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Development of MSP based Pulse oximeter with LabVIEW

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Abstract

Pulse oximeter is a non-invasive medical device that monitors the oxygen saturation of a patient's blood and heart rate. The main objective of the present work is to develop a pulseoxymeter use high-accuracy pulseoxy sensor with the implementation of Mixed Signal Microcontroller (MSP) and analog devices. The sensor samples the photo plethysmographic data using Analog Front End (AFE) and is send to a personal computer through microcontroller. The USB serial link is used to transfer data to personal computer. The device is interfaced through serial port to communicate with a LabVIEW virtual instrumentation. The device is tested successfully and compared the results with the standard instrument with n accuracy of ±0.1%.

Keywords: photoplethysmogram, Analog front-end,

1. Introduction

The most important elements needed to sustain life is oxygen (O2) because it is used by cells to turn sugars into useable energy. Oxyhemoglobin (HbO2) is the protein hemoglobin found in red blood cells bounded to O2 that delivers 98% of oxygen to cells. The measurement of the percentage of HbO2 in arterial blood is known as oxygen saturation (SpO2). [1] . Our body needs continuous supply of oxygen. While some of the parts can function without oxygen for some time period, but some cannot tolerate even for a short period of time. So it is necessary to measure the amount of oxygen carried by arterial blood to assess the functioning of various body parts.

The non−invasive measurement of pulse oximetry used for the of arterial oxygen saturation in the blood. Pulse oximetry derives SpO2 and pulse rate from a photoplethysmogram (PPG). The PPG is obtained by measuring changes in light absorbed by the blood. Red and Infrared wavelengths are used to obtain the PPG because these wavelengths are easily transmitted through tissues. The puleoxygen SpO2 is calculated from the ratio of the absorption of the red and infrared light.

Pulse oximetry allows for an accurate determination of oxygen levels in patients that are sedated, anesthetized, unconscious, and unable to regulate their own oxygen supply as well as provides information needed to avoid irreversible tissue damage. [2]

A healthy person should have sao_2 lies in between 94% to 100%. photoplethysmography technique is used to measure the sao_2 value. In this technique a part of body is illuminated and the transmitted light is detected using a suitable photo detector. The signal detected is called photoplethysmogram (PPG). This technique makes use of two PPG's to calculate sao_2 .ie., One acquired with RED led as light source and the other using Infra Red led. Typical measurement sites are the finger, toe, or lobe of the ear..etc. In the transmitted mode, emitter is on one side and detector is on the other side of the finger. A PPG signal has a small AC component superimposed on a large DC level [3]. This dc level is due to absorption of light by skin, tissue, bone, color of skin and the magnitude changes with individual. The AC component is due to absorption of light due to blood in capillaries which is arterial blood.

2. Principles of oximetry

Pulse oximetry is based on spectrophotometric measurements of changes in blood color. Oxygenated blood is distinctively red, whereas deoxygenated blood has a characteristic dark blue coloration. The principle of pulse oximetry is based on the red and infrared light absorption characteristics of oxygenated and deoxygenated hemoglobin. Oxygenated hemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated hemoglobin absorbs more red light and allows more infrared light to pass through. Red light is in the 600-750 nm wavelength light band. Infrared light is in the 850-1000nm wavelength band. Oxygenated versus de-oxygenated blood light absorption of IR and RED is as shown in Figure 1.

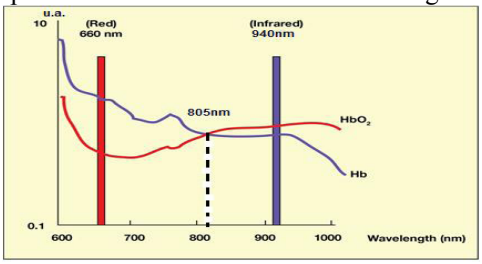

Figure1: Oxygenated versus de-oxygenated blood light absorption of IR and RED

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The oxygen chemically combined with haemoglobin inside the red blood cells makes up nearly all of the oxygen present in the blood (there is also a very small amount which is dissolved in the plasma). Oxygen saturation, which is referred to as SaO2 or SpO2, is defined as the ratio of oxyhaemoglobin (HbO2) to the total concentration of haemoglobin present in the blood (*ie* oxyhaemoglobin + reduced haemoglobin)

$$SaO_2 = \frac{[HbO_2]}{[\text{Total haemoglobin}]}$$

3. Hardware

The block diagram and circuit diagram of pulseoxymeter is as shown in fig 2, fig 3 and 4. Itconsists of the following units. They are

1. Pulseoxy sensor probe
2. Ananlog Front End
3. MSP Microcontroller

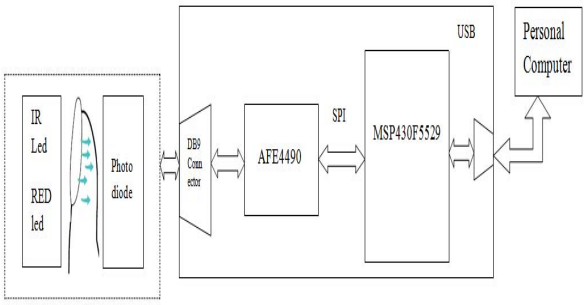

Figure 2 : Block diagram of pulseoxy meter

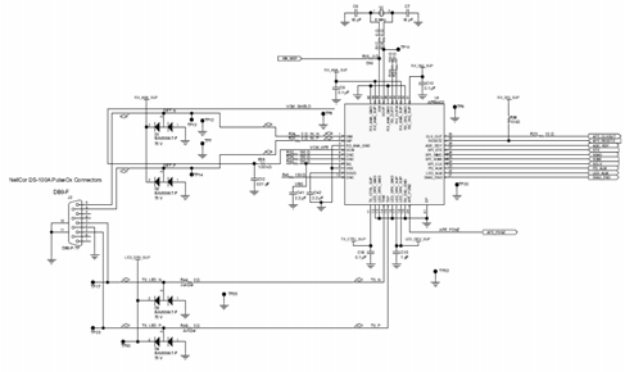

Figure 3 : AFE4490 Schematic Diagram for pulse oxymeter

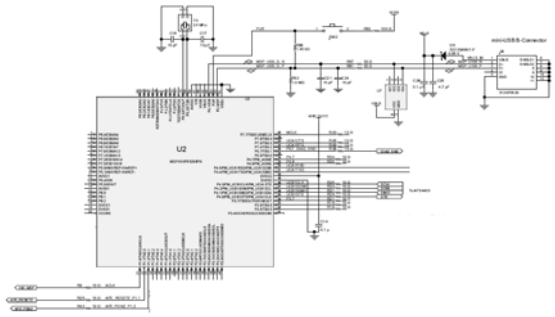

Figure 4 : MSP430 Schematic Diagram for pulse oxymeter

3.1 Pulseoxy Sensor probe

Pulse oximeter probe/ pulse oximeter sensor having light source and a photo detector. The light is shown through the tissue on the finger. As the blood passes through capillaries in the finger, the variation in blood volume causes a variation in the light detected by the phototransistor. The source and detector are mounted on either side of the finger to measure changes in transmitted light. In the present work, we used an infrared LED and Red LED.

The Pulse oximeter probe contains two light-emitting diodes of One transmits red light wavelength approximately 660 nm and the other transmits infrared light wavelength is 900-940nm. The pulseoxy probe operates at 500 on/off cycles /sec. Photo detector detects the amount of light absorbed by oxygenated and deoxygenated hemoglobin and connected to a microprocessor. The ratio of these two absorptions will give Sp02 reading [4]. This ratio number corresponds to the oxidization level of the blood

The Nellcor DS100A [5] compatible SPO_2finger clip pulseoxy probe is used in the present work. Nellcor probe is integrated with red LED, IR LED and a photodiode on both sides of the probe.

3.2. Signal conditioning unit

The main components for signal acquiring and signal-conditioning of the PPG signals are the LED, photodetector and AFE4490. AFE4490 has integrated with both the LED driver circuitry and the photodiode signal conditioning circuitry and fully-integrated analog front-end (AFE) circuit that is used for pulse-oxy measurement. It consists of 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. The AFE have flexibility to complete control of the device timing characteristics. The AFE communicate with the microcontroller using an SPI interface.

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The AFE4490 drives the LEDs by using an H-bridge configuration in transmit section. The transmit stage contains two sections: the LED driver and LED current control. The LED Driver section there is two LEDs, one for the visible red wavelength and another for the infrared wave length. An H-Bridge circuit is used to turn them on [6]. The circuit is time multiplexed to turn on either LED1 or LED2. The current source regulates the LED currents.

The LED currents in the H-bridge configuration is capable of driving upto 150 mA/leg, with short-circuit protection. They can also increase the dynamic range and create a current reference independent of the IR and red LEDs.

The Receive Stage consists of a differential current-to –voltage, transimpedance amplifier that converts the input photodiode current into an appropriated voltage. The differential voltage at the TIA output includes the pleth component [7] (the desired signal) and a component resulting from the ambient light leakage. A 22-bit ADC converts the sampled LED2, LED1, and ambient signals sequentially and provides a single digital code at the ADC output.

3.3 Microcontroller MSP430F5529

The Texas Instruments MSP430F5529 is a ultralow-power Microcontroller integrated with USB 2.0, four 16-bit timers, a high-performance 12-bit analog-to-digital converter (ADC), two universal serial communication interfaces (USCI), hardware multiplier, DMA, real-time clock module with alarm capabilities, and 63 I/O pins. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency.

It also consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with extensive low power modes, is optimized to achieve extended battery life in portable measurement applications. Typical applications include analog and digital sensor systems, data loggers, and others that require connectivity to various USB hosts.

The AFE4490 is a complete Analog Front-End (AFE) for pulse-oximeter measurement. The device consists of a low-noise receiver channel, an LED transmit section, and diagnostics for sensor and LED fault detection. The device communicates to an external microcontroller using an SPI interface

The transmit unit contains the LED driver and LED current control units. In LED Driver, there are two LEDs, one for the visible red wavelength and another for the infrared wave length. In LED Current Control unit regulates and ensures the LED currents.

The Receiver unit consists of a differential current to voltage transimpedance amplifier (TIA) that converts the input photodiode current into a voltage. The differential voltage at the TIA output includes the pleth component and a component resulting from the ambient light leakage. The TIA is followed by the digital-to-analog converter (DAC) that sources the cancellation current and an amplifier that gains up the pleth component alone.

The receiver provides digital samples corresponding to ambient duration. The microcontroller uses these ambient values to estimate the amount of ambient light leakage. The microcontroller must then set the value of the ambient cancellation DAC. Using the set value subtracts the ambient component and gains up only the pleth component of the received signal.

The output of the ambient cancellation amplifier is separated into LED2 and LED1 channels. When LED2 is on, the amplifier output is filtered and sampled on capacitor C_{LED2}, When LED1 is on, the amplifier output is filtered and sampled on capacitor C_{LED1}, In between the LED2 and LED1 pulses, the idle amplifier output is sampled to estimate the ambient signal on capacitors $C_{LED2\text{-}AMB}$ and $C_{LED2\text{-}AMB}$. The sampling duration is termed the Reveive sample time. The Reveive sample time is used for all dynamic range calculations; the minimum time supported is 50µs.

A 22-bit ADC converts the sampled LED2, LED1, and ambient signals sequentially. Each conversion takes 25% of the pulse repetition period and provides a single digital code at the ADC output. Four data streams are available at the ADC output (LED2, LED1, ambient LED2, and ambient LED1) at the same rate as the pulse repetition frequency. The ADC is followed by a digital ambient subtraction block that additionally outputs the (LED2–ambientLED2) and (LED1–ambient LED1) data values.

The Serial Peripheral Interface-compatible serial interface consists of four signals, the SCLK is the serial clock. SPI serial out master in (SPISOMI) pin is used out the AFE4490 data. SPI serial in master out (SPISIMO) pin is used in data to the AFE4490.

The present designed non-invasive pulseoxymeter use optical plethysmography [8] using the MSP430F5529 Micro controller (MCU). The pulseoxymeter consists of a peripheral pulseoxy probe combined with the MCU displaying the oxygen saturation and pulse rate on a Raspberry Pi. The same sensor is used for both heart-rate detection and pulseoxygen in this application. The probe is placed

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on a peripheral point of the body such as a fingertip, ear lobe or the nose. The probe includes two light emitting diodes (LEDs), one in the visible red spectrum (660nm) and the other in the infrared spectrum (940nm). Measuring the intensity from each frequency of light after it transmits through the body and then calculating the ratio between these two intensities work the percentage of oxygen in the body.

The Pulseoxymeter [9] is a medical instrument for monitoring the blood oxygenation of a patient. This type of monitoring is especially useful during surgery. This present design report demonstrates the implementation of a portable pulseoxymeter using the ultra low power capability of the microcontroller MSP430F5529. Because of the high level of analog integration, the external components can be kept to a minimum. Furthermore, by keeping ON time to a minimum and power cycling the two light sources, power consumption is reduced.

In a pulseoxymeter, the calculation of the level of oxygenation of blood (SaO2) is based on measuring the intensity of light that has been attenuated by body tissue. SaO2 is defined as the ratio of the level oxygenated Hemoglobin over the total Hemoglobin level (oxygenated and depleted)

SaO2 =HbO2/Total Hemoglobin

Body tissue absorbs different amounts of light depending on the oxygenation level of blood that is passing through it. Two different wavelengths of light are used, each is turned on and measured alternately. By using two different wavelengths, the mathematical complexity of measurement can be reduced.

R = log (lac) λ1/log (lac) λ 2

SaO2 α R

Where λ1 and λ2 represents the two different wavelengths of light used.

There are a DC and an AC component in the measurements. It is assumed that the DC component is a result of the absorption by the body tissue and veins. The AC component is the result of the absorption by the arteries. In practice, the relationship between SaO2 and R is not as linear as indicated by the formula.

The output data ADC code from AFE is applied to microcontroller using SPI interface. The output of the microcontroller is applied to the system for further processing through LabVIEW and to display the result in personal computer through USB port

In the present work, the acquired PPG signals are used to measure the SpO2 and pulse rate by uing LabView software. LabView is a platform and development environment for a visual programming language that helps create flexible and scalable design, control, and test applications [10].

The PPG signals can be pre-processed in the LabView. The normal frequency range of PPG signal is 0.5 Hz to 5 Hz. So the noise elements are cancelled by using the band pass filter was implemented in LabVIEW. The filter is a 3rd order Butterworth band pass filter between 0.5 and 2.5Hz. [11]

During systole, when the arterial pulsation is at its peak, the volume of blood in the tissue increases. This additional blood absorbs more light, thus reducing the light intensity which is transmitted. During diastole, less blood is present in the vascular bed, thus increasing the amount of light transmitted.

The pulsatile part of the PPG signal is considered as the "AC" component, and the non-pulsatile part, resulting mainly from the venous blood, skin and tissue, is referred to as the "DC" component. The Variations in light attenuation by tissue illustrating the rhythmic effect of arterial pulsation is as shown in figure 5

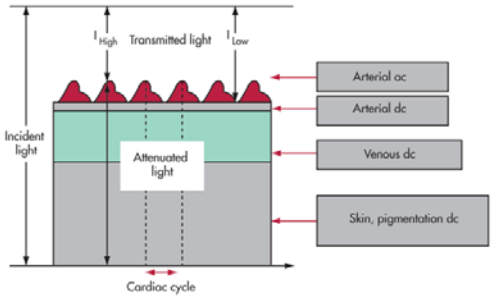

Figure 5: Variations in light attenuation by sue illustrating the rhythmic effect of arterial pulsation

In order to find the oxygen saturation the AC and DC values of the pulsating RED and IR PPG are extracted and the ratio R is found [10].

$$R = \frac{\text{Red\_AC\_Vrms} / \text{Red\_DC}}{\text{IR\_AC\_Vrms} / \text{IR\_DC}}$$

The SpO2 value is calculated from the R value using the clinical empirical formula,

$$SpO2\ \% = 110 - R * 25$$

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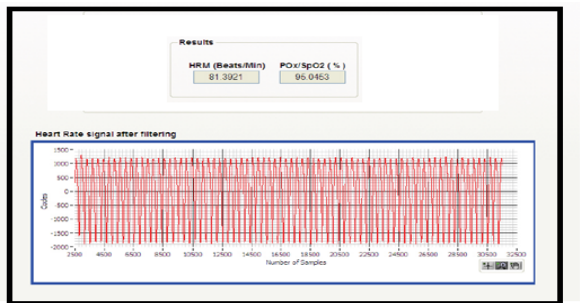

Figure 6: SpO2 & HR Display

Results and Summary

The measurements which were carried out on the system is showing good agreement values measured with standard Contec Pulseoxymeter (CMS50E) pulse oximeter. The empirical calibration process, the measurements exhibited slight deviation, but all these measurements we within the tolerance range of the system is compact it can be used at ambulance services also. The measured values are present in table

Table: pulseoxy measurement SPO_2 with Contec Pulseoxymeter (CMS50E)

S. No	Pulse oxygen		Heart rate	
	Contec Pulseoxymeter (CMS50E)	Present designed	Contec Pulseoxymeter (CMS50E)	Present designed
1	93.2	93.1	98	98
2	93.2	93.19	95	95
3	92.8	92.9	93	92
4	93.5	93.4	102	102
5	93.4	93.3	95	95

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