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DEVELOPMENT OF NIOS II SOFT-CORE PROCESSOR FOR HEART RATE AND OXYGEN SATURATION

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Abstract: This paper deals with the instrumentation development for heart rate and oxygen saturation using NIOS II soft-core processor. In this day and age checking oxygen saturation and heart rate is essential in healing centers to monitor low oxygen levels in blood. We have designed a novel soft-core processor running on NANO DE0 board with a finger probe consisting of two LED's (660nm/940nm) and a single silicon photo-detector with transimpedance amplifier to measure the absorption of ratio for two wavelengths. This system is used to monitor oxygen saturation in blood and heart rate for 5 different subjects. The result was verified with another Pulse oximeter for 20 measurements on 5 different subjects. It was discovered that the readings taken were very close to the Pulse oximeter

Keywords: *Heart rate, NIOS II, Oxygen Saturation, photoplethysmography, soft-core, SOPC.*

I INTRODUCTION

Estimation of heart rate and oxygen saturation are vital variables to access the functioning of human cardiovascular system. The percentage of oxygenated blood decides the effectiveness of a patient's respiratory system [1]. One of the most vital elements required to sustain life is oxygen (O_2) because it is used by cells to transform sugars into usable energy. Oxy-hemoglobin (HbO_2) is found in a red platelet which is attached to O_2 that conveys 98% of oxygen to the cells. The estimation and count of oxy-hemoglobin (HbO_2) in blood vessel blood is known as Oxygen Saturation (SpO_2) oximeter [2], [3].

Initially, SpO2 was measured invasively by Arterial Blood Gas (ABG) testing. In this procedure the blood test is drawn from an artery and analyzed each time, the blood vessel blood gas gives just irregular observing which may not be perfect for checking unsteady patients. Since this system is invasive, it is painful and can cause contaminations like blood vessel thrombosis and gangrene. The requirement for a non-invasive technique for measuring SpO2 continuously prompted the advancement of a gadget to gauge heart rate and oxygen saturation [3]. Once a patient begins losing oxygen, a doctor has under three minutes to avoid danger of cerebrum harm and heart failure. A healthy person should have SpO_2 in between 94% to 100% [1]. It is important to monitor oxygen level in blood when the patient is in the recovery room and intensive care unit to detect hypoxemia.

A heart rate meter is a device that allows a person to monitor their heart beat in real time. The heart rate of a healthy grown-up at rest is around 72 beats per minute (bpm). If the heart rate is lower than normal value, it is known as bradycardia, if the heart rate is higher than normal value, it is known as tachycardia. Normally Heart rate is measured by placing the thumb over the person's arterial pulsation and counting the number pulses in a 60 second period [4], [9].

II RELATED WORK

Alot of Research work is carried out in estimating Oxygen saturation and heart rate of an individual. Heart Rate Counter was designed using PIC16F628A along with LED's/Phototransistor with a signal conditioner to measure heart rate in relaxed state and stressed state [4]. Pulse Oximeter using Arduino Uno and LED’s/detector was constructed to calculate heart rate and oxygen saturation. Also pressure sensor probe was used to measure blood pressure [5]. Designed a continuous monitoring of Pulse Rate and Oxygen saturation using LED’s, photo detector and transimpedance amplifier [6]. Proposed a wireless pulse oximeter using zigbee protocol to calculate Oxygen saturation and generates alarms to the medical staff whenever it crosses the limit [7]. Designed a Wireless Pulse oximeter using Bluetooth Technology to calculate Oxygen saturation using absorption ratios for two wavelengths [8]. Heart rate monitor was designed using infrared LED and Photodiode, signal conditioner and Arduino Uno. The Processing software displayed real time heart rate and PPG waveform [9].

III HARDWARE DESIGN

Several researchers have designed Pulse Oximeter using different controllers but in our design we have chosen specific components to build a soft-core processor using NIOS II running on Field Programmable Gate Array (FPGA).

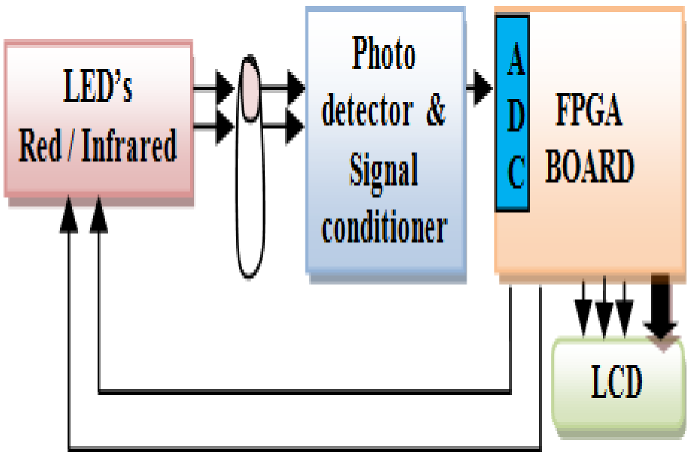

Figure 1: Block diagram of the NIOS II Soft-core Processor for Heart rate and Oxygen saturation.

The design for the non-invasive system for Heart rate and Oxygen saturation is shown in the Figure 1. It consists of finger probe with two wavelengths of LEDS and a single photo detector, signal Conditioner, FPGA Board and Liquid Crystal Display (LCD). The two LED's (660nm/940nm) timings are controlled by NANO DE0 FPGA board. Behind the finger, a single silicon photo detector with inbuilt transimpedance amplifier is used to convert the light signal into low amplified electrical signal. Variation in light intensity is due to changes in perfusion in the blood volume. The next stage is signal conditioning stage which allows only frequencies in range of 0.7 Hz to 2.28Hz. Then the analog output from the band pass filter is given to the NANO DE0 FPGA Board which has a 12-bit Analog Digital Converter (ADC) to convert analog voltage to digital voltage. It stores the digital value when either of the LED is switched ON. This value is used to calculate oxygen saturation and heart rate which is displayed on the LCD.

A. Principle of Pulse Oximetry

Pulse oximetry derives Oxygen saturation (SpO_2) and heart rate from photoplethysmogram (PPG) signal that reflects the changes in the blood volume per cardiac cycle. It is obtained by measuring changes in light absorbed by the blood. Red and infrared wavelengths are used to obtain the PPG because this wavelength are easily penetrate through tissues and has large absorption coefficients. Deoxy-haemoglobin have a high absorption at 660nm and oxy- hemoglobin has a high absorption at 940nm. [3].

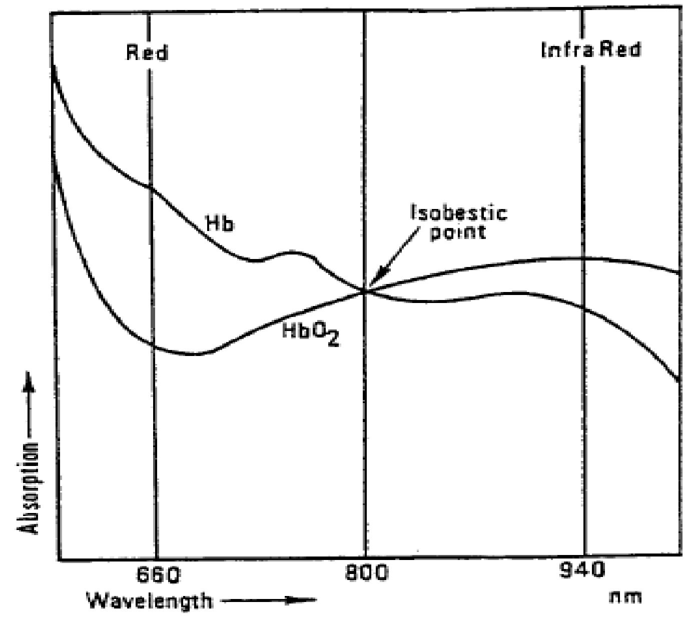

Figure 2: Absorption spectra of Oxy-haemoglobin & deoxy-haemoglobin [10].

The absorption of visible and near infrared light by haemoglobin varies with oxygenation. This is because oxy-haemoglobin (HbO_2) and deoxy-haemoglobin (Hb) have essentially unique optical spectra in the wavelength range from 600nm to 1000nm is shown in Figure 2[10].

By using Beer Lamberts Law, we can calculate the absorption ratio utilizing Eq. 1.

$$R = \frac{\left(\frac{V(ac)}{V(dc)}\right)(Red)}{\frac{V(ac)}{V(dc)}(Infrared)} \quad (1)$$

where the V_{DC} is the light absorption of the tissue and venous blood. The V_{AC} is the light absorption of the variable arterial blood [11].

$$SpO_2\% = 112 - 24*R \quad (2)$$

Equation 2 is the empirical equation to calculate the SpO_2.

IV SOFTWARE DESIGN

In our design we have used NIOS II soft-core processor to receive the analog signal for two different wavelengths and do the necessary calculations to calculate the Heart rate and Oxygen saturations using empirical formula.

The selected SOPC components for building the Non-Invasive Heart rate and Oxygen saturation are 32-bit NIOS II CPU, JTAG UART, On chip Memory, Interval Timer, ADC, LCD is shown below in Figure 3. This processor is interfaced to the on chip RAM to store the program code and the transmitted signal received from finger probe via ADC.

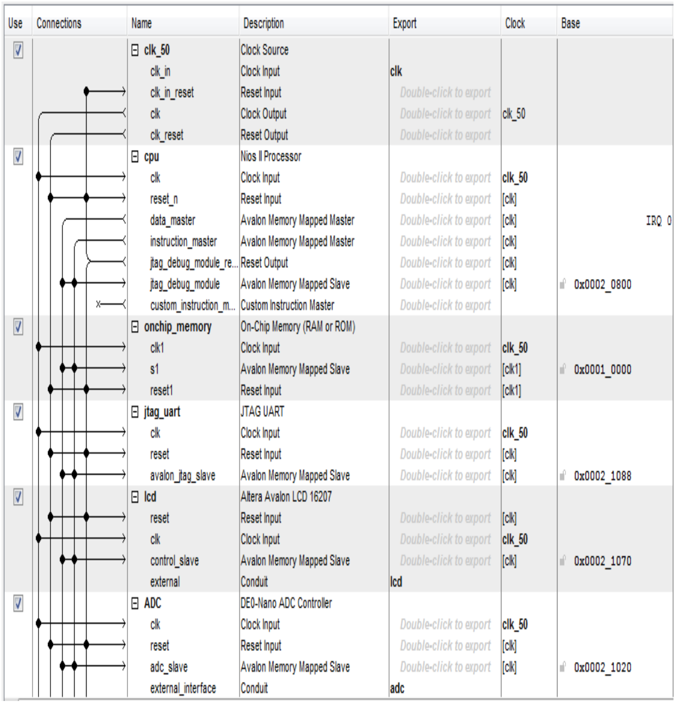

Figure 3: SOPC Block selected to build a NIOS II system

The generated system is imported to Quartus Block diagram file window and later the pin mapping is done as shown in Figure 4.

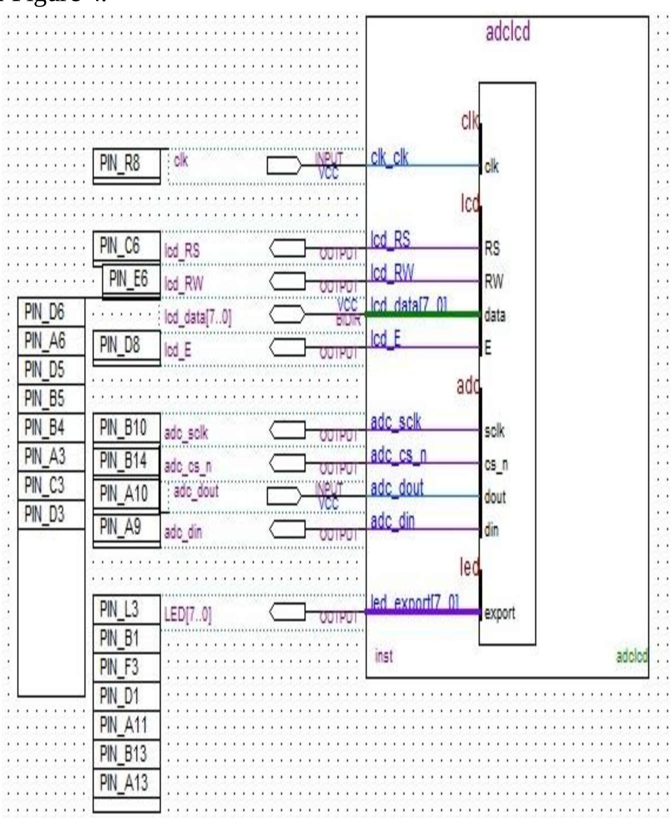

Figure 4: Finger probe and LCD interfacing with designed NIOS II system.

Once the design is compiled, the programming file is ported on NANO DE0 FPGA Board running on Cyclone IVE using USB blaster. The C program code is written on the NIOS II system to get the expected result. The flowchart for the C code for NIOS II system for Heart rate and oxygen saturation is shown in Figure 5.

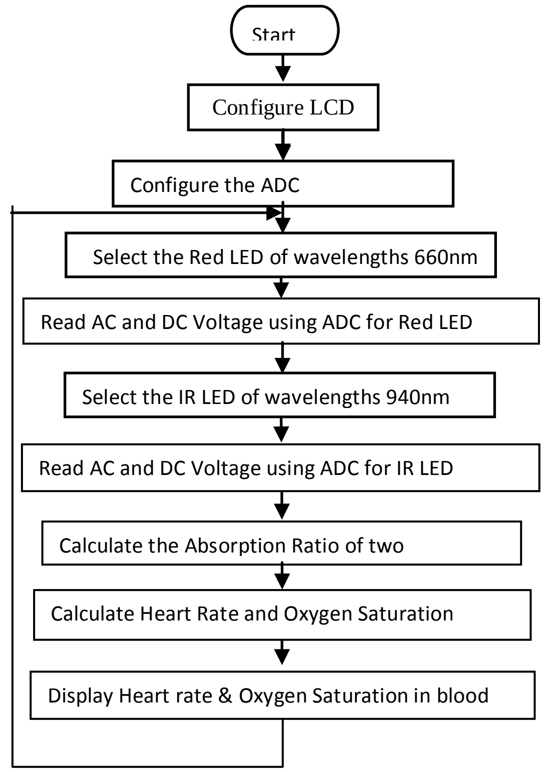

Figure 5: Flowchart for NIOS II based heart rate and oxygen saturation

First the LCD is configured as 8 bit data, display on and cursor on. The ADC is also configured to read the transmitted analog voltages from the finger probe via signal conditioner. The two wavelengths (660nm & 940nm) will be selected by the soft-core processor one at a time. The AC and DC voltage is read using 12 bit ADC when Red LED is ON. Also The AC and DC voltage is read using 12 bit ADC when Infrared LED is ON. Then the Absorption Ratio is calculated for the two wavelengths. The Heart rate is calculated by counting the number pulses per minute and Oxygen saturation is calculated using absorption ratio with empirical formula. Finally Heart rate and Oxygen Saturation are displayed on the LCD.

V RESULT AND DISCUSSIONS

The Quartus II software was used for building the NIOS II based Heart rate and oxygen saturation meter which was programmed onto NANO DE0 Board. At last it was connected to the Finger probe with two LED’s (660nm/940nm) and a single photo detector with inbuilt transamplifier and signal conditioner to get the heart rate and oxygen saturation for 5 subjects with 10 estimations each. It was discovered precise with less error when contrasted with standard Pulse Oximeter.

The PPG signal was also observed during each heart beat for two different wavelengths of LED's (660nm and 940nm) using Digital Storage Oscilloscope.

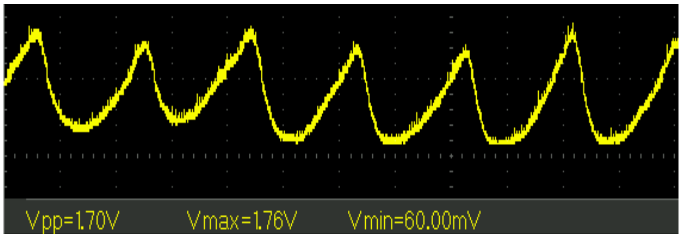

Figure 6: PPG signal for RED LED

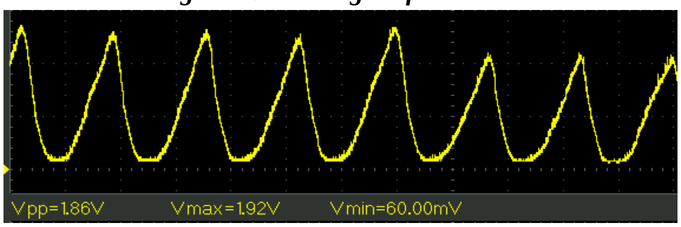

Figure 7: PPG signal for Infrared LED

Figure 6 shows that Red LED at 660nm has a small PPG signal compared to figure 7 with IR LED at 940nm. From the above figures it shows that less Red light is transmitted through finger compared to Infrared LED.

Table 1 Heart Rate and Oxygen Saturation

Subject	Red (660nm)		IR (940nm)		Ratio R	SpO_2 %	Heart Rate	SpO_2 %	Heart Rate
	V_{ac} (V)	V_{dc} (V)	V_{ac} (V)	V_{dc} (V)		Using designed NIOS II System		Using standard Pulse Oximeter	
1.	1.74	0.756	1.96	0.50	0.58	98.08	75	98	1.74
2.	1.74	0.746	1.88	0.48	0.59	97.72	72	97	1.74
3.	1.68	1.375	1.86	0.85	0.57	98.32	74	98	1.68
4.	1.68	1.375	1.82	0.77	0.51	99.76	77	98	1.68
5.	1.70	1.285	1.86	0.76	0.54	98.84	72	98	1.70

VI CONCLUSION

The Development of NIOS II Soft-Core system for Heart rate and Oxygen saturation was designed on NANO DE0 FPGA Board. The C program code was written and programmed into the FPGA for calculating and displaying heart rate and oxygen Saturation for 5 subjects. It was found accurate with fewer errors as compared with standard pulse oximeter. Further Work has to be carried out to calculate the Total Haemoglobin.

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