculated by processing the signal on a NIOS-II embedded soft-core created on a FPGA. The glucose concentration corresponding to the input will be displayed on a display.

I. Introduction

Diabetes Mellitus has proven to be serious health issue in the recent times. This condition involves prolonged high blood sugar levels. Hyperglycemia over extended periods is the primary cause of the severe complications associated with diabetes, including premature death, blindness, kidney failure, amputations, heart disease, and stroke. Effective glycemic control requires frequent blood glucose monitoring to provide the information needed to administer the proper amount of insulin while avoiding hypoglycemia[1].

There are three main types of Diabetes mellitus namely Type 1 Diabetes mellitus, Type 2 Diabetes mellitus and Gestational Diabetes mellitus.

Type 1 Diabetes mellitus results from the failure of the pancreas to produce enough insulin. This form was previously referred to as "insulin-dependentdiabetes mellitus" (IDDM) or "juvenile diabetes". The cause is unknown [2].

Type 2 Diabetes mellitus begins with insulin resistance, a condition in which cells fail to respond to insulin properly [2]. As the disease progresses a lack of insulin may also develop [3]. This form waspreviously referred to as "non-insulin-dependent diabetes mellitus" (NIDDM) or "adult-onset diabetes". The primary cause is excessive body weight and not enough exercise [2].

Gestational Diabetes mellitus is the third main form and occurs when pregnant women without a previous history of diabetes develop a high blood sugar level [2].

Glucose level in the blood changes and if this change is not monitored may cause health problems to the patient. The acceptable range of glucose concentration is from 70 mg/dL (milligrams of glucose in 100 milliliters of blood) to 110 mg/dL or 3.9 to 6.0 mM/L[4]. After consuming food glucose concentration of a person may rise to a level up to 140 mg/dL.

Traditionally invasive methods such as enzymatic or biochemical reagent methods were used to determine the blood glucose concentration. These methods are less attractive to the general population due to various reasons such as the wastage of reagent, long measuring period, pain associated and possible infection. If only we could manage to develop non invasive methods which have characteristic such as sample-free operation, pain-free and good accuracy, a diabetic patient will readily embrace it. Non Invasive methods based on Optical radiation are viable options keeping in mind the above attributes mentioned. Different optical approaches are investigated to get desired goal namely polarimetry[5], Raman spectroscopy[6], near infrared (NIR) absorption and scattering[7], and photo acoustics [8].

II. Implementation

The System consist of the 4 blocks namely glove as shown in Fig. 1

1) PROBE
2) ANALOG FRONT END
3) PROCESSING
5) DISPLAY

The Sensor is basically a probe consisting for the fixed wavelengths transmitter and Detector/Receiver. It is followed by a AFE which handles the signal condition and digitization of the analog signal. The AFE is armed with a 22 bit ADC, amplifiers, filters and LED drivers which are completely programmable using the microcontroller. The following block of the system, the FPGA NIOS-II soft core

embedded processor collects the data from the AFE using SPI interface and then transform the data using the PLSR Algorithm into glucose concentration. Once the data is processed it is thrown out on the hypertext terminal using a RS232 serial interface.

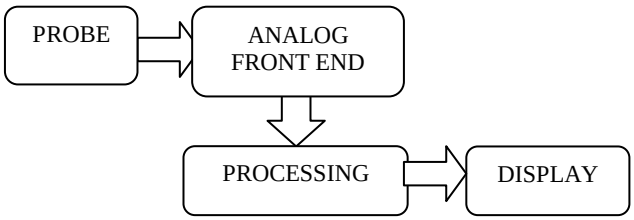

Fig 1. Block diagram.

Probe

A Standard Nellcor probe was purchased which has a standard DB7 connector. The stock LEDs were changed to YELLOW and RED. These LEDs are driven by AFE through the DB7 connector. The LED drive current and the LED On-Time are completely programmable.

The silicon photodiode is connected also through the DB7 connector to the AFE. The detected signal is amplified and filtered inside the AFE.

Fig 2. Probe.

Analog Front End

The AFE4490 is a fully-integrated analog front-end (AFE) which contains a low-noise receiver channel with a 22-bit analog-to-digital converter (ADC), an LED transmit section, and diagnostics for sensor and LED fault detection [9]. Thedevice has a very configurable timing controller. This flexibility enables the user to have a completelycontrolled device timing characteristics. To ease clocking requirements and provide a low-jitter clock to device, an oscillator is also integrated that functions from an external crystal. The device communicates to an external microcontroller or host processor using SPI interface.

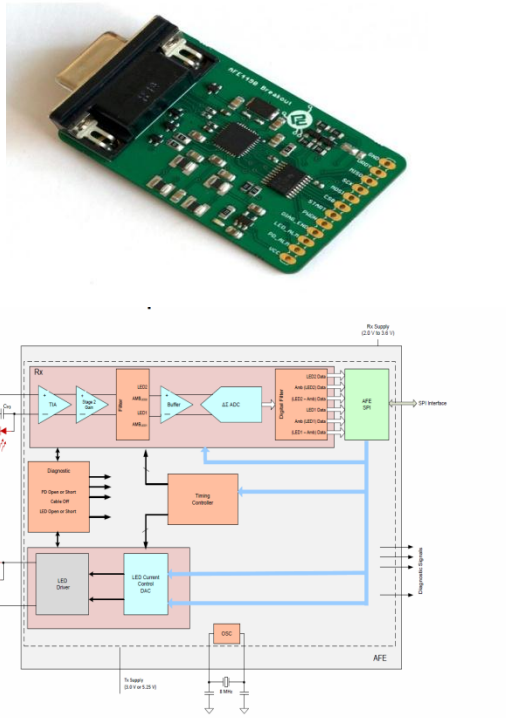

Fig 3 a) AFE4490 Board b) AFE4490 Functional Block Diag.

LED Current is programmable to the following ranges, 50mA, 75 mA, 100 mA, 150 mA, and 200 mA, Each with 8-Bit Current Resolution. The LED On-Time can be programmed from 50 µs to 4 ms.

The receiver consists of a differential current-to-voltage (I-V) transimpedance amplifier that converts the input photodiode current into an appropriate voltage. The feedback resistor of the amplifier (RF) is programmable to support a wide range of photodiode currents. The stage 2 amplifier also has a programmable gain and also supports ambient current cancellation.

The receiver provides digital samples corresponding to ambient duration. The host processor (external to the AFE) can use these ambient values to estimate the amount of ambient light leakage. The processor must then set the value of the ambient cancellation DAC using the SPI. There is a low pass filter which can be programmed before passing ADC for digitization through the buffer.

Processing

The processing block consists of a Nios-II soft core on a FPGA. The Soft core processor is the HDL model of a processor designed over an FPGA. Nios-II is the second generation of the soft-core processor from Altera. It is a 32-bit general purpose embedded RISC processor. The PLSR algorithm is implemented on the controller which is described later in this document.

Display
The display of the calculated glucose level is done on the hypertext terminal. A baud rate of 57600 is used for the serial communication therefore care must be taken to make sure that the hypertext terminal is set to the desired baud rate.

III. PLSR Algorithm

PLSR is an extension of the multiple linear regression Models. PLSR extends multiple linear regressions without imposing the restrictions imposes by DA, PCR, and CC. [10]

The general underlying model of multivariate PLS is

$$\mathbf{X} = \mathbf{T}\mathbf{P}^{\mathbf{T}} + \mathbf{E}$$
$$\mathbf{Y} = \mathbf{U}\mathbf{Q}^{\mathbf{T}} + \mathbf{E}$$

Where **X** is a *n x n* matrix of predictors, **Y** is an *n x p* matrix of responses; **T** and **U** are *n x l* matrices that are, respectively, projections of **X**(the X scores, component or factor matrix) and projection of **Y**(the Y scores); **P** and **Q** are, respectively, *m x l* and *p X l* orthogonal matrices ; and matrices **E** and **F** are the error terms, assumed to be independent and identically distributed random normal variables. The decomposition of **X** and **Y** are made so as to maximize the covariance between **T** and **U**

PLSR has been used in various disciplines such as chemistry,economics, medicine, psychology, pharmaceutical, andmedical science where predictive linear modeling, especiallywith a large number of predictors is necessary. PLSR hasbecome a standard tool for modeling linear relations betweenmultivariate measurements in chemometrics[11].

IV.References

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