Low-Cost Pulse Oximeter & Heart Rate Measurement for COVID Diagnosis

Kakumanu Vamsi Sree Sai Ganesh and A Ruhan Bevi*

1,2Department of Electronics and Communication Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, Chennai, Tamil Nadu, India
Email: *ruhanb@srmist.edu.in

Abstract: This paper presents a portable heart rate and SpO2 blood-oxygen-level monitoring system with robust performance. The system is designed to be user interactive and kept its architecture as minimalistic as possible. The system is small in size, and user compatibility is high compared with other conventional medical devices. This system is based on a MAX30100 sensor which can produce results with high accuracy. Anyone using this device can move during the monitoring of vital signs of the heart. This paper describes the practical application cases in which this type of system is mainly used where the end-user has size and mobility requirements in the first place. A custom-designed GUI is implemented on an OLED to display the measured sensor data in real-time.

Keywords: MAX30100, Spo2, COVID-19, ESP8266, I2C.

1. Introduction

The covid-19 global pandemic affected the human race like never before. During this tough phase, people need to ensure their health in good condition and monitor their vitals regularly. We even know that medical treatment for COVID-19 patients is too expensive and challenging a scenario [1]. The simple and effective way to avoid being affected is to follow the necessary instruction and monitor our blood oxygen saturation. Oxygen gas is necessary for human life [2] as it integrates the humongous biological processes.

The covid-19 affects the lungs so that the patient cannot produce oxygenated blood in the bloodstream. So, finding the amount of oxygen saturation in the blood is needed [3-4] and becomes essential.

Pulse Oximeter has been in existence since the early 1930s. By using this principle, blood oxygen levels can be determined non-invasively. As the medical treatment is not available and affordable to everyone, few medical devices are used to fill the voids of regular diagnosis and common examinations. Using a pulse oximeter is one among those [5], and pulse oximetry is a non-obtrusive and easy test that gauges your oxygen immersion level or the oxygen levels in your blood. It can quickly distinguish even little changes with how effectively oxygen is being conveyed to the limits, utmost from the heart, including the legs and the arms [6].

Measurement of the oxygen rate in blood regularly helps in the early detection of hypoxia and many serious diseases [7-8]. Nowadays, the risk of health is increasing and threatening millions of lives. There is a dynamic increment in cardiovascular ailments bringing about around 8 million passing yearly, which can be ascribed to hypertension. Moreover, 142 per 1000 live births with acute respiratory infections are among the leading causes of death [9].
A remote patient checking framework is utilized for constant observing of two wellbeing parameters. For example, oxygen immersion and temperature of the body [10] are measured. Genuine respiratory disappointment happens when blood vessel immersion of hemoglobin falls beneath 90%. This rate generally extends between 85-90% [11].

Our proposed system uses a power-efficient MAX30100 pulse oximeter sensor to detect the percentage of oxygen rate in the bloodstream in real-time. The key feature for developing pulse oximeter technology is its high mobility, low energy, wireless communication, and low price compared to all available devices in the priced high [12]. So, this project's novel idea is to deliver a cost-efficient pulse Oximeter to everyone [13-14].

The proposed paper is organized into four sections. Section 2 deals with the elaboration of system architecture [15], communication protocols, working of the system, and section 3 elaborates the system's algorithm and workflow. Section 4 deals with investigating various calculations followed by the system's improvements and the conclusion drawn in section 5.

2. Proposed Pulse Oximeter Architecture
This paper aims to deliver a cost-efficient pulse oximeter with less complexity to achieve precise results. The proposed model consumes less power when comparing with another model, as it uses few background elimination algorithms that feature to disable the calculation of Spo2 and BPM.

2.1 Sensors in the proposed architecture
As shown in figure 1, the proposed system deploys a max30100 sensor which measures the heart rate and blood oxygen level. This sensor is connected to an esp8266 based D1 MINI WEMOS microcontroller, which serves as the heart of the system via I2C protocol.

![Figure 1: The interface of Max30100 with D1mini](image)

I2C is one of the popular serial communication protocols used in embedded systems. The D1mini board even has the WI-FI capability, and this microcontroller is deployed specifically because of its small dimensions and higher processing power with 4 MB flash memory. An OLED 128x64 is used for the live display of the data, which works with the I2C communication protocol. As two I2C devices are present in this system, we differentiate the sensor's data and the data to be sent to OLED by the I2C addresses.

2.2 Communication between OLED, Microcontroller, and MAX30100
There are plenty of protocols that are categorized into synchronous and asynchronous protocols. This system uses I2C protocols, as it needs less on the data line. It uses two lines SCL for synchronization of the clock between master and slave, SDA for data transmission between master and slave. Our model needs to be less complex, so we prefer I2C over others. The master will always send the message to the slave to start the connection, and the slave acknowledges the connection initiation. The slave cannot send a message without being requested from the master device. It is that always the master generates the clock in this protocol where the multi slave devices have their unique addresses.
2.3 Architecture of the proposed model

Figure 2 gives the systems architecture and hardware connections of the proposed low-cost pulse oximeter. The communication process between master and slave is done with the unique address of the slave. If the master wants to communicate to a slave, then only that address will be sent in the message. Meanwhile, the rest of the slaves be idle, and the target slaves recognize and then start the communication. The proposed system can also be viable with multi-slave and multi-master configurations.

![Figure 2: The architecture of the proposed model](image)

We have two devices; we use pull-up resistors for the clock line and the data line. The line is always in a high state so that every master or all slaves does the output buffer in the output open drain state. Anyone who transmits data on the line will make the open-drain output go to the ground state and pull the line to a low state, which eventually means that the buses are always in a high state.

We know that pulse rate is the time of the increase and decrease of oxygenated blood. So, when the heart pumps blood, oxygenated blood increases, and when the heart relaxes, it decreases the oxygenated blood.

Every Pulse Oximeter consists of an IR led, and RED led; the red light will travel into one's skin when one's finger is placed on the sensor, then IR led will receive the red light. For measuring the blood's oxygen level, both red and IR LEDs are used, as in figure 3.

![Figure 3: The relation between hemoglobin and oxyhemoglobin](image)

The graph is generated based on the wavelength and light absorbance of the pure and oxygen-filled blood. The partial pressure of oxygen dissolved in the arterial blood is termed PaO2, and the percentage saturation of oxygen bound to hemoglobin in the arterial blood is termed SaO2. When a pulse oximeter
measures this, SaO2 is termed SpO2. So, SpO2 is the percentage of oxygen in the blood, and the BPM is the rate at which the heart pumps blood and relaxes in a minute.

Now, the MAX30100 sensor consists of 6 pins, in which we use only four pins (VCC, GND, SCL, SDA) for interfacing with esp8266 based microcontroller. The Vcc takes input from 1.8v to 5.5v, so the sensor Vcc is connected to the 5v of d1 mini, and GND is connected to GND of d1 mini.

The SCL and SDA are connected to d1, d2, GPIO's of d1 mini, and two 4.7k resistors are connected from SCL and SDA of max30100 to the VCC, to always keep them at the high condition. Now, the OLED with 128x64 graphic displays the VCC. GND of OLED is connected to 5v and GND of the d1 mini. SCL and SDA are connected to d1, d2 pins of D1 mini, and the sensor data's output is encoded and programmed to display.

3. Proposed Pulse Oximeter- Process flow
The process flow of the proposed work is explained with pseudocode and a flow chart in this section. The esp8266 uses max30100 built-in functions from its library, and the collision between OLED and max30100 is eliminated by setting different I2C addresses while communicating with a single slave at a time.

3.1 Proposed Pulse Oximeter – Flow Diagram
As shown in figure 4, the microcontroller first initializes the OLED and the max30100 sensor by synchronizing the clock. Then code is logically ‘on’ loop for every 1-second interval. The sensor value is updated to the OLED with two pushbuttons, one for maximizing the display for the elderly, and the other is to display the time when the device was active till its boot.

Figure 4: Flow diagram of the proposed pulse oximeter

Pseudocode:
input (sensor raw value) push button 1/2; if (press) then {
maximize function
} else {
filter raw value; calculate spo2; output: initialize OLED set defined character
display spo2 and bpm
}

4. Performance analysis of proposed pulse oximeter
The proposed model is experimentally set up and shown in figure 5. The boot and the time required to fetch the sensor data are measured and investigated for their performance. It is observed that the proposed
system is capable of booting and fetching the raw data from the max30100 sensor and perform the required calculations to display the SpO2 value in less than 14 secs. A special timer is set to record the time taken to arrive at the calculation and display the values. The deviation error level is about 2-3% achieved by practical tests conducted on multiple persons using a standard pulse oximeter as a standby reference.

![Image](a) ![Image](b)

![Image](c) ![Image](d)

**Figure 5:** Heart rate and oximetric pulse setup of the proposed system

The proposed setup has a high processing rate in producing output as ESP8266 is not linked to any MySQL [5] or web server for remote monitoring, making the code runtime short and accurate. We use independent lipo and rely on any solar or external power source for its power compared to [4]. So, it is portable and feasible for measuring oxygen content and heart rate in any situation.

5. **Conclusion**

In this paper, an embedded system for monitoring SpO2 and BPM in real-time is proposed. It is designed for low price, rugged, portable. The proposed model is followed to have an add-on feature to get connected to an HTML page. The live streaming of the sensor data to the person who wants to monitor our readings remotely from anywhere can still be explored.

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