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Development of pulse oximeter device for the continuous monitoring of Pulse rate and Oxygen saturation percentage and its interfacing with LabVIEW

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ABSTRACT

The continuous monitoring of intensive care patients' conditions is an important area of research in the field of Biomedical Engineering. Patients' body behaves in a dynamic manner; hence it needs continuous monitoring and recording of their conditions. These require multi-parameter systems for continuous sensing, processing and displaying the conditions of the patient. Since these systems are non-invasive in nature, it is not easy to monitor the medical parameters of patients reliably because the monitoring techniques are very sensitive to various artifacts appearing when the person is active. To overcome these difficulties, these multi parameter monitoring devices should be incorporated with advanced signal processing systems to display the accurate values of the parameters with less cost. A multi parameter system measures the vital parameters of the human body like Saturation pressure of Oxygen (SpO_2), Electro Cardiogram, Blood Pressure, etc. The system is divided into parameter based sub-modules which needs to be developed indigenously.

With the objective of developing cost effective and reliable indigenous multi-parameter modules, this paper focuses on the development of one of the vital parameters namely SpO_2 module (Pulse Oximeter). The market survey of the available pulse oximeter is conducted and a specification to design an indigenous SpO_2 module is derived. The methodology to develop the SpO_2 module is formulated. The developed module is calibrated using a simulator to give accurate and consistent results and compared against a standard module. Aftermath of the satisfactory results, the SpO2 module has been given to hospitals for real time monitoring of patients.

Keywords: *Oxygen, LabVIEW, Probe, Pulse rate, SpO_2, monitor*

1. INTRODUCTION

Multi-parameter monitor is equipment which monitors a patient's condition continuously. Multi-parameter monitors integrated with sensors attached to the patient measure, display and document physiological information about the patient. The information obtained over a period can be stored in multi-parameter monitors and can be viewed at any time to analyze the significant improvements of the patient. It can also generate an audio and visual alarm if the monitored parameter crosses the set safety limit.

Measured parameters include electrocardiogram (ECG), invasive and non-invasive blood pressure, pulse rate, pulse oximetry (SpO_2), body temperature, respiration rate, end-tidal CO_2 and other specialized parameters. Among these parameters, Pulse oximetry is first used for vital sign monitoring during operations and anaesthesia. Since the device is non-invasive and allows immediate and real time monitoring, its use has expanded to include other purposes such as screening, diagnosis, patient follow-up and self-monitoring.

1.1 Biological principles of oxygen movement

Oxygen saturation is an indicator of oxygen transport in the body, and indicates if sufficient oxygen is being supplied to the body, especially to the lungs [1], [2], [3] & [5]. The oxygen saturation is the ratio of the oxygenated hemoglobin to the hemoglobin in the blood.
Hemoglobin is stable only when bound to 4 molecules of oxygen or when not bound to any oxygen. It is very unstable when bound to 1 to 3 molecules of oxygen. Hemoglobin exists in the body in the form of deoxygenated hemoglobin (Hb) with no oxygen bound, or as oxygenated hemoglobin with 4 molecules of oxygen.

The purpose of the Pulse Oximeter is to determine the severity of a disease, analyse blood gas, deciding on hospitalization of patients with chronic diseases when in acute phase.

After making the exhaustive study of working principle [7] - [13] and the components of SpO_2 module, the steps to develop the indigenous product of SpO_2 module are derived and followed. First the design and development of SpO_2 probe sensor has been made and it is checked and tested for normal working condition. The development of SpO_2 module has been done followed by the design of SpO_2 probe. The developed SpO_2 module has been compared and tested against the standard modules available in the market for the evaluation of consistency and repeatability. Finally the results of SpO_2 module have been displayed.

2. METHODOLOGY

The methodology to develop the proposed SpO_2 module is clearly explained as follows:

The three major stages of SpO_2 pulse oximeter measuring device are listed as follows:

Sensing stage -- Design and development of SpO_2 probe sensor
Processing stage -- Development of SpO_2 module
Displaying stage -- Display of results

The methodology to design the SpO_2 probe is displayed in the form of block diagram as shown in the figure 1. The functional requirements of SpO_2 probe are studied. The modeling of SpO_2 probe's end cover is made using modeling software 'solid works 2010'. Then it is developed using Rapid prototyping machine. The electrical components are assembled with the end covers. Finally the SpO_2 probe is tested and validated for normal working conditions.

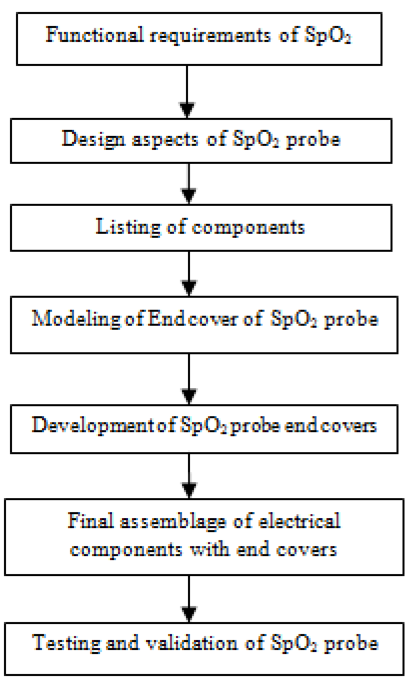

Figure 1 Block diagram to develop SpO_2 probe

The methodology to develop the SpO_2 module is presented in the form of block diagram as shown in the figure 2.

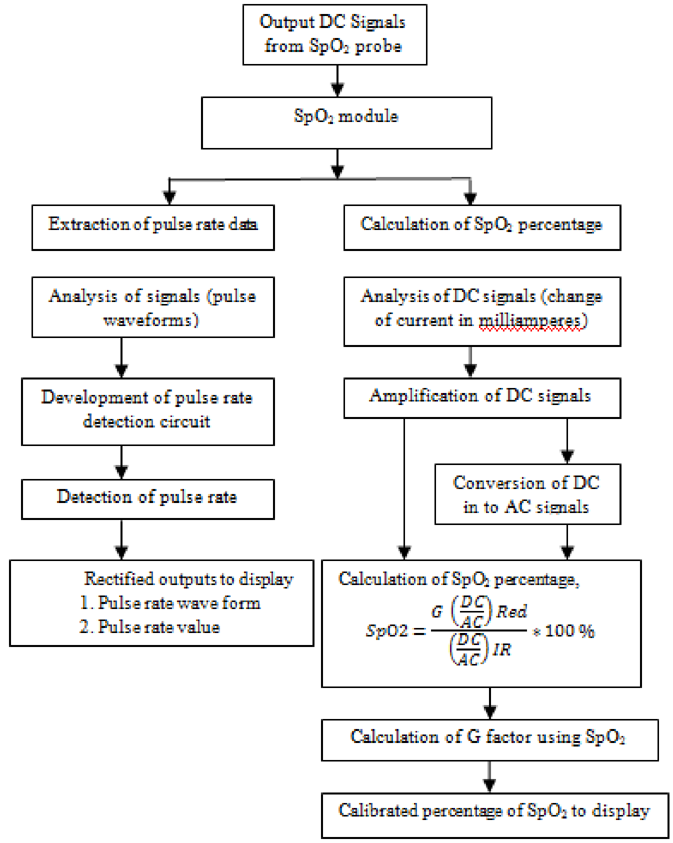

Figure 2 Block diagram to develop SpO_2 module

The output DC signals from the SpO_2 probe is passed to the module for further processing. From the signals, the extraction of pulse rate and the signals need to find the percentage of SpO_2 is done. After processing the signals, the calibrated outputs are sent to the displaying stage. The processed signals from the SpO_2 module are displayed in the different displaying platforms such as Multi parameter monitor, Front panel of LabVIEW, LCD display since the module is compatible to all such platforms.

3. DEVELOPMENT OF SPO_2 PROBE

The functional requirements and working principle of SpO_2 Probe has been studied [3], [4]. The purpose of using IR LED, which produces radiations selectively absorbed by oxygenated blood and Red LED, which produces radiations selectively absorbed by deoxygenated blood has been justified [5], [6]. The SpO_2 probe is designed and developed as per the steps depicted in the block diagram (shown in figure 1).

3.1 Testing and Validation of SpO_2 Probe

The SpO_2 probe is tested for repeatable and consistent results. For that, a standard voltage of 5V is supplied to the IR and Red LEDs one over the other for different intervals using Pulse Width Modulator (PWM).

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3.1.1Input signals

The LED timing diagram showed in figure 3 displays the sequence of switching the LED and the time period of each switching. This timing control is achieved by microcontroller or a pulse width modulator. This modulated input is given to the LEDs.

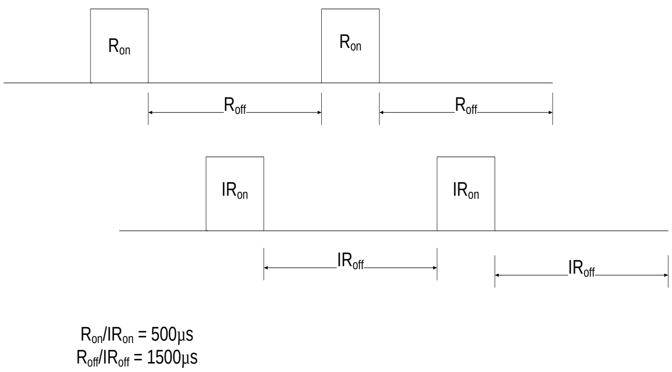

Figure 3 LED Timing Diagram

3.1.2 Output signals

The output voltage from the photo receiver is measured using multimeter. The results obtained are discussed as follows.

Case 1: From the figure 4, In a SpO_2 probe without finger, for an input of 3.3V, 3.1V is received at the photo receiver. The remaining 0.2V is lost due to the scattering of light waves.

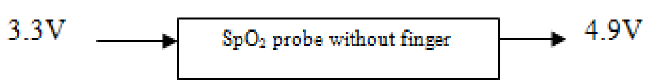

Figure 4 Voltage variation of SpO_2 probe without finger

Case 2: From the figure 5, In a SpO_2 probe with finger, for an input of 3.3V, the output voltage varies between 0.25V to 0.5V. This variation in the output voltage is due to the fluctuations in the flow rate of blood pumped from the heart which is a source for the measurement of pulse rate. The reduction in the output voltage is due to the absorption of light rays by the oxygen present in the blood which is a source for the measurement of SpO_2 percentage.

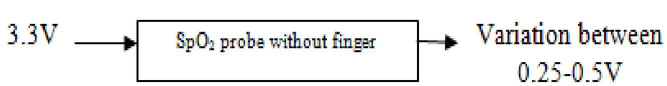

Figure 5 Voltage variation of SpO_2 probe with finger

4. EXTRACTION OF PULSE RATE

The signals from the SpO_2 sensor probe are fed to the electrical circuit for further processing. Then it is interfaced using the interfacing software 'LabVIEW' through Data Acquisition card (DAQ card) and the results are displayed in the LabVIEW front panel.

4.1 Electrical Circuit for the detection of Pulse rate

The electrical circuit for the extraction of pulse rate is shown in the figure 6. Here IC LM324, Which is used as both comparator and amplifier, is placed to exactly detect the pulses.

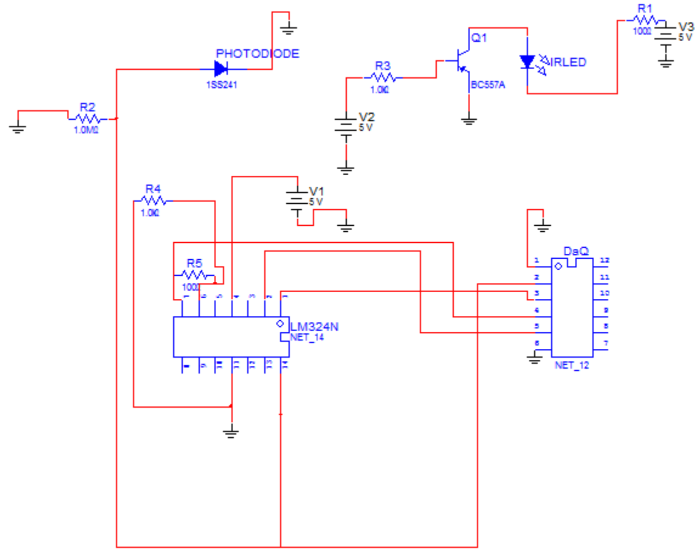

Figure 6 Electrical Circuit for the pulse rate extraction

The reference voltage is estimated by averaging the peak values obtained for 6 seconds and given it to the DAQ. This reference voltage is checked against the receiver voltage (i.e. signals from the sensor) by IC LM324. After the comparison, the pulse peaks are outputted by IC which is plotted in the waveform chart. Also the readings are displayed in the numeric indicator as 'pulse rate'.

4.2 Pulse rate results

In this display(shown in figure 7), the waveform plots are drawn for amplifier output, DAQ output, and comparator output for a time period of 10 seconds. The magnitude of all the values and the pulse rate are displayed in the numeric indicator.

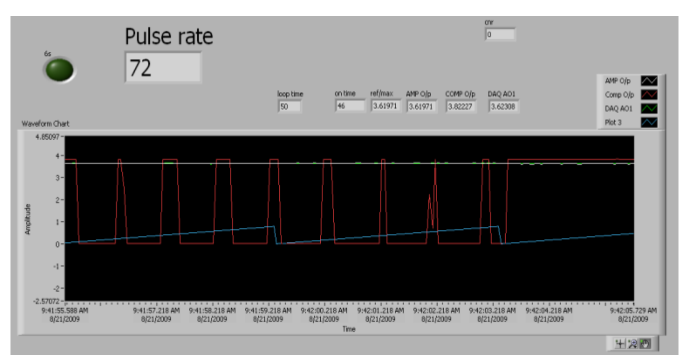

Figure 7 Pulse rate results from SpO_2 probe with the circuit

5. DEVELOPMENT OF SPO_2 PERCENTAGE

The development of SpO_2 percentage is taken place in four stages. These are as follows: signal reception, conditioning, processing and calculation of SpO_2 percentage.

5.1 LED Switching and Intensity control circuit (Stage I)

As shown in the figure 8, this circuit enables the switching of IR and Red LEDs providing options for the sequential control of IR and Red LED switching and also the intensity control of the LEDs. To achieve this, the circuit makes use of two transistors namely BC856A and MMBT2222. The transistor BC856A is used to switch the IR and Red LED ON or OFF. The transistor MMBT2222 is used for the intensity control of the LEDs. Proper resistors are provided to the ICs to prevent the damage caused due to the flow of large amount of current.

BC856A, being a PNP transistor, is activated and deactivated by connecting it to ground and power source respectively. This in turn, switches the LEDs ON and OFF. MMBT2222, being a NPN transistor, is activated and deactivated by connecting it to power source and ground respectively. The voltage supplied to the base of MMBT2222 is varied. By varying the voltage supply, the amount of current flowing to the LEDs is changed which in turn changes the intensities of LED radiations.

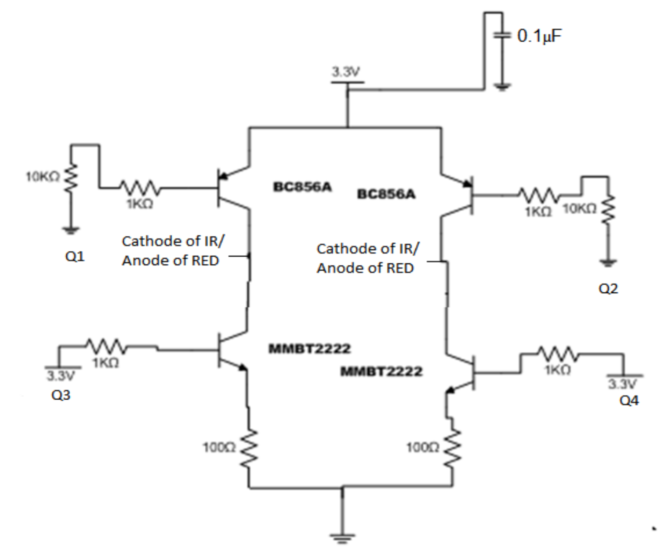

Figure 8 Drive Circuit of LED

The need for the sequential switching of LEDs provided by the LED switching and Intensity Control circuit is fulfilled by ‘Timing VIs’ in LabVIEW or ‘Counter/Timers’ in embedded systems.

The developed LED Switching and Intensity control circuit is tested using the standard probe ‘Nellcor’.

5.2 Transimpedance Amplifier Circuit (Stage II)

Transimpedance circuit is used to convert the current changes with respect to a fixed reference voltage into a significant voltage difference. The transimpedance amplifier namely OPA381 is selected for this purpose. The photoreceiver (photodiode) in the Nellcor probe varies the current output depending on the amount of light waves incident on it. The range of current is in milliamperes, which is very low.

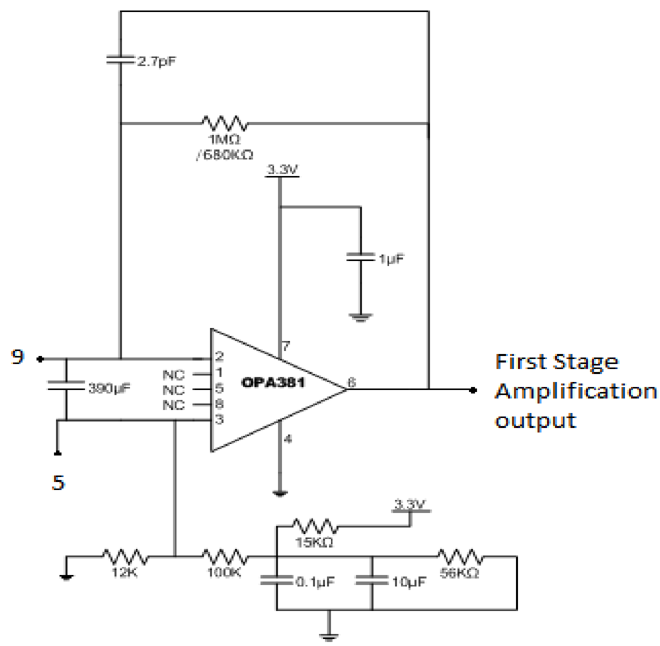

Figure 9 Transimpedance Amplifier Circuit

The circuit of transimpedance amplifier is displayed in figure 9. The reference voltage given to the transimpedance amplifier is 2.5V, which is obtained from 3.3V source by stepping it down using the resistors 56kΩ, 15kΩ and 100kΩ. This is made to avoid the need to have a separate 2.5V source. The photodiode produces current changes when the transmitted light incident on it varies due to the flow of blood when the finger is placed. This variation of current is sent to the pins 2 and 3 of the IC OPA381. The output is received from the 6^{th} pin of the IC OPA381. This is the output of First stage amplification. The output is proportional to the amount of current change caused by photodiode.

5.3 Second stage Amplifier (STAGE III)

The output difference from the first stage amplification during the flow of blood, caused by placing the finger, is around 0.3 ~ 0.7V which is very less to characterize the condition of blood. This caused the need to use a second stage amplifier. The IC chosen for this purpose is LM324. This is selected because it is meant to amplify the output of First stage amplifier as the output difference is very minimum and compare the signals with the reference voltage to generate pulses.

The selected IC is a Quad Operational Amplifier which satisfies both the above mentioned purposes simultaneously. The gain set in the IC is 1.17 using the resistors 51kΩ and 10kΩ. The gain is set such that the output does not get saturated i.e. the gain cannot be set more than the excitation voltage of the amplifier (3.3V). The output is obtained from the 1st pin of OPA381 as displayed in the figure 10.

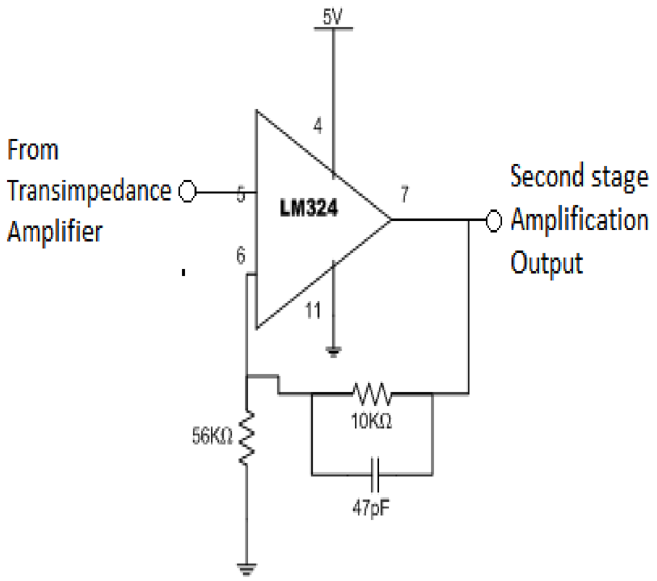

Figure 10 Second Stage Amplifier Circuit

5.4 Calculation of SpO_2 percentage (STAGE IV)

The output from Second stage amplification is used to calculate the percentage of SpO_2 using equation (1).

SpO_2 %= {Amplifier output during IR light transmission*100 / (Amplifier output during IR light transmission + Amplifier output during Red light transmission)}... (1)

The amplifier output refers to the output received from the second stage amplifier. It is clearly understood that the formula is actually a ratio of voltage absorbed by oxygenated haemoglobin to the voltage absorbed by both oxygenated haemoglobin and deoxygenated haemoglobin.

The LabVIEW program has been constructed to control the timing of LED Switching and Intensity control circuit, acquire the output signals from the First stage and Second stage amplifiers, process them to calculate the SpO2 percentage and display it. Additionally ‘Finger placed’ or ‘Finger Removed’ string is displayed when finger is placed and removed respectively.

6. RESULTS OF SPO_2 PERCENTAGE

The table 1 shows the results of SpO_2 percentage of a person taken at different intervals using a developed module.

Table 1 Results of SpO_2 Percentage

Samples	SpO_2 Percentage
1	95.8
2	98.3
3	87.6
4	98
5	93.7
6	101.2
7	105.9
8	90.7
9	88.1

The results obtained are plotted in the graph (shown in figure 11) for analyzing the values.

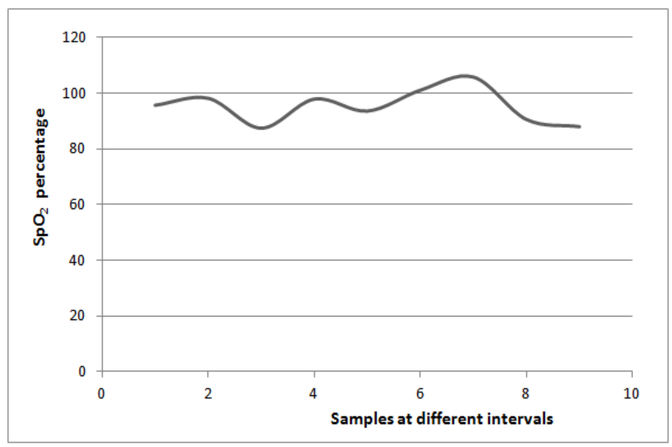

Figure 11 Sample Number Vs SpO_2 percentage

It is clearly revealed that the results need stability and also it deviates out of its range of 100%. This is rectified by using a simulator to correct the processing of outputs.

6.1 Calibration Results

The simulator used for calibration is Rigel SpO_2 simulator. The simulator is connected to the developed module. The SpO_2 percentage set in the simulator generates the corresponding current change. The transimpedance amplifier and the second stage amplifier amplifies the received signals. These outputs are used to find the ratio of SpO_2.

The value of SpO_2 set in the simulator and the corresponding output voltages from the developed module are listed in the table

2. Using these results, the ratio of SpO_2 and factor of correction namely 'G' are found.

Table 2 Calculation of G Value

Sample	SpO_2 Percentage from the developed module	SpO_2 Percentage from Standard module	Error Percentage
1	96.7	96.3	0.415369
2	98.3	97.9	0.40858
3	99	99.1	-0.10091
4	98.0	98.5	-0.50761
5	97.6	96.9	0.722394
6	98.5	95	3.684211
7	99.1	98.5	0.609137

The SpO_2 values set in the simulator and the ratio of SpO_2 are plotted in the graph (shown in figure 12) to find the relation between them.

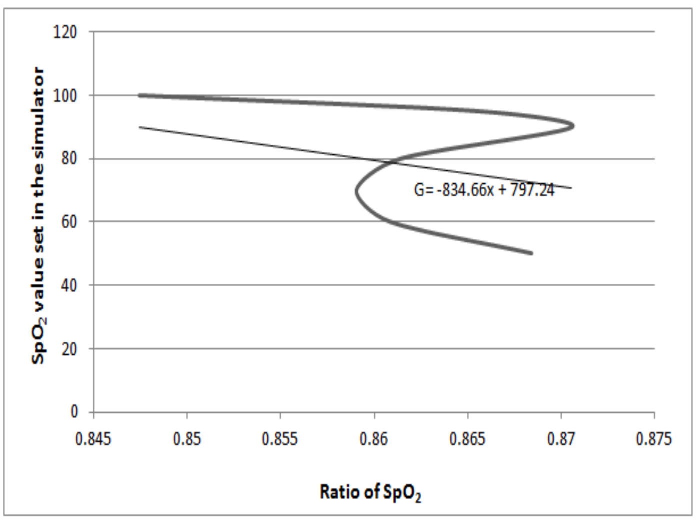

Figure 12 SpO_2 percentage Vs Ratio of SpO_2

The value of SpO_2 percentage is estimated from 834.66x + 797.24, where x denotes the Ratio of SpO_2. Using this calibration, the value of SpO_2 percentage is predicted accurately.

6.2 Comparison Results

After the calibration of results and rectification of the possible ways of errors, the results obtained from the developed module are compared with the standard module made by Dolphin [14] to check for its correctness and consistency and it is shown in the table 3.

Table 3 Comparison Results of SpO_2 Percentage

SpO_2 percentage set in the simulator	IR voltage	Red Voltage	Ratio of SpO_2 = (IR/(IR +RED))
50	0.905	0.137	0.868
60	0.869	0.140	0.861
70	0.864	0.141	0.859
80	0.895	0.144	0.861
90	0.872	0.129	0.870
95	0.861	0.134	0.866
100	0.859	0.155	0.847

From the results, it can be observed that the results are consistent and precise and its deviations from the standard module are negligible.

7. CONCLUSION

The market survey conducted for the SpO_2 products revealed that there were no manufacturers producing SpO_2 products indigenously in India. Thus the need for the development of indigenous SpO_2 product was emerged to enhance the technical competency of India and to provide the cost effective products for the hospital requirements both in urban and rural areas. The objectives and methodology were set to develop an indigenous SpO_2 Module by developing the SpO_2 probe; Pulse rate extraction Circuit and SpO_2 percentage development circuit. First the design and development of SpO_2 probe sensor was made and it was checked and tested for normal working condition. The development of SpO_2 module was done followed by the design of SpO_2 probe. The problems diagnosed in the circuit module, were studied and rectifications were made. The developed SpO_2 module was compared and tested against the standard modules available in the market for the evaluation of consistency and repeatability. The results of SpO_2 module is displayed in the front panel of the LabVIEW.

Finally the standalone product of SpO_2 has been developed. The developed product is more compatible to platforms like LabVIEW, embedded systems and Multi-parameter monitor.

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Chidambara Raja S completed his B.E Mechanical sandwich in PSG College of Technology, Coimbatore, Tamil Nadu, India in the year 2012 and obtained gold medal. Currently, he is working as an Engineering Officer in Indian Oil Corporation Limited. He has got 'Best Outgoing Student' award. He was a chairman of American Society of Mechanical Engineering, students section in PSG College of Technology and he has been honored with 'Achievement Award' of ASME.

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He has organized several national and international conferences. He has taken up many industrial consultancy activities with industries like PRICOL, LMW, ELGI, Ashok Leyland etc., He has actively participated in sixteen sponsored projects. He is currently involved in continuing education programmes for industries in the areas of Tolerance Engineering, Automation, Lean Manufacturing and Value Stream Mapping, Sensor – Interface based on virtual instrumentation. He has travelled extensively to various countries like UK, Japan, USA and Germany.

He has won several awards including the prestigious P K Das memorial best faculty award for the year 2010-2011 which was awarded by Nehru College of educational and charitable trust, Coimbatore. He is also responsible for the design and development of critical care medical ventilator indigenously with funding from Society of Bio-Medical Technology; the ventilator has been taken up for commercial production by PRICOL, Coimbatore. Recently another product "Infant Ventilator" was collaboratively developed by PSG and Pricol Medical Systems under his leadership and technology transfer has been made to the industry.