



IOT based portable heart rate and SpO2 pulse oximeter

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ABSTRACT

Ever since the COVID-19 pandemic, the necessity of new, innovative medical devices to analyse and monitor the situation has become profound. With this in mind, we have developed an IOT based portable and cost-efficient heart rate and SpO2/level sensor device with efficient performance. The proposed system is equipped with an onboard OLED with simple internet connectivity, which publishes data on the OLED and to a HTML webpage. The salient features include its portability, user compatibility and is unique in its way of transmitting collected data online, making it achieve better results than the current available solutions in various ways. The system has on board a MAX30100 sensor (Pulse Oximeter sensor) and along with the IOT based microcontroller (WeMos D1 mini) enables the facility to monitor the real time health data of patients in real-time through a HTML page.

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Specifications Table

Table 1.

Table 1

Hardware specifications.

Hardware name	IOT based portable heart rate and SpO2 pulse oximeter
Subject area	<ul style="list-style-type: none"> Engineering and the internet of things Medical diagnosis General Electronics
Type of Hardware	<ul style="list-style-type: none"> Embedded systems, the internet of things Biomedical Electrical engineering and computer science
Closest commercial analog	This IOT based pulse oximeter with a web interface replaces commercially available pulse oximeters.
Open source license	GNU-General-Public-Licence (GPL)-3.0
Hardware cost	\$17.958
Open access repository	https://doi.org/10.17605/OSF.IO/SNPF8

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Hardware in context

Medical data such as SpO₂, heart rate and blood pressure are very crucial in judging the status of an individual or a patient in a medical context. They provide very vital information regarding their current state of their body, and thus easing this process of acquiring such data with devices has substantial benefits [1,2]. Although several pulse oximeter designs are available, our design, due to its IOT capabilities, makes the entire data acquiring process very user-friendly and convenient. This design can be used anywhere by plugging into a USB adapter/port with a 5 V electrical supply [3,4,5]. Anyone with an active internet connection within the local area network of the pulse oximeter can view the patient's vital readings. The device is also very user-friendly, as the vitals are acquired when the patient places his/her finger on the onboard sensor. A time duration of just 15 s or less is computationally enough to acquire the heart rate of the individual.

The pulse oximeter is also equipped with an onboard OLED 0.96 in. 128 × 64 display [6], enabling the system to have an 'on the go visualization' capability [3]. The proposed system is designed to be a power efficient device with the use of the MAX30100 pulse oximeter sensor. The proposed device uses an ESP8266 based wemos D1 mini Wi-Fi microcontroller, which helps in hosting a HTML page. Therefore, anyone connected within the Local Area Network can access the information from the pulse oximeter through this HTML page. It is this feature, which grants this device tremendous IOT capabilities within a low price range. The project's objective is to deliver a simple and easy to interact IOT based pulse oximeter/heart monitoring system to everyone.

Hardware description

The proposed system consists of three electronic components which are cost-efficient and all are open sourced. The description of the hardware along with the open access repository is in available in Table 1.

ESP8266 wemos D1 mini

This wemos D1 mini is a wifi enabled microcontroller with a board design based on ESP8266 [78910]. It has an. 11 digital IO, interrupt/pwm/I2C/one-wire supported(except D0) [9], One analog input(3.2 V max input). a Micro USB connection [11,12]. The microcontroller is compatible with MicroPython, Arduino, nodemcu. Clock Speed is 80/160 MHz with a Flash of 4 M Bytes [13].

This device can be powered with a USB cable which provides 5 V input in order to power it. Due to its Wi-Fi capabilities, the D1 mini enables us to host a HTML page [45], have a web server running, as well as wirelessly transfer source code into it. (see Fig. 1a).

OLED module

The organic light-emitting diode (OLED) display used in this project is the SSD1306 model which is a mono colour type, resolution of 128 × 64 pixels with a display size of 0.96 in.. The speciality of this OLED display compared to LCD is that back-light isn't required for these displays, which ultimately improves the viewing contrast in low-light environments. These OLED displays are very power efficient compared to other displays. This OLED is interfaced with D1 mini, with I2C protocol [6]. The chip has 7 pins out of which only 4 pins are used to communicate(VCC,GND,SDA,SCL). As the OLED uses only 4 pins rather than the traditional LCDs which have to interface with 12 pin connections with the microcontroller. As it uses 5 V input voltage, it is easy to interface with the default output pins of most microcontrollers.(see Fig. 1b).

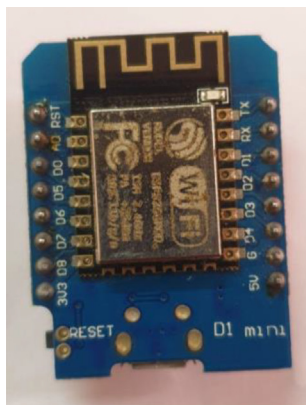
MAX30100 pulse oximeter module

The MAX30100 is a kind of sensor where pulse-oximetry as well as heart rate monitoring sensor is embedded to it. This module consists of two LEDs, optics which is well optimized, an analog signal processing unit(low noise) in order to detect the heart rate and SpO₂ signals [1415]. The operating voltage of this sensor is 1.8 V to 5 V. An inbuilt voltage regulator is embedded for any high voltage noises. A photo sensor is also integrated in it. The brightness of the LED, photo sensor detection ranges and the sample rate can be controlled programmatically. This sensor is capable of performing at high sample rate with a high data output (see Fig. 1c).

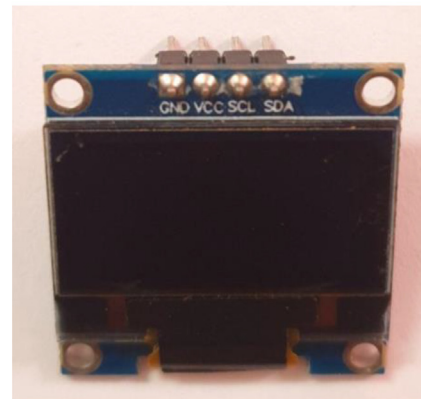
This pulse oximeter module is also interfaced using I2C protocol which uses only 4 pins to communicate(VCC,GND,SDA, SCL). Additionally, the SDA, SCL are on the same wires as OLED interfacing pins. Furthermore, several machine learning algorithms can be used with this module and predict threshold of health attacks and other classification problems related to system vitals [16].

The total hardware circuitry is assembled and soldered on a PCB which is placed in a 3D printed PLA case. The key features of this device includes:

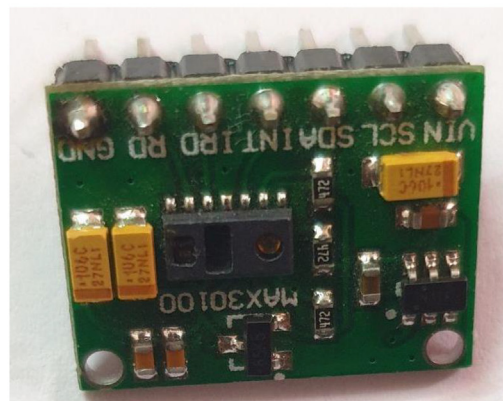
- IOT based health monitoring system
- Simple to assemble and simple to use.
- Cost-efficient



(a)



(b)



(c)

Fig. 1. The key electronic modules of the system a)D1 mini wemos microcontroller, b)128 × 64 OLED display, c)MAX30100 pulse oximeter module.

Summary of design files

Table 2.

Table 2

Design file summary.

Design file name	File type	Open source license	Location of the file
D1 mini microcontroller, adafruit 128 × 64 OLED module interfacing	jpg	CC BY-SA	(Fig. 2.)
D1 mini microcontroller,MAX30100 interfacing	jpg	CC BY-SA	(Fig. 3.)
ESP8266 based D1 mini to host a HTML page	jpg	CC BY-SA	(Fig. 4.)
Final Hardware setup	jpg	CC BY-SA	(Fig. 5.)
D1mini wemos microcontroller code to interface 128 × 64 OLED	.ino	CC BY-SA	Open access repository
D1mini wemos microcontroller code interface MAX30100	.ino	CC BY-SA	Open access repository
Full system code of IOT pulse oximeter	.ino	CC BY-SA	Open access repository
3D printed enclosure casing	.stl	CC BY-SA	Open access repository

Summary of the bill of materials

Table 3.

Table 3
Summary of Bill of Materials.

Component	Number	Cost per unit	Total cost	Source of materials	Material type
D1 Mini wemos Development Board	1	\$1.20	\$1.20	https://www.alibaba.com/product-detail/ESP8266-ESP-12-ESP-12F-CH340G_62526321989.html	Electronics
0.96 Inch OLED Display with 128 × 64 pixels	1	\$1.32	\$1.32	https://www.alibaba.com/product-detail/0-96-Inch-Display-Module-128X64_62337789629.html	Electronics
bundle of jumper wires	1	\$0.048	\$0.048	https://www.alibaba.com/product-detail/Wire-Jumper-Custom-Length-Dupont-Wire_62410435440.html	Electronics
PCB prototyping board	1	\$0.19	\$0.19	https://www.alibaba.com/product-detail/Double-Side-5-x-7-cm_60789880817.html	Electronics
Female Header Pins	2	\$0.10	\$0.20	https://www.alibaba.com/product-detail/2-54 mm-Pitch-10-Pin-Single_60451345083.html	Electronics
		Total-Components	\$2.958		
		Tax + Shipping	\$15		
		Total	\$17.958		

Build instructions

Before we go ahead with the prototype stage, it is essential to interface each component individually. In this current section, the practical functionality of each of the component will be represented using electronic circuit diagrams. Finally, the completed system design is provided, all the design files are described in Table 2 which describes all the components required to build this project. Table 3 gives us insights on the individual component cost along with the total cost to build this project, which will represent how the complete device operates as one.

D1 mini microcontroller and adafruit OLED module interfacing

Firstly we will discuss the basics of presenting numbers, characters, text and other features provided by the open sourced Arduino library [17,18]. This library tells us how the OLED has been interfaced with the microcontroller in real-time. As the OLED displays are compact with 128 × 64 pixels, it functions great in displaying special symbols and thus the sensor data. The microcontroller has an I2C protocol pins of 5 V GND,D2,D1 [8–10] which are the four pins (VCC,GND,SDA,SCL). Fig. 2. Adafruit's open-source OLED library has been used for printing custom character and GIFs on the OLED [19–22]. Since the microcontroller uses I2C, only 2 pins are required [13] to send and receive the data.

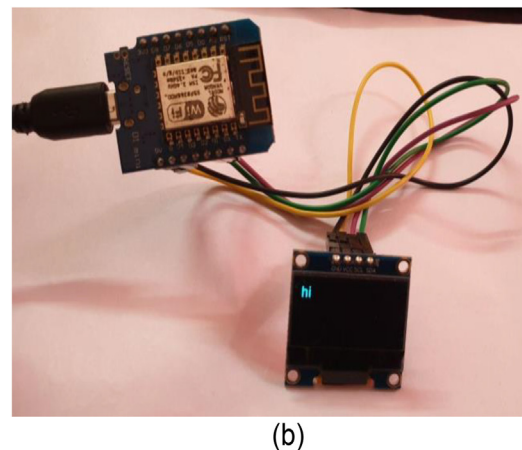
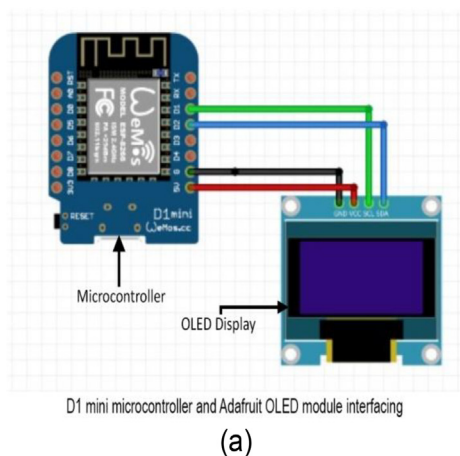


Fig. 2. D1 mini microcontroller and adafruit OLED module interfacing a)schematic diagram of OLED interfacing with D1 mini. b)Real-time connections of D1 mini wemos and 128 × 64 OLED display.

D1 mini microcontroller and MAX30100 interfacing

The pulse oximeter module(MAX30100)(Fig. 3b.) is the component that measures the percentage of oxygen in the blood-stream in real-time [22,23]. The I2C protocol is also used for communicating, which again leads to its interaction with the ESP8266 using only 2 pins [24]. The operating voltage of the module is 5 V[14].

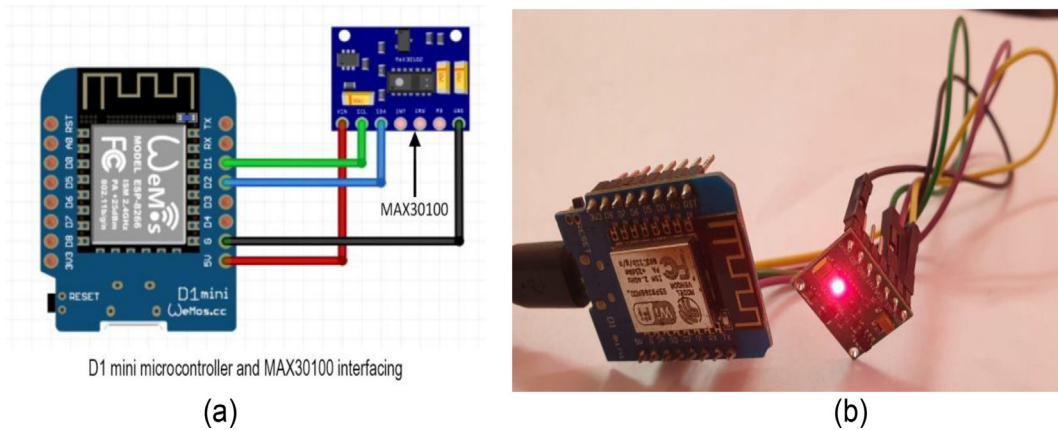


Fig. 3. D1 mini microcontroller and MAX30100 interfacing a)schematic diagram of MAX30100 interfacing with ESP8266 and b)Real-time connections of D1 mini wemos and MAX30100 pulse oximeter.

Configuring the ESP8266 based D1 mini to host a HTML page

The wemos D1 mini microcontroller is compatible with Arduino libraries [25,26]. Therefore, the task of hosting a HTML page locally is easy. We will be using a WiFi Client as well as the ESP8266 web server libraries to host a HTML page, which will display all our sensor data from the MAX30100(heart rate, SpO2 vitals) on the hosted IP address [23,26–28] (Fig. 4).

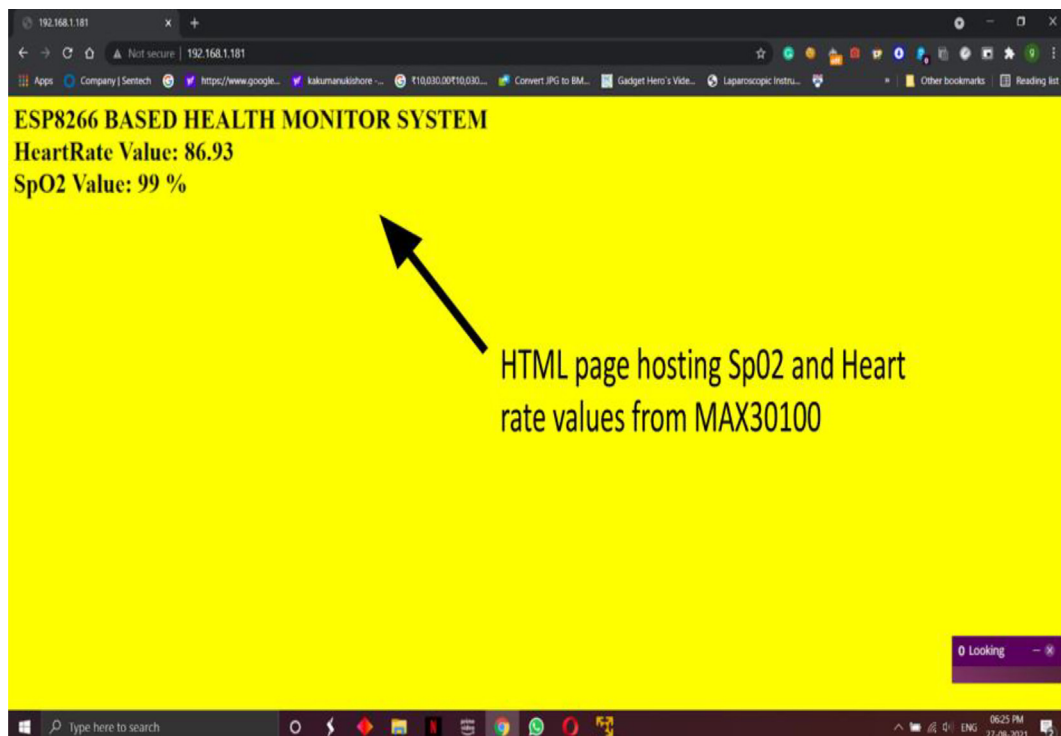


Fig. 4. ESP8266 based D1 mini hosting a HTML page.

The complete design of the system and obtained results

After interfacing all the different sensor modules with the ESP8266 D1 mini, the device is enclosed within a 3D printed box of required dimensions. This box acts as the enclosure for all the PCB and sensors present in the device. The device can now be used anywhere when plugged in with a 5 V USB port. Once the device has been successfully developed into an assembled prototype in its final form (Fig. 5.), it is necessary to test the device.

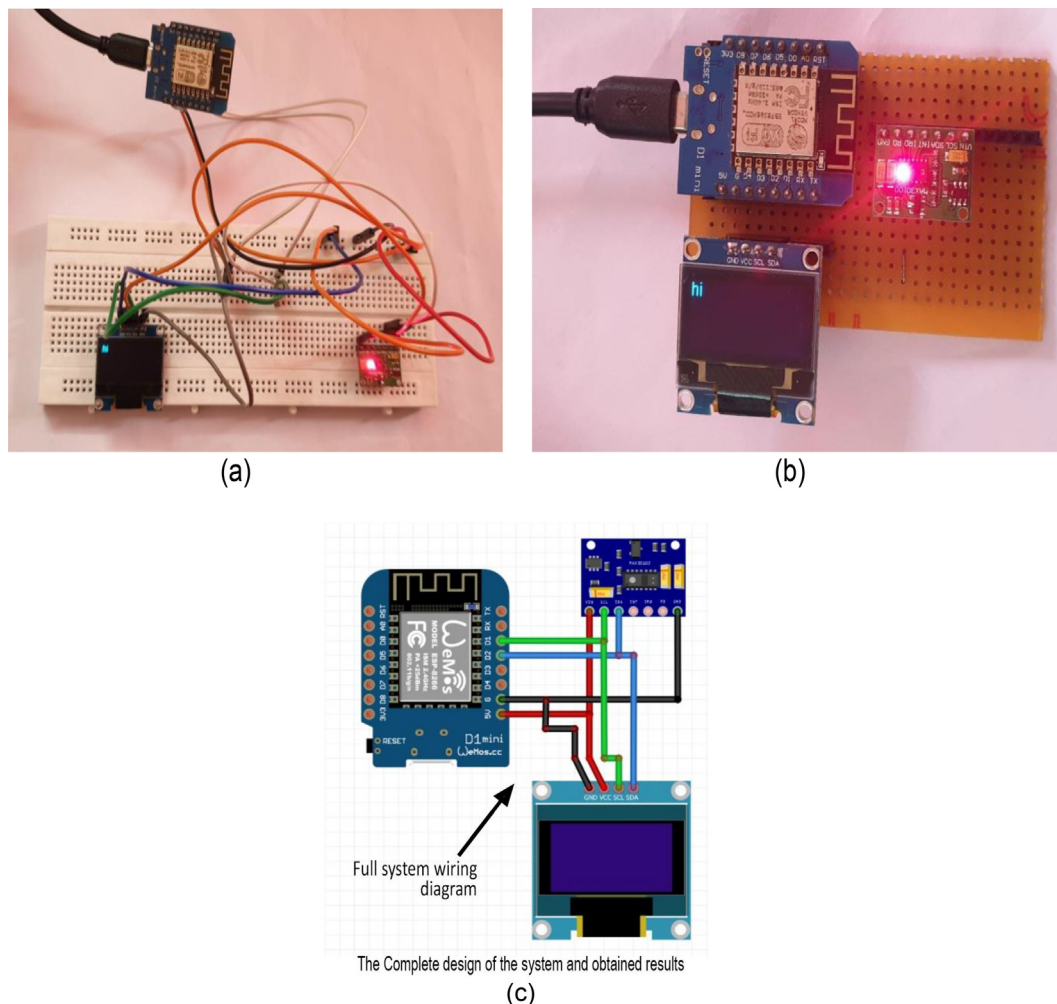


Fig. 5. Full system integration circuit a) Jumper wire connections between D1 mini wemos and modules, b) PCB arrangement of the full system. c) The schematic diagram of final circuit connection.

(Fig. 6.) provides us with the simplified version of the block diagram of the proposed system. In order to test the device's accuracy and performance comparatively to the other commercially available options, the device was used to read the heart rate and SpO2 levels of multiple users. These readings were then compared with the readings taken from a commercially available device, and the readings were found to be very similar and accurate Fig. 7 Fig. 8.

As a result of this improved pulse oximeter system which is capable of analysing the heart rate and SpO2 levels of a patient within seconds [16], it is easier to host the acquired data into an HTML page in real-time [29–31]. Therefore, miscalculation due to physical error which causes a mismatch of the readings can be avoided. Due to the cost-efficient nature of the electronics used and the simplicity of the microcontroller code, this system can be reproduced/recreated by anyone with ease [15].

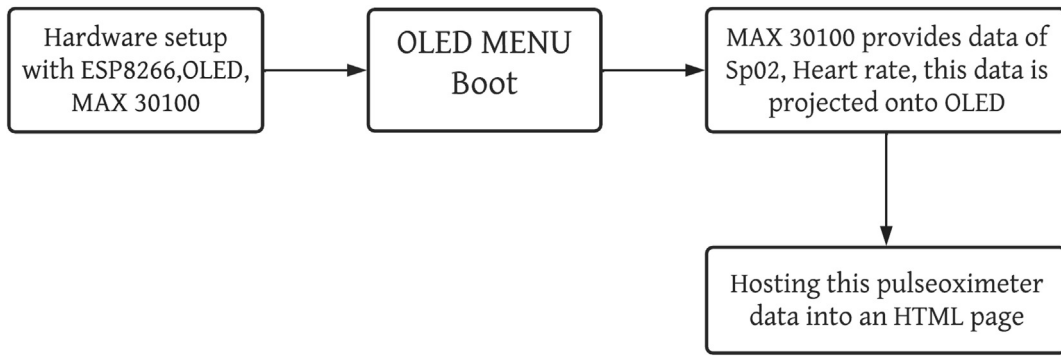


Fig. 6. Block diagram of the proposed system.



Fig. 7. A model of a commercially available pulse oximeter.

Operation instructions

First place your finger upon the sensor. The device takes around 15 s to calculate and display your average BPM, the real time heart rate and SpO2 levels on the onboard OLED in real-time with no delay. Simultaneously, these readings are sent to the HTML web server where they can be assessed, provided, you are connected to the same local network as the device [192122].

In order to set up the device, It is necessary to connect it with your router by providing the SSID and password of the router. With the obtained IP address of the local HTML web server, when entered into any device(such as a smartphone, laptop, etc) browser's URL [23,27], we would be able to access the pulse oximeter's readings in the configured HTML web server.

Validation and characterization

Our design is not one only minimalist in design, but as well as in circuitry; keeping the traditional commercially available pulse oximeter in mind, which doesn't have the features of viewing the device's data on your smart device or any device connected to the internet. This IOT based Pulseoximeter performs smarter than the already existing solutions. Keeping time complexity in mind, this device displays the real-time data both on the OLED display and on the hosted webpage. Anyone

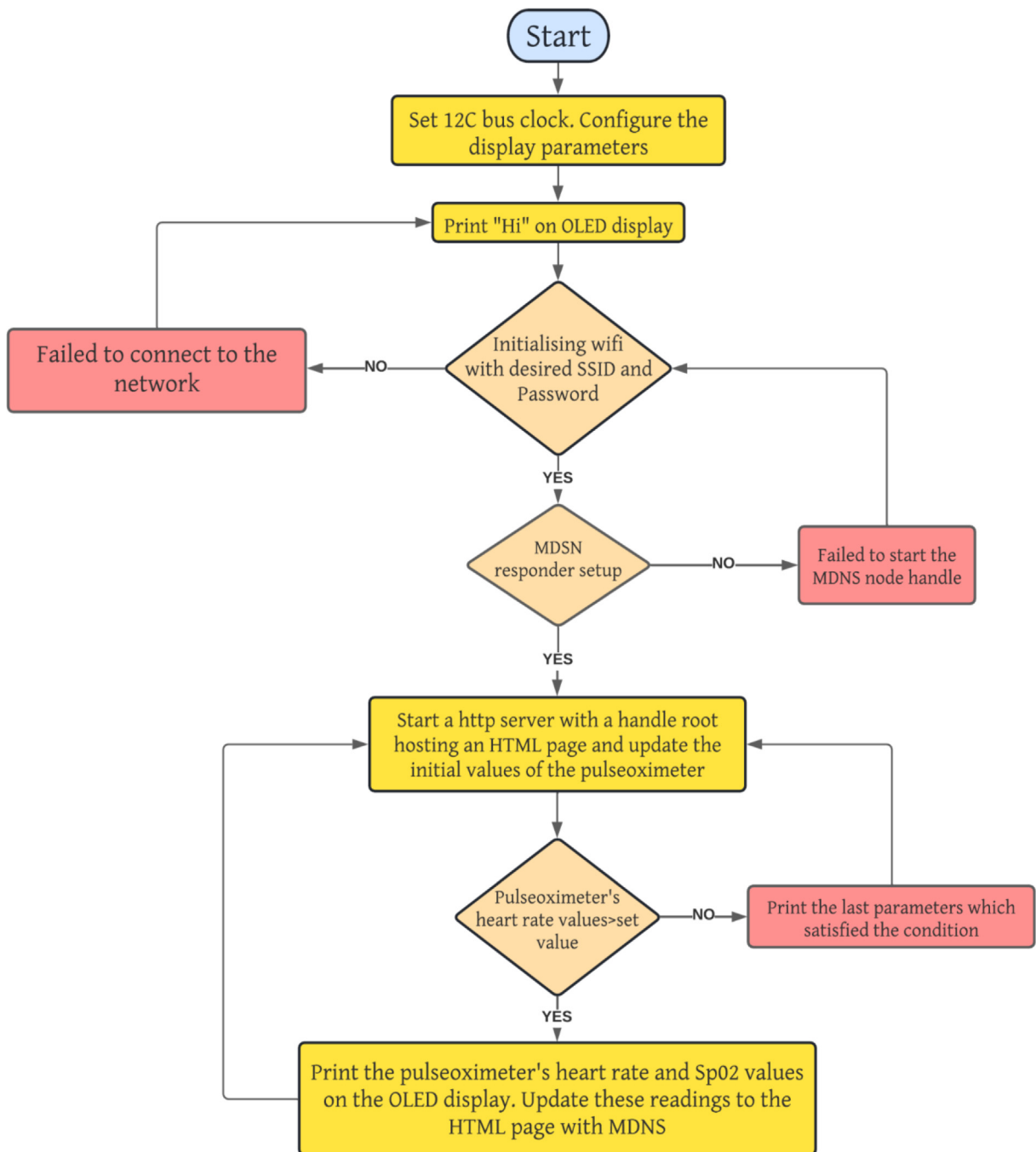


Fig. 8. The Operating Instructions Flowchart.

who wants to monitor the user's heart rate and SpO2 levels can easily access the data just by entering the IP address in any smart device which is connected to the local area network of the router. Below, the picture (Fig. 9a.) gives an insight on the proposed system which displays the heart rate on a full 0.96 in. display size when we long press button 1, the figure (Fig. 9b.) shows information on the time the device is active by long pressing button 2. (Fig. 9c.) shows how the full pulse oximeter setup is, while measuring the user's heart rate and SpO2.

To conclude this paper, the cost-efficient pulse oximeter which hosts real-time SpO2 and Heart rate vitals into an HTML page is proposed and developed. The cost-efficient pulse oximeter could be recreated with ease with the provided technical and theoretical resources as mentioned above. As the microcontroller is ESP 8266 based, the device is reprogrammable and

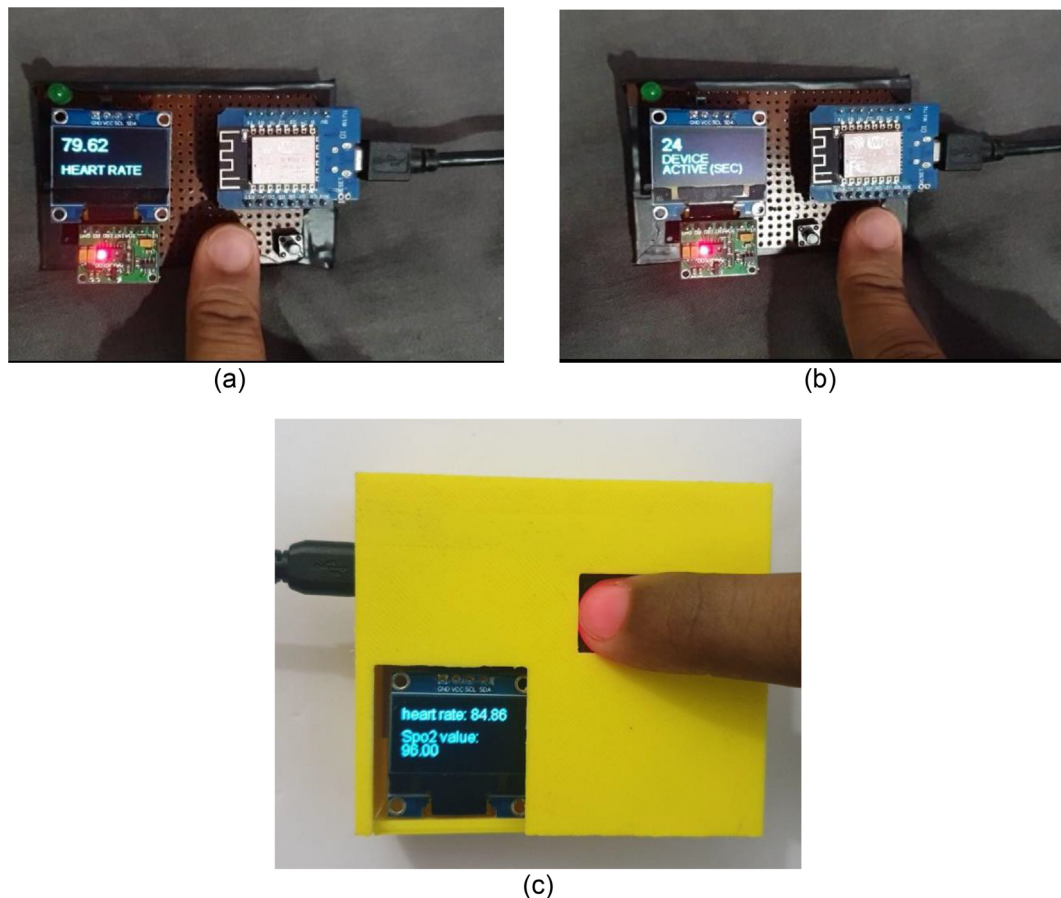


Fig. 9. a)Maximized view of Heart rate reading b)Display of device active time c)The working state of the proposed system.

therefore upgradability of features is possible. Some upgrade includes, features such as a real-time clock or a timer which could be introduced for a schedule checkup. This is the salient and unique feature of the paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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