ORIGINAL PAPER

IoT PULSE OXIMETRY STATUS MONITORING FOR HOME QUARANTINED COVID-19 PATIENTS

VIOREL MIRON-ALEXE [1]

Manuscript received: 08.09.2020; Accepted paper: 23.10.2020;
Published online: 30.12.2020.

Abstract. *This article represents a prototype experiment regarding the practical implementation of an affordable, wireless, and online monitoring pulse oximetry device, for a Covid-19 infected patient that is quarantined at home. By using an Arduino based IoT (Internet of Things) embedded platform and a free online API (Application Programming Interface) live data stream server, the family physician can remotely monitor the patient's pulse and blood oxygen level, by using a mobile phone, a tablet or a computer, without any contamination risk or contact, with the infected patient.*

Keywords: *IoT; pulse oximeter; IR sensor; Covid-19 patient; oxygen saturation.*

1. INTRODUCTION

The daily increasing, worldwide number, of Covid-19 cases that require medical attention, represents both a challenge and a concern for the family physicians and medics that are responsible to a certain degree, for their patient's health. It is widely speculated that because of the virus mutations, some strains of coronavirus can affect the lungs of certain patients, to some degree, due to genetic predisposition or weakened immune system, unlike the influenza flu that can pass without serious clinical manifestations [1].

Using the wireless communication protocols of embedded IoT systems and low power sensors [2], the remote medicine can revolutionise the patient's medical evaluation by the doctors, with minimal efforts and without any risks involved, in case of a pandemic outbreak. In this respect, the proposed system is intended for patients with any condition that affects blood oxygen levels, such as: asthma, anemia, pneumonia, lung cancer, COPD (Chronic Obstructive Pulmonary Disease), CHF (Congestive Heart Failure), and in some cases, even for the „happy hypoxia" that can be caused by the Covid-19, where the patient can have lung problems without even feeling ill, but with serious effects in the mid and long term [3].

For the proposed system, a small oximetry sensor is connected to the patient's finger, while the embedded system makes reads of the oxygen saturation and pulse. Thus the PPG (photoplethysmogram) signal captured by the sensor is internally converted into a digital signal, which is further converted into calibrated numerical values by the platform microprocessor [4]. These values are then transmitted to an online data server that streams and collects the received data, by using the API service and identification key [5]. The medic can then visualise, through an account channel, the real-time charts and csv files, with the detailed stored data, in order to monitor the patient's health [6]. The main advantage of this system is that the medic does not engage in any physical contact with the patient that can possibly be

[1] Valahia University of Targoviste, Institute of Multidisciplinary Research for Science and Technology, Energy and Environment Research Department, 130004 Targoviste, Romania.
E-mail: viorel.alexe@valahia.ro.

infected. Moreover, if the patient's health status is rapidly deteriorating, the medic can remotely call the ambulance service for patient treatment or intubation, either locally or to the ER (Emergency Room) and then be transported to the IC (Intensive Care).

2. THEORETICAL ASPECTS AND PROTOTYPE DEVELOPMENT

The pulse oximetry represents a non-invasive measurement technique of the oxygen saturation, which is an essential parameter used in medicine in order to determine the health status of a patient, in correlation with his lungs functionality and the capability of the red blood cells to carry oxygen into the body by the help of Hemoglobin proteins [7].

Thus, the peripheral oxygen saturation (SpO_2) is defined as the ratio between the concentration levels of Oxyhemoglobin (HbO_2) and the total Hemoglobin (Hb) in the blood (oxygenated and non-oxygenated Hemoglobin) [8].

The scientific experiments showed that the Hb absorbs more red light and reflects less of it, while the HbO_2 absorbs more infrared light and reflects less of it. In respect to that, a common way to conduct the measurements of the two coefficients is by using a Red LED, which emits a red light spectrum, with a wavelength of ~660 nm, and an IR LED which emits a near-infrared light (NIR) spectrum, with a wavelength of ~940 nm [9].

Some oximeters use anti-parallel configuration LEDs and switch them by using a low frequency PWM signal, with a few hundreds of microseconds time gap between the pulses, while a photodiode captures each of the two separate signals of pulsatile blood flow. As the photodiode generates a few microamperes during the light conversion process, a transimpedance operational amplifier is used to convert the microamperes into millivolts of the two alternating signals from the LEDs [10]. Then the signals enter through a high pass filtering stage to filter out the background noise, while an inverting high gain amplifier inverts and amplifies the pulsating analog signals that will be converted into digital ones, by the microcontroller's or sensor's ADC. The processed signal has two distinct components: an AC component, resulted from the light absorbed by the pulsatile arterial blood and a DC component, resulted from the light absorbed by the tissue and non-pulsatile blood [11].

The proposed pulse oximetry system is based on a RCWL-0530 module with a MAX30100 sensor (Fig. 1), that operates on a 1.8 V power supply voltage and 3.3 V LED supply voltage (for IR and Red), it also has an internal 16-bit sigma-delta ADC (Analog to Digital Converter) with internal temperature compensating sensor for accurate measurement calibration. The typical supply current consumption is of 600 μA; also the IR LED peak wavelength ($IR_{Led}\lambda_p$) is typically 880 nm with a forward voltage (V_F) of 1.4 V, while the Red LED peak wavelength ($Red_{Led}\lambda_p$) is typically 660 nm with a forward voltage (V_F) of 2.1 V [12].

Figure. 1. RCWL-0530 module based on MAX30100 pulse oximetry sensor with pinout.

Fig. 2 describes a system block diagram of the MAX30100 sensor [13], with the internal active components for measuring the HbO_2 and Hb values captured with the photodiode, while the Red and the IR LEDs are operating.

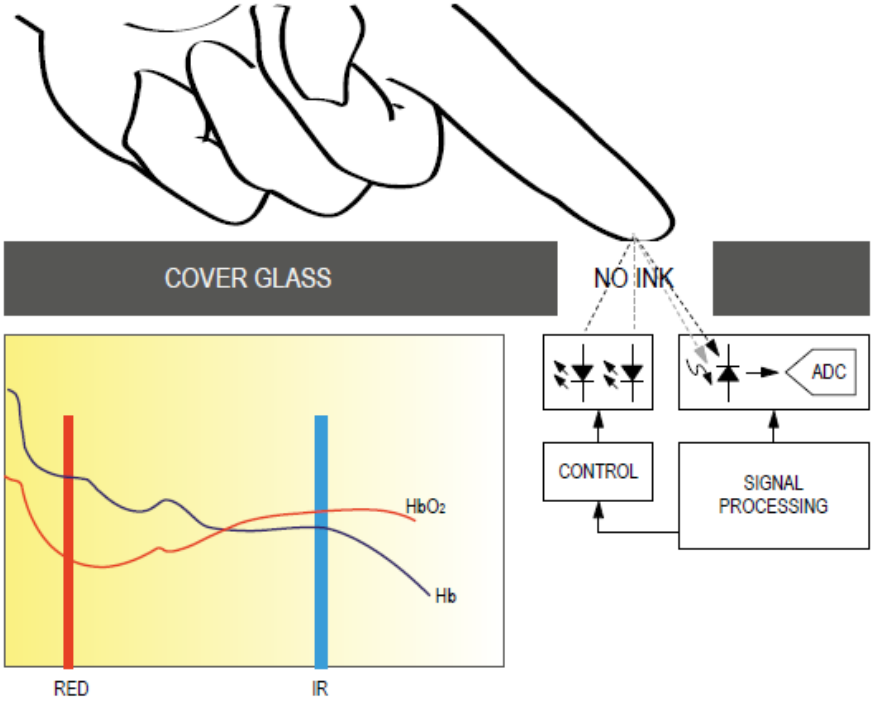

Figure. 2. Pulse oximetry sensor block diagram and absorption spectra of HbO_2 and Hb.

To better comprehend the internal electronic subsystem of the sensor, in Fig. 3 it is described the sensor functional block diagram extracted from the manufacturer's datasheet [14]. The external communication and control of the sensor are both achieved by the internal I2C data protocol through a wire connection to the IoT embedded platform.

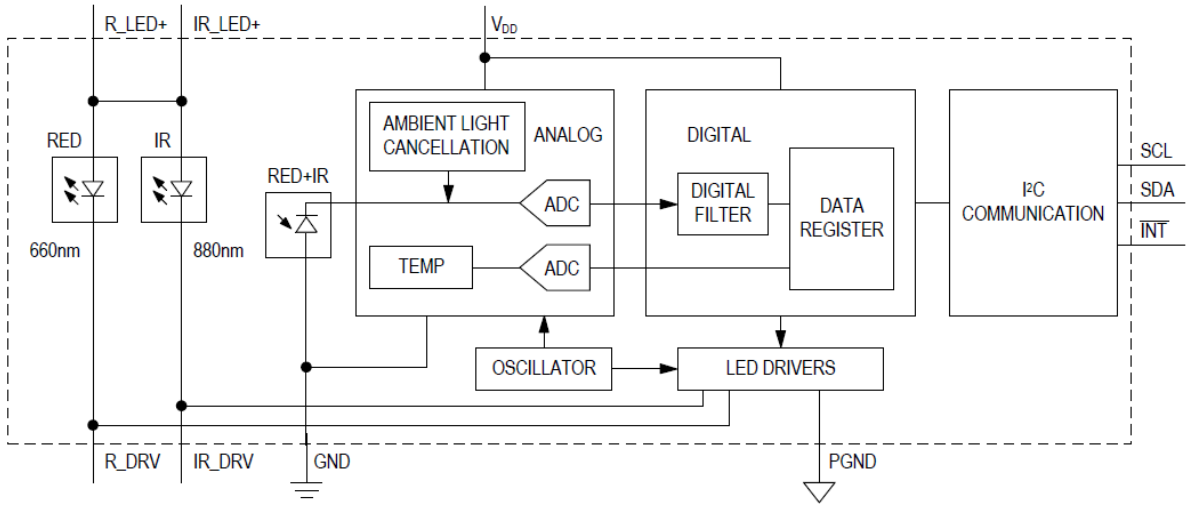

Figure. 3. MAX30100 sensor functional block diagram.

In order to conduct the experimentation measurements, in Fig. 4 it is proposed the following system configuration, where an ESP32 IoT embedded platform with WiFi capabilities is used [15]. Thus, the pulse and the SpO_2 values are collected by the sensor from the patient's finger, then the values are transmitted via an internet connected router to the ThingSpeak API server, by using an "API write" key and a channel number ID, to a previously made user account, which is periodically monitored by the personal physician on a smartphone, a tablet or a PC.

The free user account panel is configurable and can support up to 8 value fields for charting. The sampling rate of the live data stream in the charts is done at a minimum of 20 seconds. Overall, in the standard version of the account, up to 4 patients can be simultaneously monitored, each one having reserved a set of fields for pulse and SpO_2, for displaying.

Another advantage is that the account stores the history data, which can also be downloaded as a csv report for later viewing. The sampling rate of the sensor is programmed at 0.5 s, but it can also be configured to sample faster or slower, depending on the external environment. Being an open sensor experimentation, it is recommended that the bright sources of light to be isolated from the patient in order to make accurate readings of the values, although the sensor has a built-in error compensation circuit [16].

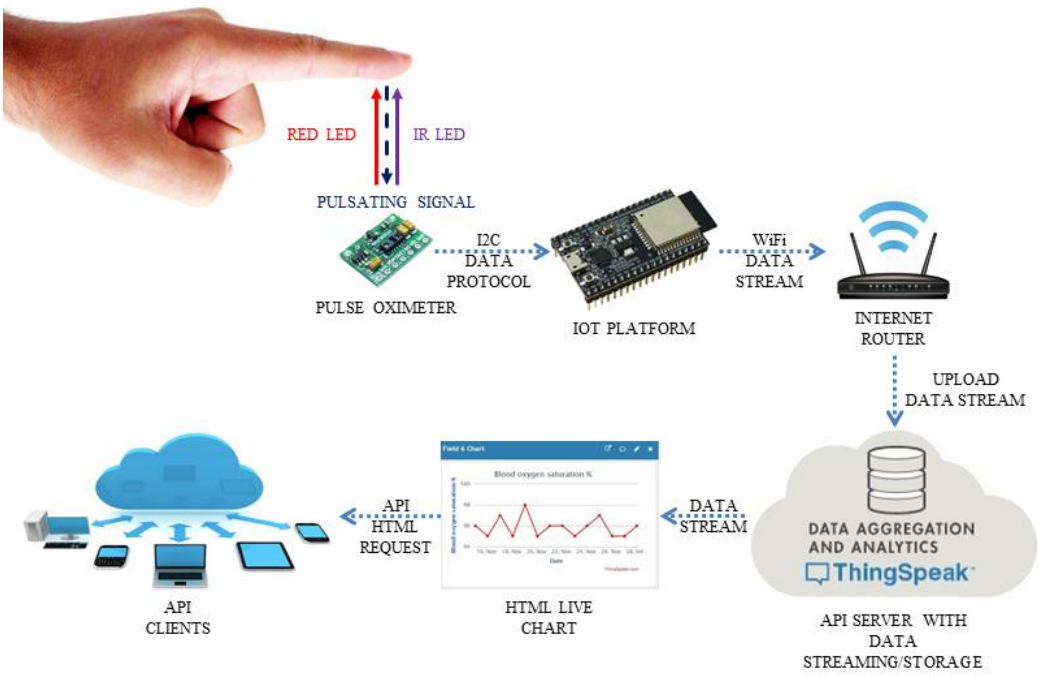

Figure. 4. Proposed pulse oximetry system - functional block diagram.

In the experimentation process, after powering and booting sequence of the ESP32 platform, the system started to make a batch of 40 measurement samples in 20 seconds time span, after which only the last set of measurements regarding the pulse and SpO_2 values, were reported to the API server for live streaming, in order to respect the server broadcast timing.

The algorithm's simplified flowchart is described in Fig. 5, executing the measurement and broadcasting instructions, in a loop.

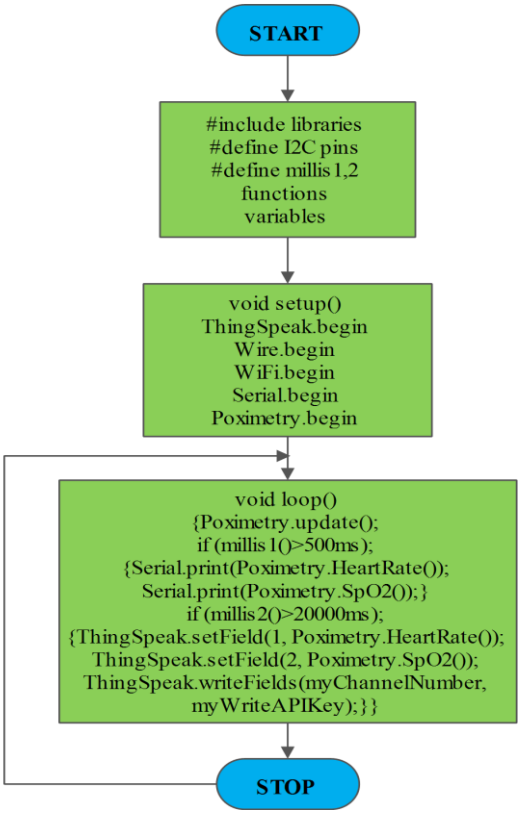

Figure. 5. Simplified algorithm flowchart for the ESP32 platform pulse/SpO_2 measurements.

3. EXPERIMENTAL RESULTS AND CALCULUS

After conducting multiple measurements on a patient, a chart capture from the server was saved, that reveals the data points for heart rate (95 bpm) and oxygen saturation (97%). In the respective measurements session, a number of 60 data points were reported in a 20 minutes time span.

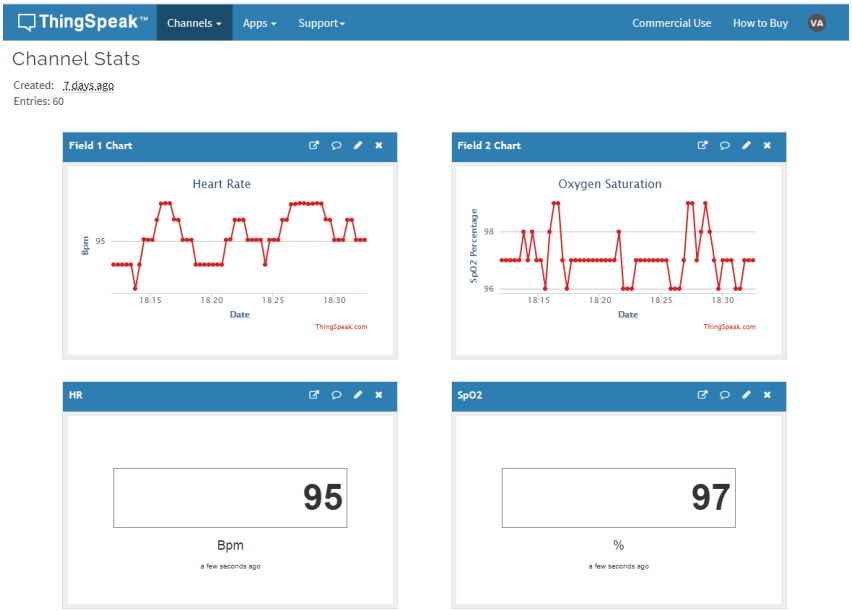

Figure. 6. ThingSpeak data point charts of Bpm and SpO_2 conducted on a patient.

An additional batch of measurements has also been experimented on 4 different patients of various sex, age, weight and height. The comparative measurements were conducted between a certified commercial finger-pulse-oximeter and the proposed ESP32 embedded system with the MAX30100 sensor. A more detailed report is presented in Table 1.

Table 1. Comparative measurements of 4 patients, using two different pulse oximeters.

Patient	Data				Measurements			
	Description				Commercial pulse oximeter		MAX30100 pulse oximeter	
#	sex	age [y]	weight [kg]	height [m]	Pulse [bpm]	SpO_2 [%]	Pulse [bpm]	SpO_2 [%]
1	m	36	82	1.89	96	98	96	97
2	f	58	78	1.56	85	96	84	96
3	m	47	70	1.69	102	94	101	93
4	f	29	66	1.74	81	95	80	95

As mentioned in the introduction of the article, for each red and infrared wavelength (λ) of the two PPG signals, the oximeter determines the *AC/DC* pulsatile and non-pulsatile components absorption ratio (*R*) [17], with relation (1):

$$R = \frac{AC_{\mathrm{Red}} / DC_{\mathrm{Red}}}{AC_{IR} / DC_{IR}} = \frac{AC_{660nm} / DC_{660nm}}{AC_{940nm} / DC_{940nm}} \tag{1}$$

where AC_{Red} and AC_{IR} represent the *AC* component of the red and infrared LEDs, while DC_{Red} and DC_{IR} represent the *DC* component of the red and infrared LEDs. For example, if the ratio of red to infrared absorbance equals to 1.00, then the saturation is approximately 81% [18].

The arterial oxygen saturation (SpO_2) represents the concentration ratio of Oxyhemoglobin (HbO_2) to the total amount of Hemoglobin in the blood (HbO_2+Hb) as stated in (2).

$$SpO_2 = \frac{(HbO_2)}{(Hb)+(HbO_2)} \times 100\% \tag{2}$$

The Beer-Lambert's law relates the attenuation of light with the properties of the material through which the light is travelling [19]. Thus, according to this law, there is:

$$I = I_0 e^{-\varepsilon(\lambda)Cd} \tag{3}$$

also expressed as:

$$A = \ln\left(\frac{I_0}{I}\right) = \varepsilon(\lambda)Cd \tag{4}$$

where I is the received light intensity, I_0 is the incident light intensity, $\varepsilon(\lambda)$ is the molar extinction coefficient, A is the attenuation, d is the optical path length and C is the concentration of the material.

Taking into consideration the molecular compound of tissue, the Beer-Lambert law can be adapted to this case as:

$$A = d\left[\varepsilon_{HbO_2}(\lambda)C[HbO_2] + \varepsilon_{Hb}(\lambda)C[Hb] + \varepsilon_x(\lambda)C[x]\right] \quad (5)$$

where x is the non pulsatile tissue (bone, muscle, blood, skin), HbO_2 is the Oxyhemoglobin and Hb is the Deoxyhemoglobin [20].

4. CONCLUSIONS

As a minor observation, the measurements described in Table 1, between the two pulse oximeters have very close values and while knowing that the commercial one is certified and tested, it can be taken as the measurement reference, thus it can safely be deduced that the proposed system using the ESP32 platform and MAX30100 sensor, is accurate enough for further use.

As the proposed pulse oximetry system is still in the developing and improvement stage, some adaptations are further required to make it more accessible, smaller and portable. A future portability implementation would mandatory require a standalone power supply based on a rechargeable Li-Ion battery, as both the ESP32 and the MAX30100 sensor, can have a low current consumption while operating, if correctly optimized and configured. Also future upgrades regard: the alarm implementation when threshold values are exceeded and the use of a faster real time data streaming server.

Some of the benefits of pulse oximetry are: monitoring oxygen saturation over time; alerting to dangerously low-oxygen levels; mental comfort to people with chronic respiratory or cardiovascular conditions; assessing the need for supplemental oxygen; monitoring oxygen saturation levels in people under anesthesia; indicating dangerous side effects in people taking drugs that affect breathing or oxygen saturation.

Pulse oximetry also has its own limitations. The factors that can affect the readings to a certain degree are: hemoglobin deficiency (e.g., anemia), external light interference, skin pigmentation, methemoglobin, blood volume deficiency, fingernail polish and pressed nails, intravenous dyes, irregular heartbeats, carbon monoxide and bilirubin levels. In conclusion, the pulse oximetry should never be a substitute for a medical investigation, but only a helpful medical accessory.

REFERENCES

[1] Shereen, M.A., Khan, S., Kazmi, A., Bashir, N., Siddique, R., *Journal of Advanced Research*, **24**, 91, 2020.
[2] Vasile, I., Vasile, V., Diaconu, E., Andrei, H., Angelescu, N., *Journal of Science and Arts*, **3**, 793, 2019.
[3] Dhont, S., Derom, E., Van Braeckel, E. et al., *Respiratory Research*, **21**, 198, 2020.
[4] Castaneda D., Esparza A., Ghamari M., Soltanpur C., Nazeran H., *International Journal of Biosensors & Bioelectronics*, **4**, 195, 2018.

[5] Dimiter, V.D., *Healthcare Informatics Research*, **22**, 156, 2016.
[6] Suresh, A., Shalika, R., *International Journal of Scientific & Engineering Research*, **8**, 386, 2017.
[7] Chan, Edward, D., Chan, Michael, M., Chan, Mallory, M., *Respiratory Medicine*, **107**, 789, 2013.
[8] Coyle, S., Diamond, D., *Woodhead Publishing Series in Textiles*, Multidisciplinary Know-How for Smart-Textiles Developers, 420, 2013.
[9] Von Chong, A., Terosiet, M., Histace, A., Romain, O., *Microelectronics Journal*, **88**, 128, 2019.
[10] López Silva, S. M., Dotor Castilla, M. L., Silveira Martín, J. P., *Journal of Biomedical Optics*, **8**, 525, 2003.
[11] Chatterjee, S., Kyriacou, P. A., *Sensors*, **19**, 789, 2019.
[12] Rodrigues, Eduardo M.G., Godina, R., Cabrita, Carlos M.P., Catalão, João P.S., *Biomedical Signal Processing and Control*, **31**, 419, 2017.
[13] Partha Pratim, R., Dinesh D., Neeraj K., *Computer Communications*, **160**, 111, 2020.
[14] Suprayitno, E. A., Marlianto, M. R., Mauliana, M. I., *Journal of Physics: Conference Series*, **1402**, 2019.
[15] Kadhim, T. K., Ali M. A., Salim M. W., Hussein T.K., *Al-Furat Journal of Innovations in Electronics and Computer Engineering*, **1**, 9, 2020.
[16] Kebe, M., Gadhafi, R., Mohammad, B., Sanduleanu, M., Saleh, H., Al-Qutayri, M., *Sensors*, **20**, 1454, 2020.
[17] Bagha, S., Shaw, L., *International Journal of Computer Applications*, **36**, 45, 2011.
[18] Nitzan, M., Romem, A., Koppel, R., *Medical Devices (Auckland, N.Z.)*, **7**, 231, 2014.
[19] Pisano, A., *Physics for Anesthesiologists: From Daily Life to the Operating Room*,1st ed.,Springer, pp. 117-127, 2017.
[20] Kaufman, D.P., Kandle, P.F., Murray, I., Dhamoon, A.S., *Treasure Island (FL): StatPearls Publishing*, Physiology, Oxyhemoglobin Dissociation Curve, 2020.