

Design of Pulse Oximeter with WiFi Connectivity

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Abstract. Given that health is so relevant for global productivity and competitiveness, and that the TICs play an important role in all of the productivity factors, this work makes use of the TICs in health matters with a proposal to use a WiFi oximeter. This article will describe the operating principles of a Pulse Oximeter (PO), which is an opto-electronic non-invasive medical instrument capable of measuring changes in HR and SpO₂ at the fingertip; its design, and its validation against the three existing devices. Variables (SpO₂%, Ppm, Temperature) were compared, and the WiFi oximeter had a greater impact because of its performance in responses; in addition, the WiFi oximeter incorporates the Temperature variable and the WiFi connectivity, for which we can conclude that implementing this device, will contribute to global competitiveness.

Keywords. Pulse oximetry, optical sensor, heart rate level, wifi protocol.

1 Introduction

Health is very important to be a competitive person in a world like ours, so this paper is related about a biodevice (Oximeter WiFi) for health. Pohjola, Venturini (2009) say that ICT investments have a positive impact on economic growth of GDP, also Edwards (2001) said that areas need large investments in ICT research, development, education, infrastructure and health to generate economic growth. Baily, Katz and West (2011) suggest the investment of ICT innovation as a key factor in the economy, so we can conclude that the oximeter is a technology that can help economic growth regardless of health satisfier give the population [2, 3, 4, 5].

The pulse oximeter has become a vital NICU instrument [15], [16] and may have been adopted as a standard [17]. Various studies have concluded that with better technology, pulse oximeters now provide highly accurate measurements of oxygenation [17-18]. Bierman demonstrated that with other factors being equal, pulse oximetry significantly reduced the need for arterial blood gas collection [17], [19-20]. Zengel examined the effects of subareolar isosulfan blue injection on pulse oximeter (SpO₂) readings and concluded that Time to peak SpO₂ fall, and the recovery period, are delayed in the subareolar technique [21].

On the another hand Rodríguez, Garrido, Martínez, & García (2013) presented a paper was related with the accuracy of pulse oximeters. It included a brief introduc-

tion to the pulse oximetry operation principles, calibration procedure, and discusses main aspects related with the accuracy of measurements and said that the magnitudes of the errors due variations of the wavelengths of the LEDs used were highlighted together with the risks that those errors produced to the patients [1]. And we take this very serious for the design process.

Hülsbusch, et. al (2010) studied about cardiovascular diseases of irregularities in the human cardiovascular system was developed, which was based on a micro-optic in-ear sensor. The resulting signal was then transferred wirelessly to a personal digital assistant (PDA) smart phone or PC where the heart beat, oxygen saturation (SpO_2), breathing frequency and slower perfusion rhythms could be calculated. This contribution introduced the system concept of the monitoring [13].

Besides, the oxygen is vital to the functioning of each cell in the human body. Without oxygen for a prolonged amount of time, cells will die. Thus, oxygen delivery to cells is an important indicator of a patient health. Several methods have been developed to analyze oxygen delivery. Pulse oximetry is a common, noninvasive method used in clinical environments [6].

Blood red cells contain a protein called hemoglobin. Red cells with oxygenated hemoglobin circulate in the blood through the whole body, irrigating tissues. When blood gets in contact with a cell, the red cells hemoglobin releases oxygen and becomes Deoxyhemoglobin (Hb) (deoxygenated hemoglobin) [7].

More over pulse oximetry is the non-invasive measurement of the oxygen saturation (SpO_2). And pulse oximetry systems are based on two principles related to the characteristic of blood flow rate in the context of the oxy-hemoglobin and deoxy-hemoglobin status. Both oxy-hemoglobin and deoxy-hemoglobin are different in their absorption of red (660 nm to 750 nm) and infrared light (850nm-1000nm), and because the volume of the arterial blood in tissue changes as the pulse changes. With each heartbeat, the volume of the arteries becomes larger before the blood enters the capillaries. This change makes possible for the oximetry system to differentiate the arterial blood from all other absorbing substances [8, 9].

When light is emitted into the body tissue, some light will be absorbed by the skin, bones and muscle tissue. This represents the static direct current (DC) component of the signal received at the photo detector receiver. The pulsatile flow in arteries and arterioles during diastole and systole will create some variation in light intensity. This will produce the alternating current (AC) part of the signal [9]. At this point the absorption that occurs is known as the Beer-Lambert Law. Both AC and DC components are shown in figure 1. [10].

As mentioned above, we agree with Shafique, Kyriacou, & Pal (2012), who investigated about Photoplethysmography (PPG), which is a technique widely used to monitor volumetric blood changes induced by cardiac pulsations and pulse oximetry uses the technique of PPG to estimate arterial oxygen saturation values (SpO_2) [14].

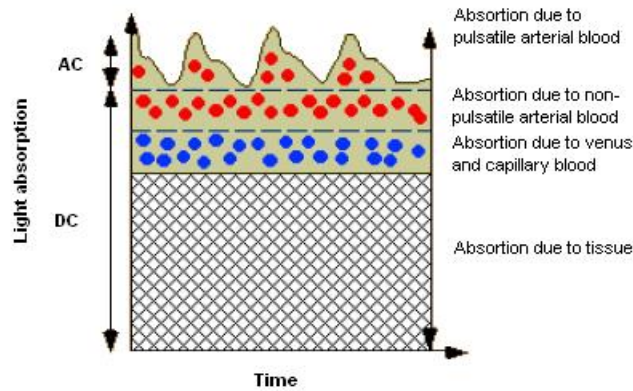


Fig. 1. Light absorption through living tissue.

2 Descriptive and methodological section

This research was conducted as an experiment in Mexico, at the “Hospital de Ortopedia y Traumatología - Dr. Victorio De La Fuente Narváez” in Mexico City, in the year 2013, with a sample of 32 patients. This experiment consisted of taking samples of variables 1) SpO₂%, 2) Ppm and 3) The temperature, which are shown in Figure 8 and are described in Table 1.

Table 1. Study variables.

Variable	Description
SpO ₂ %	Oxygen level (0 to 100%)
Ppm	Pulses per minute (0 to 200ppm)
Temperature	Body Temperature (0 to 100°C)

The research instrument consisted of a form where measures of values resulting from the three variables SpO₂%, ppm, temperature were written down. This instrument was applied to 32 patients. Three treatments were also used, i.e., oximeters: Nonin, Mazimo, and oximeter WiFi.

An intensive care monitor alarm has been a major burden on both nurses and patients. Between 44 and 63 % of alarms are caused by pulse oximeters, with 94 % of these being non-significant [22-24]. Any technique for measuring pulse oximeter saturation (SpO₂) has been developed this technique uses mathematical manipulation of the pulse oximeter is red and infrared light absorbance to identify and subtract the noise components associated with these signals [25]. Theoretically the pulse oximeter analyzes the light absorption of two wavelengths from the pulsatile-added volume of

oxygenated arterial blood ($AC_{\text{red light}}/DC_{\text{infrared light}}$) and calculates the absorption ratio "R" using the following equation 1.

$$R = \frac{AC_{660}/DC_{660}}{AC_{940}/DC_{940}} \tag{1}$$

SpO₂ is taken out from a table stored on the memory calculated with empirical formulas. A ratio of 1 represents a SpO₂ of 85%, a ratio of 0.4 represents SpO₂ of 100 %, and a ratio of 3.4 represents SpO₂ of 0 %. For more reliability, the table must be based on experimental measurements of healthy patients.

Another way to calculate SpO₂ is taking the AC component only of the signal and determines its ratio by using the following equation 2. SpO₂ is the value of "R" X 100.

$$R = \frac{\text{Log}_{10}/(I_{AC_{660}})}{\text{Log}_{10}/(I_{AC_{940}})} \times 100 \tag{2}$$

Where:

I_{ac} = Light intensity at 1 (660nm) or 2 (940nm), where only the AC level is present.

R= Absorption ratio of light.

The system will consist of five parts; sensor, amplifier, processing, LCD display and WiFi communication protocol, as shown in figure 2.

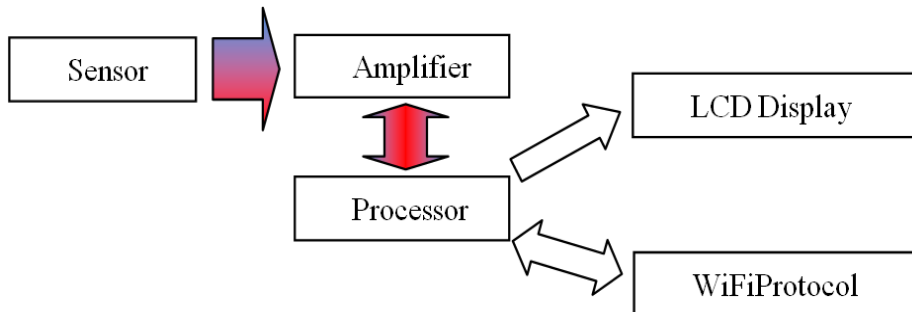


Fig. 2. Block diagram showing the flow of operation for the Pulse Oxymetry WiFi System.

2.1 Sensor of pulse oximetry

The designed Pulse Oximeter WiFi system will consist of a probe (sensor); the sensing probe consists of two LEDs, and a photo-detector. The two LEDs used in the sensor part are the red and infrared (refer to figure 3). The signal collected from the photo-detector. To perform our tests, we used the finger. The detectors must be highly sensitive and be able to measure the weak emission through to the tissues.

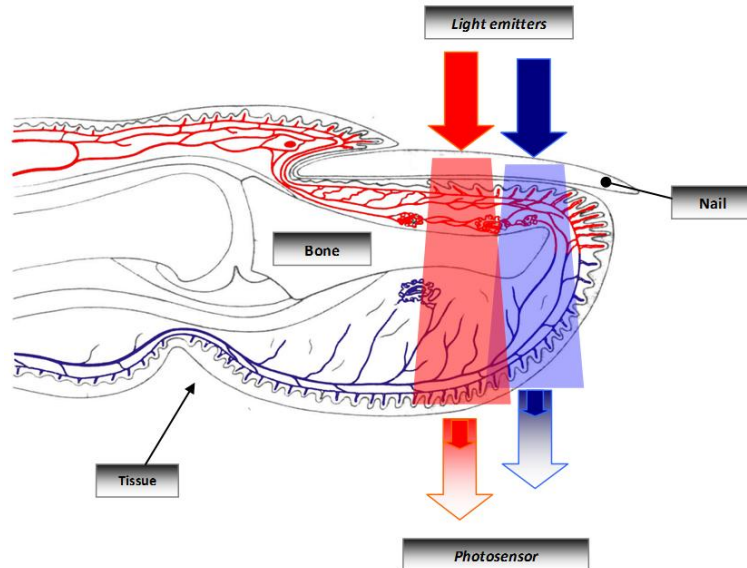


Fig. 3. Sensor orientation for light transmittance in the designed pulse oximeter.

2.2 Acquiring the signal

The optical receiver element is the photodiode. For the purpose of acquiring the signal, we have to amplify and filter, the signal that amplification from the photocurrent to be transformed into moderate voltage output impedance is then taken to a bandpass filter section designed to operate at frequencies of 0.15 Hz to 7.5 Hz mainly intended to eliminate DC component and high frequency noise. [12] See Figure 4.

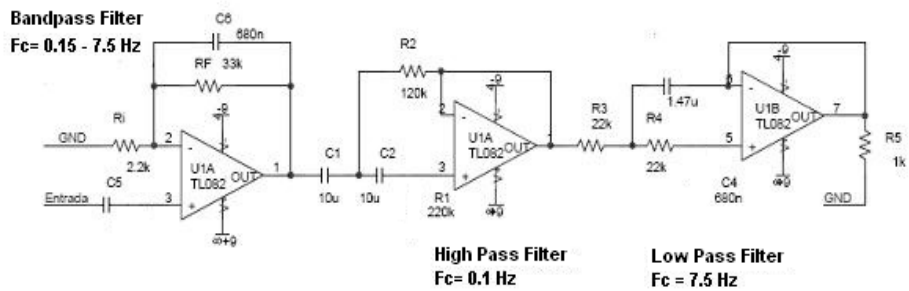


Fig. 4. Filtering and Amplifying Circuits.

2.3 Processing pulse oximetry signal

The output signal from the sensors (filtered and amplified) will be further supplied to a Programmable Interface Controller which will be converted from analogue signal

into digital signal through the built-in Analogue to Digital Converter of 12bit. However, this converting process will require a C programming software and C18 compilation process to generate the Hexadecimal “.hex” file. An example of line code in C18 to calculate de SpO₂%, applying equation 2:

$$\text{calculoSpo2} = (((\log((1 / \text{red}))) / (\log((1 / \text{infrared})))) * 100) \tag{3}$$

2.4 Display of pulse oximetry

For the device to be user friendly, the measured values are shown; the output produced by the PO will be displayed via a Liquid Crystal Display (LCD) screen. The organization chacters are as shown in figure 5.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
P	p	m	=				S	p	O	2	%	=			
T	e	m	p	=			P	r	e	=	n	o	r	m	

Fig. 5. Display test data processed as the Table 1.

2.5 The WiFi protocol and communication

To implement the WiFi protocol, we use the Microchip TCP/IP Stack because it is a suite of programs that provides services to standard TCP/IP-based applications (HTTP Server, Mail Client, etc.). The software stack has an integrated driver that implements the API that is used in the modules for command and control, and for management and data packet traffic [11].

When the device has the final results (SpO₂% and the HR), we use a micro embedded WiFi card to communicate the microcontroller with the most nearest access point (AP) to enable the Pulse Oximeter WiFi system to be reachable for other devices like laptops, computers, Smartphones connected to the same AP. See figure 6.

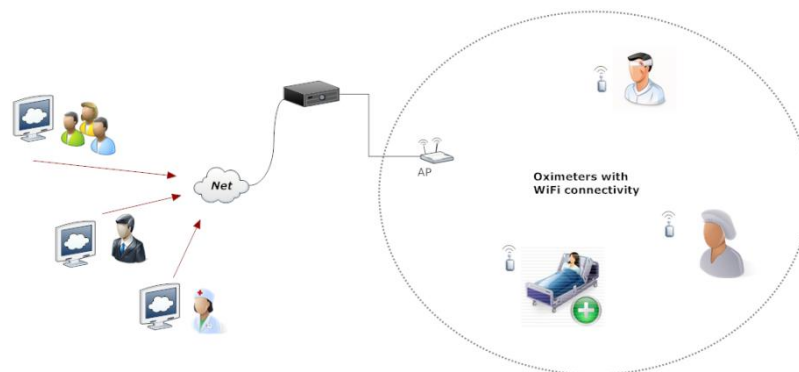


Fig. 6. Oximeters with WiFi connectivity over the network.

2.6 Implementation

Since, the pediatricians used a Nellcor pulse oximeter to measure SpO₂. The prolonged measurements took into account the pulsatile nature of arterial flow, as well as the highest SpO₂ value recorded and its stability, their results below < 95% were verified by a second measurement, and only the highest value was recorded [26].

As a result of, the first implementation was made at the “Hospital de Ortopedia y Traumatología - Dr. Victorio De La Fuente Narváez” in Mexico City, with optimum results at the moment the Pulse Oximeter was tested [8]. All tests were reviewed by specialist doctors under the ISO 9919:2005, in which ISO defines the procedure to prove the Oximeters. [14] figure 7 shows the tests.



Fig. 7. Oximeters test; Mazimo, Nonin and Oximeter WiFi in a patient.

3 Results and discussion

The results obtained from the three treatments (Nonin, Mazimo and Oximeter WiFi), are quite similar as to the minimum, maximum and average measures. Regarding temperature, only the Oximeter WIFI treatment shows the temperature by using descriptive Statistics in table 2.

Table 2. Results from the Three Treatments.

	Nonin			Mazimo			Oximeter WiFi		
	SpO ₂ %	PPM	Tem.	SpO ₂ %	PPM	Temp.	SpO ₂ %	PPM	Temperature
Min.	87.00	70.00		86.00	69.00		86.00	70.00	29.00
Max.	99.00	94.00		100.00	93.00		100.00	94.00	32.00
Average	94.16	82.84		93.72	82.78		93.78	83.00	30.38

In the figure 8 shows visually the values obtained for the SpO₂% variable, which gives reliability on the results by using the WiFi proposed treatment.

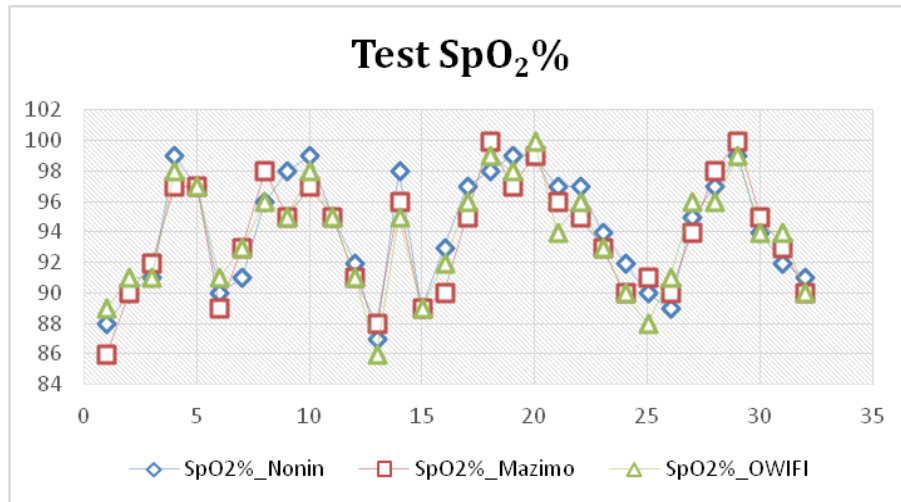


Fig. 8. Test Results SpO₂%.

Discussion: Many authors have worked with pulse oximeter. However in connection with the figure 8, the treatments are quite similar and the proposal (Oximeter WiFi) has good results. We show the same result with a plus (Temperature). So we think that it is important to help the health, and we agree with authors Pohjola (2000), Venturini (2009), in that the treatment will be a call for health, which will promote an economic growth [4].

4 Conclusions at the moment

The preliminary conclusions are: First, from the electronic point of view, the necessary research and tests were carried out to join the project and bring it to a first phase of its construction. Second, notwithstanding that results were successful in its implementation, doctors made it clear that further testing in a more specialized area was needed. And of course, there will be a more advanced version of this oximeter. This was because doctors asked if the oximeter could autosave the results into a system or database and the answer was yes, this gives the opportunity to continue the development of a second phase of this oximeter. The following features are emphasized: scalable technology, on-line monitoring, provides connectivity and networking, will provide more timely and easy monitoring, use of Standard ISO 9919:2005.

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References

1. Rodríguez, J., Garrido, H., Martínez, A., & García, M.: Exactitud y Errores de la Oximetría de Pulso. IFMBE Proceedings (33), 758–761, (2013).
2. Baily, M., Katz, B., & West, D.: Building a Long-Term Strategy for Growth through Innovation. Brookings, (2012).
3. Edwards, S.: Information Technology and Economic Growth in the Emerging Economies. 1-22, (2001).
4. Pohjola, M.: Information technology and economic growth: a cross-country analysis. UNU World Institute for Development Economics Research, Working Papers No. 173, pp 1, (2000).
5. Venturini, F.: The long-run impact of ICT. *Empirical Economics*, 37(3), 497–515, (2009).
6. John G.: Design of Pulse Oximeters. En: John G II, USA: Taylor & Francis; pages. 12-25, (1997).
7. Santiago L.: Pulse Oximeter Fundamentals and Design, Freescale Semiconductor Document Number: AN4327, (2012).
8. Hoff, D. Zhang, R. Stalter, T. and Carlson, M.: Pulse Oximetry. Undergraduate Thesis Electrical and Computer Engineering, North Carolina State University, USA, (2003).
9. Oximetry.org: Principles of Pulse Oximetry Technology. Retrieved on: 16th of June 2013 URL: (<http://www.oximeter.org/pulseox/principles.htm>).
10. The analysis of transesophageal oxygen saturation photoplethysmography from different signal sources. Retrieved on: 16th of June 2013 URL: (<http://www.ncbi.nlm.nih.gov/pubmed/23475176>).
11. Nilesh R: The Microchip TCP/IP Stack, Microchip Document Number: AN833, (2002).
12. J. T. B. Moyle, Pulse Oximetry, 1st ed. London, U.K.: BMJ, (1994).
13. Hülsbusch, M., Blazek, V., Herzog, M., Vogel, S., Wartzek, T., Starke, D., & Hennig, T. (2010). Development of a miniaturized in-ear pulse oximeter for long term monitoring of risk patients. En O. Dössel, & W. C. Schlegel, World Congress on Medical Physics and Biomedical Engineering (Vol. 25, pags. 779-781). springer. doi:10.1007/978-3-642-03882-2_207.
14. ISO 9919:2005 Medical electrical equipment - Particular requirements for the basic safety and essential performance of pulse oximeter equipment for medical use. URL: (http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?csnumber=33780). Retrieved on: 16th of June 2013.
15. Cresi, F., Pelle, E., Calabrese, R., Costa, L., Farinasso, D., & Silvestro, L.: Perfusion index variations in clinically and hemodynamically stable preterm newborns in the first week of life. *Italian journal of pediatrics*, 36(1), 1-5, (2010).
16. Salyer, J. W.: Neonatal and pediatric pulse oximetry. 48(4):386-396, *Respir Care* 2003.

17. Shah, A., & Shelley, K. H.: Is pulse oximetry an essential tool or just another distraction? The role of the pulse oximeter in modern anesthesia care. *Journal of clinical monitoring and computing*, 1-8, (2013).
18. Anesth, J.: Pulse oximetry: its invention, theory, and future. *17(4):259-66*, (2003).
19. Pedersen T, Moller A, Pedersen B. Pulse oximetry for perioperative monitoring: systemic review of randomized, controlled trials. *Anesth Analg*. 96(2):426, (2003).
20. Bierman, M, Stein, K, Snyder J. Pulse oximetry in the postoperative care of cardiac surgical patients. A randomized controlledtrial. *Chest*. 102(5):1367-70, (1992).
21. Zengel, B., Yazarbas, U., Bingolballi, O., &Denecli, A. G.: The Effect of Subareolar Isosulfan Blue Injection on Pulse Oximeter Readings. *Indian Journal of Surgery*, 1-5, (2012).
22. Sabar, R., Zmora, E.: Nurses' response to alarms from monitoring systems in NICU. *Pediatr Res* 41: 174A, (1997).
23. Lawless, S. T.: Crying wolf: false alarms in a pediatric intensive care unit. *Crit Care Med* 22:981-985, (1994).
24. Bohnhorst, B., & Poets, C. F.: Major reduction in alarm frequency with a new pulse oximeter. *Intensivecare medicine*, 24(3), 277-278, (1998).
25. Dumas, C., Wahr, J. A., Tremper, K. K.: Clinical evaluation of a prototype motion artifact resistant pulse oximeter in the recovery room. *Anesth Analg* 83:269, (1996).
26. Corrad, F., de La Rocque, F., Martin, E., Wollner, C., Elbez, A., Koskas, M., & Cohen, R.: Food intake during the previous 24 h as a percentage of usual in take: a marker of hypoxia in infants with bronchiolitis: an observational, prospective, multicenter study. *BMC pediatrics*, (2013).