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Design of a Pulse Oximeter with Altitude Measurement Bluetooth Communication and Android Application

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Abstract

Implementation of a pulse oximeter with measurement of altitude, heart rate (HR) and oxygen saturation (SpO_2) with bluetooth communication, in the need of real-time as well as remote monitoring by the therapist with the purpose of avoiding the spread of the SARS-CoV-2 virus. With the use of bluetooth technology, the data is transmitted in real-time to a mobile phone through an application in the Android operating system, a medical history record is generated using the MIT App Inventor platform, likewise an audible alarm is activated in case the saturation level is out of range, taking into consideration the variation in oxygen saturation depending on the altitude where measurement is taken.

Keywords: Rehabilitation; COVID-19; SpO_2; Monitoring; Oximetry

Introduction

Mexico suffers large-scale consequences, not only from the point of view of the health sector, but also from social and economic effects; the systems that provide health services, particularly Rehabilitation Medicine, cannot ignore the effects of the disease or actively participate in the fight against it and its consequences [1].

For a long time, rehabilitation services have participated in the care of cases with Acute Respiratory Distress Syndrome (ARDS), clearly contributing to an improvement in the quality of life of people, and a faster integration into daily activities of those affected [2].

Post-COVID Sequels and Syndrome

The definition of post-COVID syndrome implies the persistence of symptoms or the development of sequelae beyond 4 weeks after the start of the acute symptoms of the disease. The most common manifestation is the dyspnea that can lead to the need for supplementary oxygen due to persistent hypoxemia. A pulmonary rehabilitation therapy with the monitoring of blood oxygen saturation as a progress record means a possibility for patients to stop the deterioration caused by the disease and recover their previous pulmonary capacity as much as possible.

The purpose of respiratory rehabilitation in patients with COVID-19 is to improve symptoms of shortness of breath, decrease anxiety, reduce complications, preserve pulmonary function, and improve life quality [3].

Objective

The objective of this paper is the design of a pulse oximeter with Bluetooth communication and altitude measurement, heart rate and SpO_2, corresponding to the need of a real-time as well as remote monitoring by the therapist with the purpose of avoiding the spread of the SARS-CoV-2 virus.

With the use of Bluetooth technology, the data is transmitted in real-time to a mobile phone through an application in the Android operating system, an automatized medical history record is generated in the rehabilitation process, this information can be downloaded via email for further processing.

Moreover, the device incorporates an audible alarm which is activated in case the blood oxygen saturation level is out of range, taking into consideration the variation of this parameter in respect to the height measurement above sea level.

Oximetry

Pulse oximetry is a technology that measures the percentage of SpO_2 by light emitting diodes (LED). When hemoglobin carries oxygen, it is called oxyhemoglobin (HbO_2) and is of an intense red color; when it transports carbon dioxide, it is called deoxyhemoglobin (Hb) and is a bluish red color. This color difference is because Hb and HbO_2 have a difference in the optical spectrum in the range of wavelengths between 660nm (near red) and 1000nm (near infrared), as can be seen in Fig. 1. This technology is based on Beer-Lambert-Bouguer's law which relates the intensity of incoming light in a medium with the outgoing intensity after absorption has occurred in this medium, in other words, it is possible to determine the concentration of an unknown solute in a solvent by the absorption of light [4].

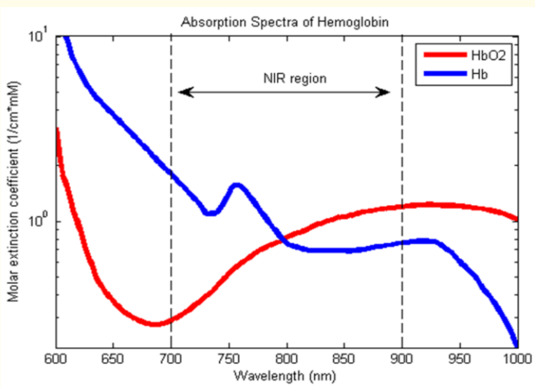

Figure 1: Hemoglobin and Oxyhemoglobin absorption spectra [4].

Photoplethysmography (PPG)

PPG is an optical technique that measures blood volume variations. The main application of dual-wavelength PPG is pulse oximetry, in which the SpO_2 is calculated non- invasively.

Combining two technologies: spectrometry and optical plethysmography, a pulse oximeter can provide information, such as heart rate HR and SpO_2, which is an indirect measure of oxygen contained in the blood and represents an estimation of SpO_2.

Pulse oximetry refers to the determination of the percentage of oxygen saturation in the blood, following equation (1), where SpO_2 is the concentration ratio between oxygenated hemoglobin and all the hemoglobin, Hb is the deoxyhemoglobin and HbO_2+Hb present all the hemoglobin in the blood [5].

$$SpO_2 = \frac{HbO_2}{HbO_2+Hb} \times 100 \quad (1)$$

Optimal Saturation levels

The atmospheric pressure (P atm) or barometric pressure (PB) decreases as the altitude increases, this reduces the partial pressure of oxygen (PO_2) and therefore of the SpO_2; the resulting state of hypoxia causes various physiological variations.

Normally a person must have between 95% and 98% oxygen in the blood. In Table 1, presents, may vary according to the altitude above sea level in which the person is located. Mexico City is located at 2240 meters above sea level.

Saturation State	*0 m.a.s.l.*	*1000 m.a.s.l.*	*3000 m.a.s.l.*	*3400 m.a.s.l.*	*3600 m.a.s.l.*	*3900 m.a.s.l.*
Normal	93-100%	92-99%	88-96%	87-95%	84-93%	83-92%
Mild Hypoxia	89-92%	88-91%	84-87%	83-86%	80-83%	79-82%
Moderate Hypoxia	85-88%	84-87%	80-83%	79-82%	76-79%	75-78%
Severe Hypoxia	< 85%	< 83%	< 79%	< 78%	<75%	< 74%

*m.a.s.l = meters above sea level.

Table 1: Oxygen saturation state according to elevation in meters above sea level (m.a.s.l.).

The Pan American Health Organization (PAHO), in its guide [6], agrees that having less than 90% oxygenation is already considered a risk case, however a specialist doctor should be consulted for a complete diagnosis [7].

Methods and Materials

Pulsatile Oximetry by the Reflective Method

The design and implementation of a pulse oximeter based on reflection techniques was carried out, this method presents less sensitivity to the movements performed by the user or patient [8]. In this prototype we use difference components who has specific functions.

Altitude Sensor/Barometric Pressure MPL3115A2

The Freescale MPL3115A2 sensor is a low-cost detector for barometric pressure and altitude. It has a resolution of 1.5 Pascals at an altitude of 0.3 m. In addition is has a temperature sensor with a precision of ± 1°C. This sensor does not require calibration, and uses I2C digital output interface.

Bluetooth HC-06 Module

The Bluetooth HC-06 module complies with the standard Bluetooth 2.0 specifications compatible with Android cellphones and with the Arduino devices. It contains an EDR module; and the modulation depth change range: 2Mbps - 3Mbps. Has the external 8 Mbit FLASH, build-in 2.4GHz antenna and can work at the low voltage (3.1V~4.2V).

Oled SSD128X64 0.96

SSD1306 is a single-chip CMOS OLED/PLED driver with controller. It consists of 128 segments and 64 commons. OLED (Organic light-emitting diode) is a type of LED in which the emissive layer is formed by an organic compound that emits light in response to electricity.

Sensor MAX30102

Maxim Integrated's MAX30102 is a module for pulse oximetry and heart rate applications, including two LEDs, a photodetector, low-noise electronics and optics with ambient light suppression, it operates on a 1,8 V power supply. and another of 3,3 V for the internal LEDs and has a communications module that works through I²C [9].

The MAX30102 is fully adjustable through software registers, and the digital out- put data can be stored in a 32-deep FIFO within the IC. The SpO_2 subsystem of the MAX30102 contains ambient light cancellation (ALC).

In Fig.2, the emission spectrum of each of the LEDs is shown, it is worth mentioning that the emission wavelength is configurable, so values of 660 nm and 940 nm were used, being the recommended values of the device.

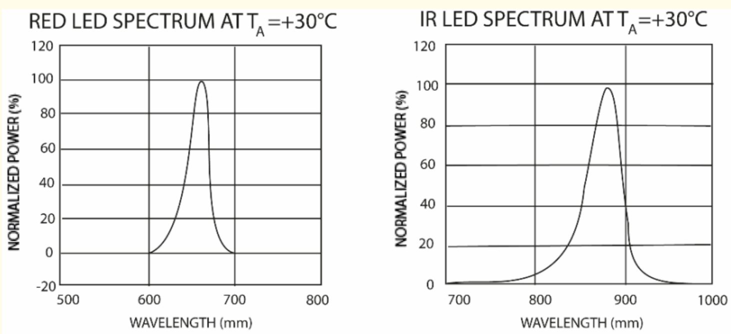

Figure 2: Red and infrared LED operation bandwidth found in the MAX30102, manufacturer information.

Arduino Nano

The microcontroller used is the low-power 8-bit ATmega328 installed in the Arduino nano v3.3 board. It runs at a clock frequency of 16 MHz and has the ability to interface external devices through serial communication via UART TTL (5 V), I²C (TWI) and SPI. All Arduino boards can be programmed with Arduino software and take advantage of the Arduino libraries. Two 4,7v 800 mA rechargeable batteries are required to make it portable.

Measurement of SpO_2

MAX30102 SpO_2 measurements employ two different wavelength LEDs to identify the ratio of oxygenated hemoglobin to the deoxygenated hemoglobin. Red and IR LEDs are used to determine separate PPG signals. As the DC components and AC components of the two LEDS have different amplitudes, they must be normalized to make useful comparisons. For this comparison, a ratio 'R' is determined, which is directly proportional to SpO_2. The following equation for R is known as "ratio of ratios:"

In this method the peaks and valleys are located in each period:

$$R = \frac{\frac{AC_{red}}{DC_{red}}}{\frac{AC_{IR}}{DC_{IR}}} \qquad (2)$$

In Fig.4, the DC and AC values of this method with respect to the peaks and valleys of the signal are defined [10]. Once R is determined, a curvilinear approximation or a lookup table can be used to determine the SpO_2 estimate.

Therefore, it can be concluded that, in a period, AC = Max – Min, and DC = Max.
The peaks and valleys method for calculating oxygen saturation is used.

Calibration

In practice, the empirical clinical form for the calculation of the SpO_2 is used.

$$S = a - bR \qquad (3)$$

In the Ec.3, To obtain the values of a and b of equation 2 that relate the SpO_2 with the R it is necessary to obtain data using a calibrated pulse oximeter. Coefficients a and b can be determined by interpolation.

Table 2 and Table 3 shows the data collected without previous calibration of the device. There were selected 10 volunteers, who underwent 12 samples for two minutes. The data shown in Table 2 represents the average sampling per subject. A commercial oximeter model P2000 certified by the Food and drug Administration (FDA) was taken as the gold standard.

Sample	***Age***	***Gender***	***Oximetry SpO_2***	***Prototype SpO_2***	***Error (%)***
1	48	Man	97.3%	94.1%	3.28
2	61	Man	98.0%	92.5%	5.61
3	52	Man	97.8%	92.3%	5.62
4	59	Man	96.4%	91.9%	4.66
5	53	Man	95.5%	92.7%	2.93
6	51	Woman	97.6%	95.2%	2.45
7	84	Woman	95.9%	92.0%	4.06
8	27	Woman	95.3%	91.4%	4.09
9	57	Woman	96.7%	91.7%	5.17
10	25	Woman	97.4%	92.5%	5.03

*SpO_2 = Pulse Oximetry.

Table 2: Oxygen saturation percentage sampling without calibration.

Sample	***Age***	***Gender***	***Oximetry (p.p.m)***	***Prototype (p.p.m)***	***Error (%)***
1	48	Man	89.4	95.3	6.59
2	61	Man	68.8	73.5	6.83
3	52	Man	88.6	95.3	7.56
4	59	Man	70.7	66.9	5.37
5	53	Man	77.3	72.1	6.72
6	51	Woman	97.9	92.4	5.61
7	84	Woman	87.1	82.6	5.16
8	27	Woman	65.8	69.8	6.07
9	57	Woman	89.2	95.1	6.61
10	25	Woman	68.4	64.3	5.99

*p.p.m = Pulsations per minute.

Table 3: Heart rate sampling without calibration.

Carrying out the calibration curve based on the data in Table 2, we obtained a = 110 and b = 16. In this way Table 4 and Table 5 is obtained. We observe that the percentage of error decreases in most of the samples.

Sample	***Age***	***Gender***	***Oximetry SpO_2***	***Prototype SpO_2***	***Error (%)***
1	48	Man	91.3%	92.6%	1.42
2	61	Man	93.4%	93.7%	0.32
3	52	Man	95.7%	94.7%	1.04
4	59	Man	92.1%	92.9%	0.89
5	53	Man	96.0%	95.1%	0.93
6	51	Woman	95.7%	93.8%	1.98
7	84	Woman	92.2%	93.2%	1.08
8	27	Woman	96.6%	95.0%	1.66
9	57	Woman	95.0%	94.4%	0.63
10	25	Woman	93.8%	94.8%	1.07

*SpO_2 = Pulse Oximetry.

Table 4: Oxygen saturation percentage sampling with calibration.

Sample	***Age***	***Gender***	***Oximetry (p.p.m)***	***Prototype (p.p.m)***	***Error (%)***
1	48	Man	76.8	75.6	1.56
2	61	Man	76.8	79.1	2.99
3	52	Man	78.3	76.4	2.42
4	59	Man	86.7	89.7	3.46
5	53	Man	88.9	89.1	0.22
6	51	Woman	76.4	77.2	1.04
7	84	Woman	78.2	80.6	3.06
8	27	Woman	75.7	77.6	2.50
9	57	Woman	82.6	84.3	2.05
10	25	Woman	70.8	72.1	1.83

*p.p.m = Pulsation per minute.

Table 5: Heart rate sampling with calibration.

An Arduino Nano microprocessor was used in order to take advantage of all the technical properties of the MAX30102 circuit and its digital filtering, as shown in Fig.3.

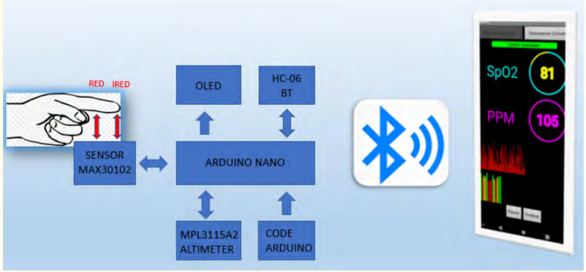

Figure 3: Oximeter block diagram with the mobile.

Design and manufacture

This version weighs 160 grams and measures 56 mm wide, 72 mm long and 25 mm high. The selected manufacturing material is PVC. Fig. 4.

To mount the MAX30102 sensor, two rings were designed, considering the anthropometric measurements of the Latin American population of the index finger for both sexes [11], below a 95th percentile, in this way the patient can perform movements comfortably without affecting the measurement readings. Therefore, there are two rings with measurements of 23.45mm and 22mm, for the male and female sex, respectively.

Figure 4: Design and manufacture of housing and thimble.

The oximeter consists of five stages: SpO_2 and HR sensor, altitude sensor, Oled type display, Bluetooth, and the processing unit with the Arduino Nano, the components of each stage are detailed in section 3.2 Measurement of SpO_2, the schematic diagram is shown in Fig.5

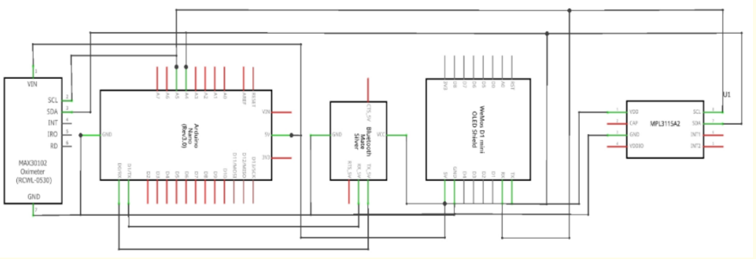

Figure 5: Schematic diagram of the oximeter stage.

The electronic components were optimally placed to reduce the size of the case, in addition to having an on/off switch, a reset, as well as a plug to charge the battery, also a strap for easy fastening was placed as observed in Fig.6.

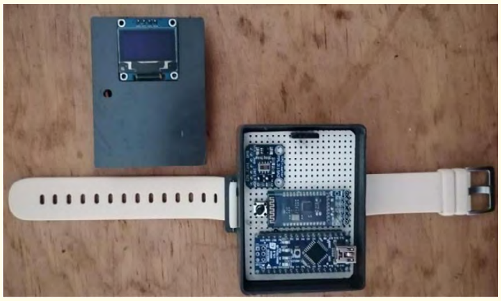

Figure 6: Functional prototype electronics.

Software development

It was decided to use Arduino as a development platform for the hardware and soft-ware of the device.

The MAX30102 sensor together with the SparkFun libraries performs the function of calculating SpO_2 and HR, the calculation algorithm requires the parameters in Table 6.

Parameter	***Value***	***Description***
Sample Av-erage	4	Number of samples to perform an Arithmetic mean and take it as valid sample.
Sample Rate	200	Frequency of samples per second.
Pulse Width	41	The pulse width of the LED was fixed at 411 µs this optimize the calculation of SpO_2 and HR, additionally it serves for energy consumption since it is configured to turn off the LED if there is no variation in the measurement.
Adc Range	4096	The full range of the 12-bit ADC (Analog to Digital Converter) scale is set. Therefore, the sample rate is 50 sps.

Table 6: Parameters for SpO_2 and HR algorithm.

App in App Inventor

The Android application offers the deployment of SpO_2 measurements without looking at the oximeter display, in addition to being able to access and administer the data-base with the records associated with each patient. MIT APP Inventor is an intuitive and visual programming environment that allows all interested to build applications for Android and iOS smartphones. Fig. 7 shows the way in which you can navigate through the application.

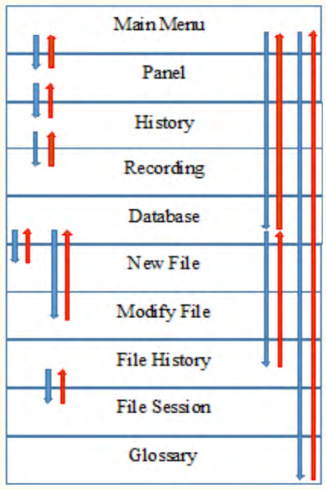

Figure 7: Functions in the app.

The visual deployment of oximeter measurements requires establishing a connection with the Bluetooth module of the pulse oximeter processing unit to receive the information in the form of text strings and be processed by different blocks that make up the Android application, culminating in its visual presentation, ordered on the smart device screen.

Main Menu: Screen where you can find the options to start the measurements (Panel), see the available databases (Data Bases) and open the visual glossary (Represents with the interrogation symbol). Fig. 8.

Figure 8: Screen Main Menu.

File History: It is a direct access to see the historical records available from the menu in Fig. 9.

Panel: Here the connection with the oximeter must be established. Once connected, the measurements of SpO_2 and PPM are shown in real time, being the direct interface with the oximeter. You can also record the session (Recording) and access the patient's history (History). Fig. 9.

Figure 9: Oximeter connection window, with SpO_2 and PPM indicators.

History: Shows a list of each of the records, when selecting the file, it can be opened or deleted. Right side Fig.10. Recording: This section shows the information collected in the previously selected record. Left side Fig.10.

Figure 10: Right: History recording list window. Left: window with data deployed from SpO_2 and PPM of a recording.

Databases: Records is displayed. In addition to having the option to create new files or modify the information of existing ones (Modify File). Fig. 11.

Figure 11: Databases screen.

New File: Collects the patient's personal data to create a file. Left side Fig.12.

Modify File: Modify the personal data of already existing files. Right side Fig.12.

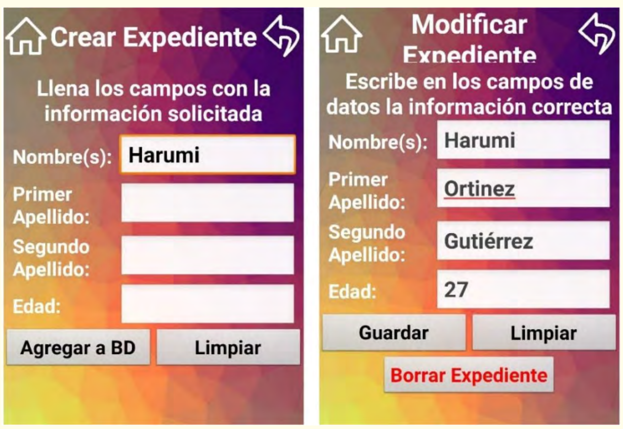

Figure 12: Right: Modify File options Left: New File list window.

Glossary: The glossary provides summary information to understand the oximeter measurements. Fig.13

Figure 13: Glossary window.

As a visual complement to show the evolution of measurements throughout the rehabilitation therapy session, a real-time graph has been designed with a colored code Fig.14 for the relevant values of % of SpO_2, using Table 1 as reference.

Figure 14: Color gradient for oxygen saturation values from 80 to 100% from 0 to 1000 m.a.s.l. or 3000 to 4000 m.a.s.l.

The application has the option of generating a text file with the measurements of SpO_2 and PPM of each recording, such file may be consulted with a text editor or as a spreadsheet.

Results and Discussion

Once the oximeter device is implemented, we observe that the SpO_2 and PPM readings remain stable and without interruptions. Likewise, the design of the sensor ring allows the user to carry out movements comfortably without interrupting the measurements.

In addition, the oximeter has an Android application with different functions that facilitate the visualization and analysis of data for the continuous monitoring of rehabilitation.

Oximeter implementation and prototype

In the Fig.15 shows the integration of the components that give complete operation to the prototype, fulfilling the objective of precisely measuring the SpO_2 and displaying the information on the oximeter screen; simultaneously, these data are transmitted via Bluetooth to the computer.

Figure 15: Functional oximeter prototype.

The results obtained by the reflective method with the MAX30102 circuit are positive, the signals recorded by the sensor remain stable and without interruptions with the moving user. The improvements made at the thimble allow the cable to connect freely with the useful wrist without limiting the movement.

The sensor signal is broadcasted via Bluetooth protocol by means of the HC-06 device to an intelligent mobile phone with Android Operating System. The application has a friendly interface that allows the user to store, access and visualize the measurements of SpO_2 and PPM sent by the oximeter to their convenience.

Conclusions

The device is able to measure blood oxygen saturation and heart rate accurately, in addition to transmitting data to a mobile device. Likewise, a thimble and a wristband were implemented to take the readings in motion without compromising the effective- ness.

In the Android application the measurements of SpO_2 and PPM are deployed in real time and are stored linking the data to a file, which creates a historical record for the subject.

Contrary to other oximeters, our prototype establishes a normal range considering the elevation with respect of sea level, in case of having any oxygen deficiency, a preventive alarm is activated, this with the purpose of assisting the medical specialist. Also, our prototype has an error range of 1.09% in the SpO_2 and 2.11% in the heart rate com- pared with commercial oximeters certificate by the FDA. However, this still is a proto- type with areas of opportunity for improvement like reduce de size.

Our prototype oximeter has 2 main advantages over commercial products, one is that when fully charged the battery last 15 hours of continues work, whereas commercial oximeters turn off approximately after 2 minutes, this feature allow our prototype to monitor continuously in rehabilitations exercises. The second advantages that the pro- duction cost is approximately 60% lower than other alternatives found in market with similar functionalities.

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