

# Designing, Implementing, and Testing of a Microcontroller and IoT-based Pulse Oximeter Device

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## Abstract:

*In this research paper, design, implementation, and testing of an Arduino microcontroller and IoT-based low-cost pulse oxygen saturation detection device using an integrated circuit sensor as the central part of the system. The measured physiological parameters are the pulse rate and blood oxygen saturation state (SpO<sub>2</sub>) from the peripheral capillary. The Arduino Uno R3 microcontroller is the heart of this system to process the detected electrical signals and convert them ultimately into the SpO<sub>2</sub> value with the appropriate unit. A wireless platform for this system was developed to send the measured data to a mobile device through the Internet of Things (IoT) and mobile apps. The microcontroller unit and its IoT module were used to transfer the data from the measuring device to the smartphone and an Android program was made to link the IoT module and collect and then store the measured data. The system was designed using the EasyEDA software to review its applicability. Then the hardware implementation is done on a printed circuit board. The optical type sensor senses the arterial oxygen saturation status from the bloodstream of the fingertips of a patient and transforms it into the appropriate digital format to be read by the microcontroller's ports according to its instruction sets. Finally, the system was assessed by measuring the SpO<sub>2</sub> level of 54 persons of diverse ages ranging from 12 to 57 years. The data were validated against a standard oximeter available commercially in the market. Then the designed measuring meter was evaluated by computing the percentage of errors for each data at the same instant. The computational results revealed that the designed system is capable of measuring the pulse rate and pulse oxygen saturation level with an average percentage of error within  $\pm 1.1\%$  and  $\pm 0.6\%$  respectively.*

**Keywords:** Pulse Oximeter, Internet of Things, Design, Implementation, Testing, Microcontroller.

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## I. Introduction

The ongoing novel coronavirus (COVID-19) pandemic was detected in Wuhan, China in 2019. At the start of the year 2020, the COVID-19 pandemic spread almost all over the world [1]. The World Health Organization (WHO) declared it as a pandemic [2]. Bangladesh detected the very first COVID-19 case on 8 March 2020 [3]. The current death rate due to coronavirus infection is around 2.2% in closed cases [4]. However, the death rate can be minimized if the oxygen saturation of a COVID-19 patient can be measured properly and regularly.

On the other hand, pneumonia disease causes 15% of childhood deaths around the globe [5]. The main reasons are hypoxaemia (i.e., oxygen saturation level or SpO<sub>2</sub> becomes less than 90% [6]) and malnutrition of the children who get admitted to hospitals with pneumonia, and of them, 15% of the patients aged less than 5 years are diagnosed with hypoxaemia and that around 1.5 million children with severe pneumonia cases need oxygen therapy each year [7]. As such, better prognostic and diagnostic tools are needed to diminish pneumonia-related morbidity and mortality significantly. However, due to the non-availability of proper prognostic tools, the World Health Organization (WHO) recommended using of oral medicines as per its Integrated Management of Childhood Illness (IMCI), and as such very often antibiotics or oxygen therapies are applied [8].

Engineering and technology have made our everyday and professional life very safe, secure, and easy today. The jobs of health professionals have become very easy with the progress and applications of engineering and technology in their fields. Recent progress of bio-sensors and wearable biomedical devices has helped to grow this field rapidly. With such devices, healthcare professionals can monitor, detect, observe, and treat their patients to save the lives of their patients and thus can save their time and efforts as well. Most of these devices can measure the physiological parameters of the patients, such as oxygen saturation or SpO<sub>2</sub> level, heart rate, blood sugar, blood pressure, body temperature, etc. and such devices are synchronized with the doctors' laptops

or smartphones from where they can observe the desired data and analyze through any software. Hence they can track their patients' health conditions regularly and whenever required [9-11].

Among the physiological data of the human body, the oxygen saturation state is one the most widely used parameter to diagnose the disease severity cases of COVID-19 and pneumonia. This parameter is known as the "fifth vital sign" of the human body [9]. A protein in the Red Blood Cells (RBCs) is called hemoglobin (Hb) that transports the maximum amount of oxygen (approximately 98%) in the human body. An oxygen molecule forms bonds with the protein and then it is called oxyhemoglobin or  $\text{HbO}_2$ . On the other hand, oxygen saturation state ( $\text{SpO}_2$ ) is a measure of the percentage of  $\text{HbO}_2$  in arterial blood. It indicates the amount of oxygen level in the blood stream as compared to its full volume that means, it is a ratio of the amount of hemoglobin in the blood having oxygen to that of without oxygen expressed in percentage. A healthy person with no physical complexity must have a  $\text{SpO}_2$  level greater than 95% [12]. The value of  $\text{SpO}_2$  level less than 95% indicates that the person may be with any respiratory diseases viz. pneumonia or asthma [13-15] or may be with any other systemic inflammatory or infectious diseases [16]. At present, over 17.65 million people on earth are at a high risk of receiving heart attacks, and one of the main reasons for it is low oxygen level [17]. To diagnose such diseases at an initial phase, a pulse oximeter is a helpful device, which can indicate how severe the disease is. If the oxygen saturation level goes very low and it persists for a long period then it may cause serious harm to the human organs. So, to measure it accurately, the pulse oximeter device is being used widely because it requires little or no training of the health professionals and no clinical symptoms to identify those diseases [9].

In the present context, a massive amount of research endeavors are going on to provide the best healthcare amenities at an inexpensive way over a few eras. With the fast progressions in engineering and technological fields, efficient, faster-responding, low-power, dependable, user-friendly, and cost-effective biomedical equipment are available. Currently, the Arduino microcontroller has become very cheap and widely existing in the market and its programming is so easy the designers can develop their programs so quickly with it to design an automated system. In biomedical applications, the designers also need compact, light-weight, portable, low-power, high-speed, chips, and Arduino microcontroller can provide such facilities. This Arduino microcontroller can be interfaced with analog circuits, sensors, etc. to its output ports [18-25].

The major objective of this research work is to design an automatic blood oxygen saturation measuring device to assist the doctors and nurses so that they can monitor their patients remotely in cases of their physical places at all places due to the pandemic and/or other such situations. This would reduce the risk of treatment failure and thereby preventing unusual deaths and providing benefits to the frontline medical professionals.

The research paper has been structured according to the following outline-

Section II reviews the literature, section III describes the hardware design steps using microcontroller and IoT, section IV explains software design using flow charts and assembly language programming, section V demonstrates the real-time data and its discussions, and finally, section V summarizes the paper with final remarks and ideas for upcoming tasks.

## **II. Literature Review**

Several research papers on pulse oximeters were found. Of them, the most recent and related works were studied to have an idea of the ongoing research activities on oxygen saturation level measurement.

Laghrouche et al. designed such a device using a microcontroller and sensors. However, they didn't provide the cost breakdown and comparative analysis of cost reduction and experimental data to that of a standard device. They also didn't present how they reduced the device size and weight, or how they used the wireless transmission as well as signal and data processing facilities [18].

Petersen et al. implemented an oxygen meter for the iPod Touch and iPhone smartphones to connect the device for auto authentication and their measured and simulated oxygen saturation and heart rate data matched very well over a wide range of the optical spectrum. However, these devices are expensive and as such are not suitable for the people of low- and mid-income regions in the world [19].

Abdullah and Ercelebi designed an oximeter to measure both the oxygen saturation and heart rate data in real-time accurately and reliably. They used a 32-bit ARM cortex microcontroller and sensors in their research. Their experimental results were compared to the data obtained from the literature [20].

Deivasigamani et al. designed an eco-friendly and cost-effective solar energy-driven digital pulse oximeter with the Internet of Thing (IoT) using the MAX30102 sensor in Eagle software platform to send the measured data to the physicians residing in remote areas in real-time though they didn't provide the cost analysis to prove their claims of cost-effectiveness. However, it is anticipated that the cost may be higher due to its superior features [21].

Longmore et al. studied reflective photoplethysmography (PPG) in the red and infrared spectrum to get the oxygen saturation and respiration level data at 8 points of the human body at steady-state and in motion conditions. They obtained the most accurate outcomes at-rest state and at the lowest points of the human body [26].

Fu and Liu measured the blood oxygen saturation (SpO<sub>2</sub>) and pulse rate by designing an oximeter using a near-infrared sensor and an STM32 microprocessor non-invasively. They used the smartphones via GPRS/WiFi/Zigbee networks to display the measured data to the observers accurately and steadily [27].

Digital Signal Processor (DSP) was used in power electronics system design and real-time implementation [28-29]. In the recent past, DSP-based ECG and other physiological parameters measurement devices were also found in several copies of literature [30-32] though, in other recent research papers, microcontroller-based biomedical and other devices were found very effective in terms of cost, sizes, weight, portability, simplicity, and reliability [22-25, 33]. Therefore, in this work, a microcontroller-based blood oxygen saturation (SpO<sub>2</sub>) and pulse rate measurement device has been proposed with the Internet of Things (IoT).

### III. Design of Oximeter using Arduino Microcontroller and IoT

The system is designed using an Arduino microcontroller, a pulse oxygen sensor IC, an Organic Light Emitting Diode (OLED) based display unit, a module in the microcontroller to be used as an IoT, and a DC power supply unit. The connection of each module is depicted in the block diagram of Fig. 1. At first, the circuit was designed in EasyEDA- an electrical and electronic circuit design software tool. Then the designed circuit was implemented by integrating each component of the system.

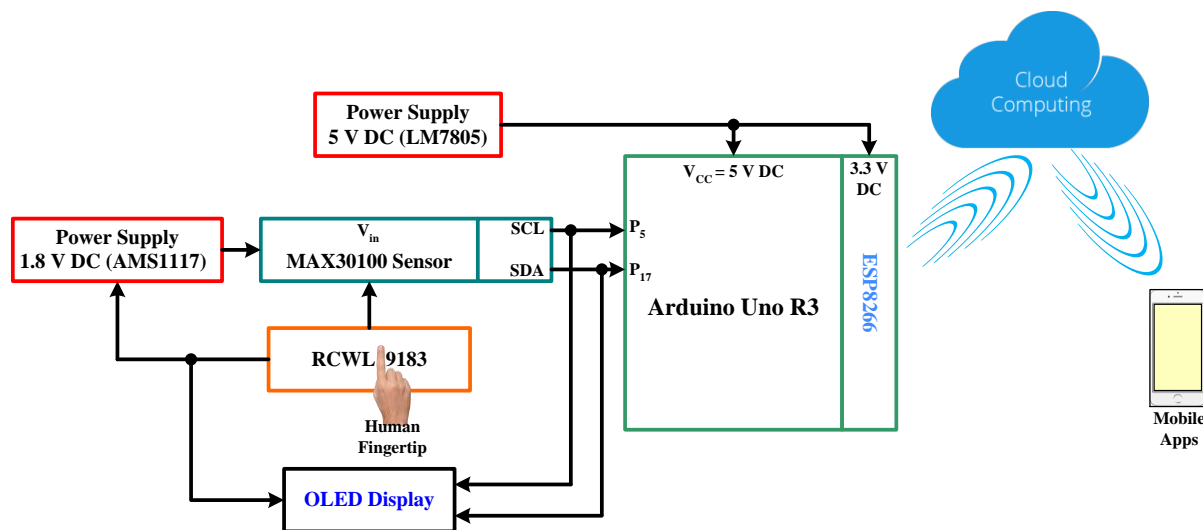


Figure 1: A functional block diagram of the pulse oxygen saturation state measuring device

The Arduino Uno microcontroller IC is the central part of this system. This unit has 6 analog inputs, 14 digital input/output (I/O) ports, 32 KB of program/flash memory, 1 KB of EEPROM, 2 KB of RAM. The Arduino Uno can be programmed as a USB-to-serial converter. The processor's operating frequency is 16 MHz and can be operated by a DC supply voltage from both 5V and 3.3V power rails. Arduino has its programming language the same as C++. However, it can use Python or other high-level programming languages as well. Besides, if an onboard ESP8266 chip (Wi-Fi firmware has been burnt in it) is used then Wi-Fi connectivity is possible through its serial ports to visit the internet.

The MAX30100 is an integrated circuit (IC) sensor solution for pulse oximetry and heart-rate monitoring. It has two LEDs, a photodetector, an optical unit for signal optimization, and a low-noise analog signal processing unit. The LED transmits the optical signal to the human fingertip and the photodetector receives the reflected optical signal which contains information of oxygen saturation state and pulse/heart rate of the human body. However, this reflected signal contains low-frequency noise signals that can be eliminated by low-pass filtering techniques to determine both SpO<sub>2</sub> and heart rate data. The MAX30100 unit can function at a 1.8 V or 3.3 V DC power supply with a current of 0.6 mA to 1.2 mA. Thus, its power drawn varies from 1 mW to 4 mW though it can be minimized using software commands by reducing the backup current [34]. However, in this work, a 1.8 V DC supply was given from a voltage regulator IC AMS1117.

The display unit consists of an Organic Light Emitting Diode (OLED, a kind of organic electroluminescent diode) based display due to its great image quality, bright colors, very high contrast, fast motion, self-illuminating, wide viewing angle, energy efficiency, lightweight, and, affordable cost. It has 4 displaying lines each line having several characters including symbols, that is, it can display several characters and symbols in each line. It requires also a DC voltage of 5 V. It has 7 pins. However, only one pin (Pin # 4) is used for receiving the data to be displayed. That is, the data communication protocol is serial type, so the data transfer process occurs bit-by-bit through a single wire, which is called the SDA line. This communication

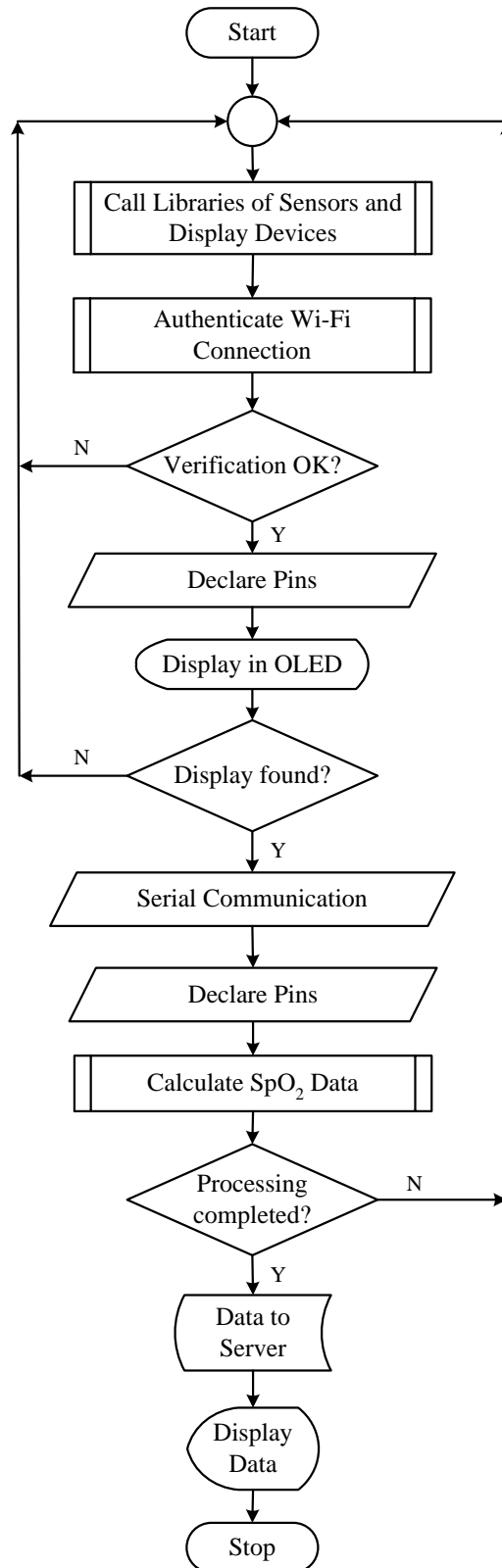
protocol is called Inter-Integrated Circuits (I2C) protocol that is synchronous and half-duplex type, that is, bits are synchronized to the clock signal of the microcontroller unit connected with the input pin # 3 of OLED. The I2C's maximum clock frequency is 100 kHz. Pin # 1 and 2 of the OLEDs are used for ground and supply voltage connections and are directly connected with the Arduino board's ground and supply voltage pins respectively. Pin # 3 (Synchronizing Clock, SCL) and pin # 4 (Serial Data, SDA) pins of the OLED display are connected to the Arduino board's A5 and A4 pins respectively. Besides, pins # 5-7 are used for reset, changing the data and command registers as per input requests, and selecting/enabling the chip.

NodeMCU is an Internet of Things (IoT) platform. It runs on the ESP8266 Wi-Fi System-on-Chip (SoC). It is an open-source type software and hardware connection board. It has 4 MB of flash ROM, 128 KB of RAM, and an antenna [35-36]. The developed program on a PC should be converted to low-level machine instructions so that the chip can interpret it properly. It possesses high processing power with in-built Wi-Fi/Bluetooth and Deep Sleep Operating features and thus it is suitable for connecting IoT devices. It works on IEEE 802.11 b/g/n standards to enable microcontrollers to connect to the 2.4 GHz Wi-Fi module and can be powered by a USB cable and external power supply voltage of 3.3 V [37-38]. Inter-Integrated Circuits (I2C) half-duplex serial data communication protocol is used to transfer the data bit-by-bit through a single data channel (SDA line) synchronously with the sampling clock, which can be a maximum of 100 kHz. That is why; it can be connected with low-speed devices, viz. microcontroller, ROM, RAM, EPROM, EEPROM, A/D and D/A converters, I/O interface devices, and such other similar peripheral devices used in the embedded systems. Here also SCL and SDA lines are used like in OLED. It can communicate with multiple devices using their device addresses [39].

The circuit requires DC power at various voltage levels from 1.8 V to 5 V, and as such, a 5 V DC power supply unit is designed from which the appropriate voltage levels and currents were given to the microcontroller, pulse sensor, Bluetooth module, and the display unit. The DC power supply block of 5V was designed using a voltage regulator IC, LM7805, diodes, capacitors, and a step-down (220 V/6 V, AC) center-tap transformer. The AC power line supply voltage of 220V at 50 Hz was stepped down to 6 V level and then was rectified by a center-tapped rectifier consisting of two diodes. This rectified signal contains ripples that are eliminated to have a pure DC voltage of 5 V with passive capacitive filters of 1  $\mu$ F and 470  $\mu$ F at the input and output ports of the voltage regulator IC respectively. The capacitors eradicate the noise signals from the circuit [40]. However, for a 1.8 V DC supply for the MAX30100 sensor IC, a separate IC AMS1117 is used along with two 0.1  $\mu$ F capacitors at the input and output terminals and another 10  $\mu$ F capacitor at the output terminal only for filtering the unwanted signals because this regulator IC has low drop out voltage and low voltage regulation (< 0.2%) [41].

#### **IV. Software Design**

To exhibit the pulse oxygen saturation state and pulse rate at the selected display device (an OLED display), the software was prepared accordingly. The software receives the data, then processes the same, and finally sends them to the output port for displaying in the appropriate format. As such, the input and output ports are to be reset so that the data can be sent to the OLED screen's inputs as revealed in Fig. 1. To do this, we need to use the related libraries, such as Wire.h to use the I2C communication, Adafruit\_GFX.h to use any graphical interface Adafruit\_SSD1306.h to ensure that the output port gets the data instantaneously. To operate the microcontroller and IoT-based appropriate, an assembly language program was developed based on the established algorithm. Besides, a mobile application was also designed to store and display data on smartphones via cloud computing. However, in the device level programming, hardware was configured to work properly and in the application programming, calculation of the pulse oxygen saturation data in percentage was obtained to be displayed in the appropriate format and unit. The program flow chart is exemplified in Fig. 2. The data collected by the sensor is processed by the microcontroller as per the software and is then sent to the OLED display device and cloud via IoT.



**Figure 2:** Flow chart of the pulse oxygen saturation data measuring device using IoT

### V. System Operation

The selected components described in Section III of the whole system are connected as per the circuit diagram revealed in Fig. 3 to explain the system operation. When the pulse sensor module, RCWL9183 senses the analog signals from the human fingertips placed on it, the sensor module sends an optical signal from its LED and then receives the reflected signal by an optical detector working in the infra-red spectrum range. The

received weak analog signal goes to the MAX30100 IC where it is amplified and then an Arduino library function converts the analog signal into a digital signal. This also converts it to the appropriate data format by monitoring the ambient temperature and using the pulse width modulation technique for the Arduino microcontroller's input.

After that, the Arduino microcontroller unit interprets and processes the signals acquired at its input from the sensor and then computes the pulse oxygen saturation state in percentage (%) as per the programming instruction sets written using an Assembler in a personal computer. Then it directs the detected SpO<sub>2</sub> data to the OLED to be displayed in an appropriate layout as shown in Fig. 4. To display the data on the smartphone, remote control, or remote operation, an integrated IoT server suite named Blynk has been used.

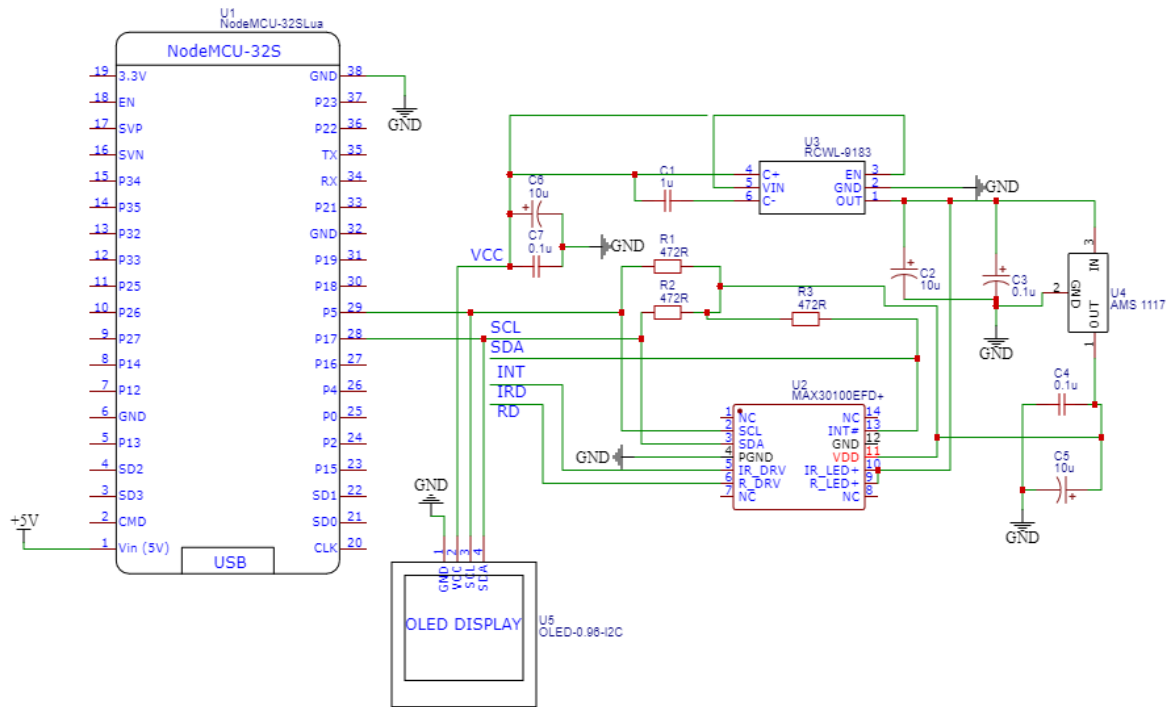


Figure 3: The complete circuit diagram of the designed pulse oxygen saturation state measuring device in EasyEDA

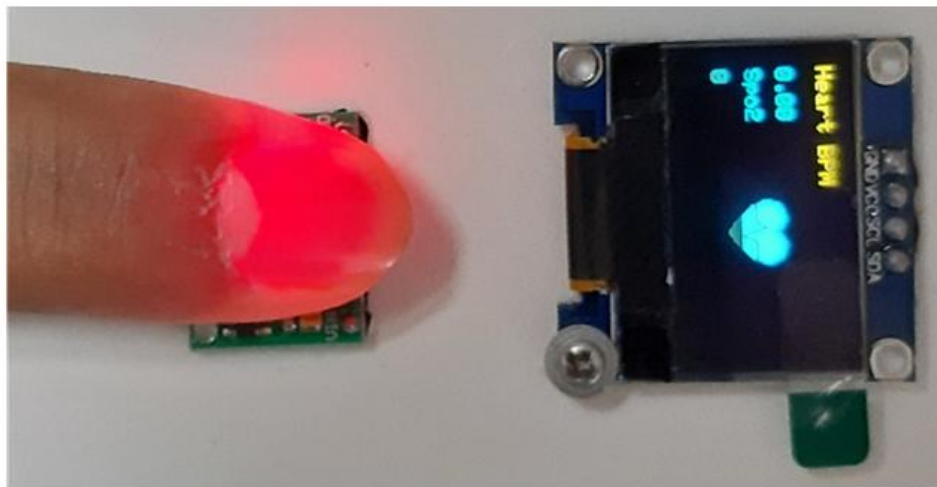
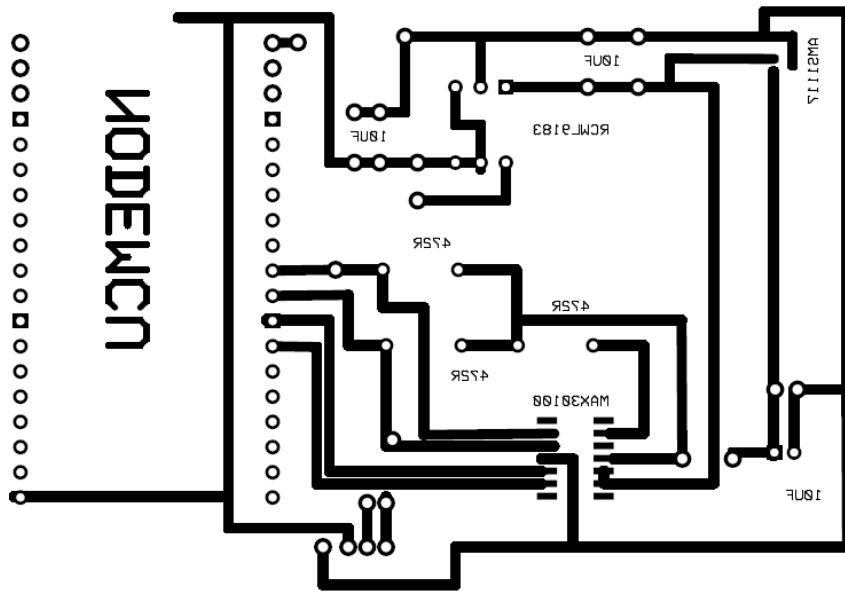


Figure 4: Exhibiting the SpO<sub>2</sub> data on an OLED screen (finger-tip is used to get the real-time data)

## VI. Real-Time Data and Discussions

To observe the real-time experimental data of the pulse oxygen saturation and heart rate values, the Printed Circuit Board (PCB) of the whole system was designed using the ExpressPCB software, which is a simple electronic circuit board design tool that facilitates easy placement of the parts on the drawing page and then connecting their I/O pins. This is shown in Fig. 5. Then the system has been realized in practice by placing

all the components on it and then connecting by soldering iron on the printed circuit board. After that, the whole system was housed in a white casing. The practical system is shown in Fig. 6. The measured results for each person were observed on an OLED display unit as well as on the cloud server.



**Figure 5:** Printed Circuit Board (PCB) design of the whole system was drawn in ExpressPCB software for the real-time implementation of pulse oxygen saturation state measuring device



**Figure 6:** Real-time implemented pulse oxygen saturation level measuring device on a printed circuit board and enclosed in a casing

The measured data observed on the cloud server are shown in Fig. 7. We rounded the values to the nearest integer numbers. These are also shown in Table I as well.



Figure 7: Screen-shots of the real-time data observed on the cloud server

The heart rates and pulse oxygen saturation values are measured for 31 persons of different ages by using our implemented pulse oximeter device and a standard commercially available oximeter purchased from the medicine store simultaneously. The data are presented in Table I for all persons. The percentages of error between the data measured by the two machines are computed based on equation (1).

$$\text{Experimental error of the designed machine, } \varepsilon = \frac{RTD_i - RTD_c}{RTD_c} \times 100\% \quad (1)$$

,where  $RTD_i$  indicates the real-time data measured by the implemented pulse oximeter device and  $RTD_c$  indicates the real-time data measured by the standard commercial pulse oximeter device.

In Table I, the measured data by both machines are presented for 31 persons aged from 10 to 70 years with an average age of 33.3 years. The measured minimum and maximum values of heart rate were observed as 59 pulse/min and 101 pulse/min respectively and that of oxygen saturation data were 95% and 99% respectively. The percentage of errors varies from 0% to 1.7% and from 0% to 1.1% with an average percentage of errors of only 1.1% and 0.6% for heart rate and oxygen saturation data respectively.

TABLE I  
MEASUREMENT DATA

Sl #	Person	Age (Years)	Measured Real-Time Heart Rate (in pulse/min) and SpO <sub>2</sub> Data (in %)				Experimental Error, ε (in %)	
			By the Implemented Oximeter		By a Standard Commercial Machine		For Heart Rate	For SpO <sub>2</sub> Value
			Heart Rate (in pulse/min)	SpO <sub>2</sub> Value (in %)	Heart Rate (in pulse/min)	SpO <sub>2</sub> Value (in %)		
1	Person1	10	101	97	102	98	1.0%	1.0%
2	Person2	60	88	96	87	95	1.1%	1.1%
3	Person3	25	74	95	74	96	0.0%	1.0%
4	Person4	70	59	95	60	95	1.7%	0.0%
5	Person5	26	81	96	80	95	1.3%	1.1%
6	Person6	13	80	98	79	99	1.3%	1.0%
7	Person7	39	80	98	79	99	1.3%	1.0%
8	Person8	24	94	96	93	97	1.1%	1.0%
9	Person9	18	92	98	91	98	1.1%	0.0%
10	Person10	18	79	97	79	97	0.0%	0.0%
11	Person11	27	81	98	82	98	1.2%	0.0%
12	Person12	25	92	99	91	99	1.1%	0.0%
13	Person13	22	88	98	89	98	1.1%	0.0%
14	Person14	35	82	97	81	97	1.2%	0.0%
15	Person15	49	68	95	67	96	1.5%	1.0%
16	Person16	45	72	97	71	96	1.4%	1.0%
17	Person17	54	77	96	77	96	0.0%	0.0%
18	Person18	48	79	95	79	96	0.0%	1.0%
19	Person19	23	81	96	80	95	1.3%	1.1%
20	Person20	45	80	97	80	96	0.0%	1.0%
21	Person21	37	73	97	72	98	1.4%	1.0%
22	Person22	40	69	95	68	96	1.5%	1.0%



Sl #	Person	Age (Years)	Measured Real-Time Heart Rate (in pulse/min) and SpO <sub>2</sub> Data (in %)				Experimental Error, $\epsilon$ (in %)	
			By the Implemented Oximeter		By a Standard Commercial Machine		For Heart Rate	For SpO <sub>2</sub> Value
			Heart Rate (in pulse/min)	SpO <sub>2</sub> Value (in %)	Heart Rate (in pulse/min)	SpO <sub>2</sub> Value (in %)		
23	Person23	20	71	99	72	99	1.4%	0.0%
24	Person24	55	78	96	77	97	1.3%	1.0%
25	Person25	19	85	97	84	97	1.2%	0.0%
26	Person26	11	82	98	81	99	1.2%	1.0%
27	Person27	40	71	98	70	98	1.4%	0.0%
28	Person28	43	78	97	79	96	1.3%	1.0%
29	Person29	22	93	98	94	99	1.1%	1.0%
30	Person30	27	102	96	101	97	1.0%	1.0%
31	Person31	38	76	95	75	95	1.3%	0.0%
<b>Average Values</b>		<b>33.3</b>	<b>80.8</b>	<b>96.8</b>	<b>80.5</b>	<b>97.0</b>	<b>1.1%</b>	<b>0.6%</b>

TABLE II  
EXPENDITURES INVOLVED IN THIS WORK

Sl #	Component Name	Quantity	Unit Price (US\$)	Total Price (US\$)
1	NodeMCU-325 with ESP8266	1	6.20	6.20
2	MAX30100 and RCWL9183Sensors	1	10.25	10.25
3	16x128 OLED Display	1	5.00	5.00
4	Casing	1	2.60	2.60
5	PCB Board	1	2.60	2.60
6	Power Supply Module	1	1.50	1.50
7	Cable	-	1.80	1.80
			<b>Total Price (US\$)</b>	<b>29.95</b>

The component-wise expenditures involved in this work are shown in Table II. From Table II, we see that the total implementation cost is only US\$29.95. If we go for a mass scale commercial implementation then the real-time manufacturing expenditures would be cheaper substantially.

### VII. Conclusions

In this work, a simple, microcontroller and IoT-based robust pulse oxygen saturation measuring device design process is described and then its experimental results are presented with a brief explanation of it. The implemented system is portable and is shown in the paper. It requires no expert medical personnel to measure the SpO<sub>2</sub> state or heart/pulse rate of a person. The person himself/herself can also measure it easily. Due to the easy connectivity with the internet through the IoT, the designed machine has the facility to send the measured data through the IoT to the mobile phones to get advice or treatment from any doctors who reside in remote areas without any physical or on-site visits. The measured data and its accuracy rate were satisfactory as compared to the standard commercial device bought from the drug store with average error rates of 1.1% and 0.6% for heart rate and SpO<sub>2</sub> data. Besides, sending data to the mobile device was successful and displayed on the smartphone screen. Besides, the implementation cost was very low, of the order of US\$30 (US Dollar thirty only).

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