The implementation of an impulse oximeter using Arduino microcontroller

Maria Revythi
Department of Electrical and Computer Engineering, University of Patras, 26504 Patras, Greece

Abstract

The oxygen saturation is an important parameter for health. A pulse oximeter measures oxygen saturation and can detect early respiratory difficulties such as hypoxemia. This paper describes the design and implementation of low-cost pulse oximeter. The principal components of that device are a Red led light, an Infrared led light, a photodiode and an Arduino Uno microcontroller. The system is designed in Tinkercad and then simulated to test its performance. After that, the hardware implementation was followed. A system of led lights and a photodiode was used to measure the oxygen saturation. The Arduino microcontroller was used for calculating the oxygen saturation, for calibration and signal processing techniques. The designed system was tested by measuring the SpO2 levels of several people from various ages. Furthermore, the same individuals were tested using a standard machine purchased from the market. The test results were found to be very accurate, with an average percentage of error of only 0.52 percent

Keywords: pulse oximeter; oxygen saturation; Arduino Uno microcontroller;

Introduction

Near infrared spectroscopy (NIRS) is a technique, which calculates the changes in oxygenated hemoglobin and deoxygenated hemoglobin in the tissue Boushel *et al.* (2001) . NIRS measurements have a variety of applications such as in connective and muscle tissue and the control of changes in brain Abay and Kyriacou (2016) , . One application of the technique is pulse oximeter. The main principal of a pulse oximetry is to measure the percentage of oxygenated hemoglobin in the arterial blood Metcalfe *et al.* (2021).

Pulse oximetry was widely used in coronavirus pandemic. The Coronavirus firstly showed up in December 2019 and it was spread rapidly all over the world. As a result, the healthcare system was weak in order to deal simultaneously with the multiple Coronavirus cases Metcalfe *et al.* (2021), Bhuyan (2021). The decompression can be enhanced, when people follow the doctor's instructions after the infection, while they are home. One factor, which is possible to show the severity of the situation, is the pulse oximeter. Some advantages of a pulse oximeter are the following:

- it is a non-invasive method
- it is easy to use, even a child can use a pulse oximeter
- it can be used at home
- it detects hypoxaemia early Hakemi and Bender (2005)

Engineers work in order to make medical instrumentation, which will be convenient for the patient and doctors could regulate the patient's situation from distance. The main principal of a pulse oximeter is to measure the percentage of the oxygen in blood. Oxygen saturation is considered to be the fifth vital sign Chan *et al.* (2013). Other vital signs are temperature, blood pressure, heart rate, and breathing or respiratory rate of the human body. Oxygen saturation shows the quantity of the hemoglobin, which contains oxygen in the blood, in comparison to the whole hemoglobin. It is an important parameter for patient's condition. Low oxygen saturation can provoke malfunction to internal organs, such as brain, kidneys and heart Hafen and Sharma (2021). The early detection of low oxygen can prevent those malfunctions .

The pandemic situation requires to control patient's condition remotely. A pulse oximeter is an essential tool for everyone. However, people can not afford the pulse oximeter's cost in low-development countries. Biomedical engineers try to find a solution to this problem. Arduino micro-controller is cheap and easily available in the market. Moreover, engineers use widely Arduino micro-controller because of its compactness, its portability, its less power consumption, its enhanced battery life and its high operating speed Bhuyan (2021).

State-of-the-art

A lot of variations of pulse oxymetry can be discovered in the literature. The majority of such devices were constructed around a microcontroller. The microcontroller is our criterion for classification, because we have used a microcontroller in order to implement our pulse oximeter. Laghrouche et al. introduced in one such paper a medical device, which consisted of a low-cost microcontroller and medical sensor, and can simultaneously measure the oxygen saturation level of the blood and the heart rate. Despite the fact that they claimed that it is a low-cost device, they did not provide data in order to support their work. Moreover, they did not provide measurement data in comparison to the standard deviceLaghrouche *et al.* (2010).

Petersen et al. made another fascinating attempt. They created an oximeter that was linked to a smartphone through the headset jack audio interface, and they validated the system with a simulator for sensor interface smartphones. The results of both oxygen saturation level and heartbeat rate matched remarkably based on simulation and experiments by the designed oximeter over a wide range of optical spectrum on various types of the iPod Touch and iPhone devices. However, iPhones and iPods are costly devices that are not commonly used by the general public in an intermediate country like Brazil. Petersen *et al.* (2013).

Another paper introduced an oximeter, which controlled physiological parameters such as oxygen saturation. Abdullah et al. attempted to use the best method to achieve good accuracy of their results for both heart rate and SPO2. They tested numerous MCU-based ARM cortex 32-bit and different sensors and methods and compared their results to those found in the literature. Nevertheless, they did not explain why this method was accurate WALEED MOHMOOD ABDULLAH (????).

Moreover, another paper introduced a a solar-powered pulse oximeter. This device can be described as eco-friendly, cost-effective and longer lifespan. Furthermore, the device was linked to the Internet of Things (IoT) to monitor and alert the data of the blood oxygen saturation level from any remote location, as well as to update the monitoring device in real-time. As a result, the doctor can control the patient's condition. The device was created using the Eagle software and the MAX30102 model [14]. However, no cost analysis was provided in this paper. Its price must be higher due to the enhanced features Deivasigamani *et al.* (2020).

Another study estimated oxygen saturation using a near-infrared portable tissue oximeter with an STM32 microprocessor-based detection module. Continuous-wave spectrometers measured the oxygenated and deoxygenated hemoglobin levels in blood vessels. After obtaining the values, the portable device can transmit the data to doctors' smartphones via GPRS/WiFi/Zigbee networks. The values can be presented based on the users' needs. The detection module detects the signal produced by a fluctuation in blood oxygen saturation data and sends it to the STM32 microprocessor, which processes it using the expert decision making system to provide accurate data to coaches and doctors. Their measurements were considered to be significantly accurate and consistent.Fu and Liu (2015).

Another review investigated into the use of red and infrared-reflective PPG to obtain oxygen saturation measurements from eight different sites on the human body while an individual is at rest and while walking. They were looking for an optimal anatomical location on the human body where a reflective PPG sensor could detect and accurately record the three most important physiological parameters, such as heart rate, SpO2, both at rest and while exercising. Longmore *et al.* (2019).

Origin of pulse oximetry

The investigation for a noninvasive continuous measuring mechanism for SaO2 began before WWII. However, no satisfied results were achieved at that time. Following the war, E.H. Wood was successful in implementing the first quantitative SaO2 monitoring. This device has been used in clinical trials. Nevertheless, its application did not spread Aoyagi (2003).

The pulse oximeter was the first widely used oximeter. Pulse oximetry, invented in Japan in the early 1970s, is widely regarded as the most significant advancement in patient monitoring since the invention of the electrocardiogram Elliott *et al.* (2006). Nellcor's pulse oximeter was offered to the public in 1983. It was well-made and easy to use. Since then, the pulse oximeter has spread rapidly around the world. Aoyagi (2003). In the absence of a general theory of pulse oximetry, this spread was primarily based on the properties discussed below.

Physical properties of pulse oximetry

The primary function of a pulse oximeter is to measure oxygen saturation. Oxygen is an essential element for humans. Oxygen enters the lungs and then enters the bloodstream. The blood transports oxygen to the various organs in the human body. Hemoglobin is the primary carrier of oxygen in the blood (Hb). Deoxygenated hemoglobin (deoxy Hb) is hemoglobin without oxygen, whereas oxygenated hemoglobin is hemoglobin with oxygen (oxy Hb). The percentage of available hemoglobin that carries oxygen is referred to as oxygen saturation.

Light can be used to measure oxygen saturation. A pulse oximeter is made up of two light sources and one light detector. Two light emitting diodes (LEDs) function as the light sources, while one photo-diode functions as the light detector. Light is emitted by light sources and travels across the pulse oximeter probe to the light detector. A finger is placed between the light sources and the light detector in the case of a pulse oximeter. As a result, the finger will absorb some of the light. The portion of the light that is not absorbed by the finger reaches the light detector.

The amount of light absorbed by the finger is determined by a variety of physical properties, which are used by the pulse oximeter to calculate oxygen saturation. These are the properties:

- the concentration of the absorbing substance: the more the number of molecules attract to light, the more will be the absorption
- the path by which light travels : as the artery narrowers, light takes shorter paths and for wider artery light path will be long
- the fact that oxygenated hemoglobin and deoxygenated hemoglobin absorb red and infrared light in different ways Anupama and Ravishankar (2018).

Light is absorbed by hemoglobin. Light absorption is proportional to the concentration of Hb in the blood vessel. In other words, the greater the amount of hemoglobin per unit area, the greater the amount of light absorbed. Beer's Law can be used to describe this property. According to Beer's Law, the amount of light that can be absorbed is proportional to the concentration of the light absorbing substance. The amount of light absorbed by the finger is estimated by measuring the amount of light that reaches the light detector.

The length of the light path in the absorbing substance is another property. The longer the light has to travel, the more light is absorbed. Lambert's Law can be used to describe this property. Lambert's Law states that the amount of light absorbed is proportional to the length of the light's path through the absorbing substance.

The final property is that oxygenated and deoxygenated hemoglobin absorb light at different wavelengths in different ways. This property is used by pulse oximeters to estimate oxygen saturation. A pulse oximeter is designed with two light sources: one red and one infrared. Because red and infrared light perfuse tissues easily, they are used, whereas blue, green, yellow, and far-infrared light are significantly absorbed by nonvascular tissues and water. Oxygenated hemoglobin absorbs more infrared light than red light, while deoxygenated hemoglobin absorbs more red light than infrared light. It is critical to understand how much red and infrared light is absorbed by the blood. A pulse oximeter can calculate the oxygen saturation by knowing this information.

Oxygen saturation

A pulse oximeter is a noninvasive medical device that measures a patient's blood oxygen saturation and pulse rate. These are critical vital signs, and accurate readings are essential. A normal oxygen level is usually 95 percent or higher. Nitzan *et al.* (2014). However, values under 90 percent for healthy people are considered low, and indicate the need for supplemental oxygen. This condition is often referred to as hypoxemia, and its symptoms include severe shortness of breath, increased heart rate and chest pain.

Oxygen saturation is often referred as Sa02 and Sp02. Oxygen saturation is defined by the ratio of oxygenated hemoglobin concentration to total hemoglobin concentration in the blood, as it is described below:

$$Sa02 = [Hb02]/([Hb02] + [Hb]) \tag{1}$$

Pulse oximeter is based on the photoplethysmography(PPG). A part of emitted light penetrate the tissue without being absorbed and finally it reaches the photo-diode. This part creates signals with a relatively stable and non-pulsatile "direct current" (DC) component and a pulsatile "alternating current" (AC) component. A pulse oximeter uses the amplitude of the absorbances to calculate the Red:IR Modulation Ratio(R), which is defined by equation below:

$$R = (A_{red,AC}/A_{red,DC})/(A_{IR,AC}/A_{IR,DC}) \tag{2}$$

A pulse oximeter does not calculate directly the oxygen saturation. It uses R in order to define the oxygen saturation Chan *et al.* (2013).

Principles of pulse oximetry

The definition of oxygen saturation does not be affected by venous blood. This can be proven by Beer-Lambert Law of absorbance Mannheimer (2008). The Beer-Lambert Law can be described by the following equation:

$$A = \epsilon bc \tag{3}$$

where A refers to absorbance, ϵ refers to extinction coefficient of hemoglobin at a specified wavelength, b refers pathlength traveled by the emitted light through the blood vessel and c refers to concetration of hemoglobin.

A pulse oximeter can calculate the arterial oxygen saturation by measuring changes in absorbance over time. This can be proven by the following procedure Chan *et al.* (2013). The total absorbance can be defined by the sum of venous and arterial absorbance:

$$A_t = A_v + A_a = \epsilon_v b_v c_v + \epsilon_a b_a c_a \tag{4}$$

. Because a pulse oximeter measures the changes in absorbance over time, this equation must be converted to the following:

$$dA_t/dt = d(\epsilon_v b_v c_v)/dt + d(\epsilon_a b_a c_a)/dt \tag{5}$$

E and c are constant quantities over time, as a result the previous equation can be converted to

$$dA_t/dt = (db_v/dt)(\epsilon_v c_v) + (db_a/dt)(\epsilon_a c_a) \tag{6}$$

However, arteries can constrict and dilate more than veins, as a result the total absorbance can be considered as equal to arterial absorbance with little or no contribution by the venous blood.

Another principal, which must be taken into consideration, is the calibration adjustment. According to Beer and Lambert law light must penetrate directly the detector. However, this can not happened. Blood contains also some particles, which scatter the light, As a result, light does not penetrate directly the photo-detector. If Beer and Lambert law is been applied directly, the oxygen saturation will not be calculated correct. A calibration adjustment is required. Human volunteers are used to calibrate a test pulse oximeter. The volunteer is then asked to breathe in decreasing amounts of oxygen while wearing the test pulse oximeter. At regular intervals, arterial blood samples are collected. As the volunteers' blood desaturates, direct arterial blood measurements are compared to test pulse oximeter readings. The errors caused by the inability to strictly apply Beers and Lambert's laws are thus identified, and a correction calibration graph is created. However, in order to protect the volunteers, the oxygen saturation must remain between 75 and 80 percent. As a result, oxygen saturation measurements under 70 percent must not be considered as reliable measurements. When a pulse oxymeter works, it uses the calibration graph in order to make accurate calculations.

Limitations of pulse oximeters

Pulse oximeters are an essential tool for all the clinical cases. However, the accurate measurements might be spoiled due to special circumstances, such technical and clinical issues. As a result the measurements can be converted to unreliable measurements Hafen and Sharma (2021), Mendelson (1992). Some of the most common issues are discussed further below.

Low peripheral vascular perfusion. The measurement in pulse oximeter is based on adequate arterial pulsation. However, a small inadequate signal could be created in some cases such as in hypotension, in low temperature, in vasoconstriction, in hypothermia or in low cardiac output Nitzan *et al.* (2014). Some vasodilating drugs could be a solution in such cases. Furthermore, manufacturers created pulse oximeters more susceptible to small signals Mendelson (1992).

Another problem in oxygen measurement is the venous congestion. The measurement in pulse oximeter is based on arterial pulsation. A pulse often contains also venous blood, which has lower concentration of oxygen. As a result, the measurement becomes less accurate Mendelson (1992). In order to separate venous and arterial blood, some researchers suggest the use of NIRS technique. This can be done, during venous occlusion by hand or by a pressure cuff Nitzan *et al.* (2014).

Artifacts of motion. Pulse oximeters detect a pulsatile signal, which is typically a small percentage of the total photoplethysmographic signal. Therefore, any motion of the body during measurement can cause a inaccurate measurement. This inaccuracy because of motion can be solved by digital signal processing methods Mendelson (1992).

A study, which took place in 1996, compare a majority of pulse oximeters to their response to motion. The study showed that the Masimo SET® prototype as the the best resistor to motion Barker (2002). This prototype uses the signal extraction technology in order to reduce the impact of the motion. The manufacturer synchronize the optical measurements with the R-wave of the patient's electrocardiogram. This improves the detection of noisy pulsatile signals by increasing the signal-to-noise ratio of the measurements through the use of multiple timeaveraged signals Dumas *et al.* (1996).

The consequence of fetal hemoglobin. The total hemoglobin in neonates consists of 60 to 95 percent of fetal hemoglobin Mendelson (1992). As a result, the oxygen measurement in neonates may not be accurate, because the calibration have been done for adults. However, later studies showed that the difference between the adult and fetal hemoglobin is small (less than 3 percent), therefore the fetal hemoglobin approximately does not affect the oxygen measurement Chan *et al.* (2013).

Electrical energy and stray light cause interference. Light sources such as infrared, xenon, and fluorescent lamps can interfere with pulse oximeter measurements. Some manufacturers attempted to correct this by taking intermittent optical background readings when both LEDs in the sensor were turned off and then subtracting these readings from photodetector measurements when either the red or infrared LED was turned on. Another way to reduce stray light in a pulse oximeter is to wrap the sensor in a dark material.Mendelson (1992).

Interpretation of pulse oximeter readings. A pulse oximeter contains two light sources and it is based at the measurements of two different wavelengths. Except from oxygenated hemoglobin and deoxygenated hemoglobin, blood contains also other types of hemoglobin such as HbCO and methemoglobin. These can affect the accuracy of the measurement. For instance, Hb and methemoglobin have similar absorbance at 660nm Nitzan *et al.* (2014). However, several studies showed that the amount of metheglobin is particular low, as a result it does not affect the measurement. However, several drugs such as sodium nitroprusside can cause an increased amount of metheglobin, which will lead to wrong measurements Mendelson (1992).

Furthermore, HbCO absorbs light with wavelength same with oxygenated hemoglobin. The concentration of HbCO is usually under 2 percent. However, the concentration of HbCO in active and passive smokers is more that 10 percent. Several clinical studies showed that this phenomenon effects the readings of pulse oximeter Mendelson (1992).

The recognition of such problems can result in the improvement of pulse oximeters. The pulse oximetry becomes a developing tool for oxygen saturation because it does not require the analysis of blood samples.

Applications of pulse oximeter

Because of its non invasiveness, pulse oximetry is now widely used in various clinical applications Mendelson (1992). Some of the are described bellow.

Units for Surgery and Post-Anesthetic Care Pulse oximetry is commonly used as an early indicator of physiological change after or before surgery, as well as during anesthesia. Pujary (2004).During anesthesia, a lack of oxygen is common. The majority of anesthetics cause respiratory depression and must be avoided. A pulse oximeter can help to reduce the negative effects of hypoxia, such as arrhythmias, myocardial ischemia, and brain ischemia. Mildenhall (2008).

Fetal and Neonate Care. Pulse oximetry is a useful tool for the estimation of the neonates stability. Blood samples for oxygen saturation is a useful technique, however a pulse oximeter provides some interesting advantages. The major advantages are its non invasiveness and its rapid result.

Pulse oximetry can be used as a home monitor for apnea in infants and children at risk for sudden infant death syndrome, as well as to assess the effectiveness of oxygen therapy in chronic respiratory patients. Nitzan *et al.* (2014). A pulse oximeter can estimate severity of patient's situation without being constantly in the hospital.

Future Applications in Combat Casualty Care. The pulse oximeter can be used as a useful tool in emergency situations. The rapid result of the measurement would be a indicator of the severity of the situation, because the most serious injuries result in oxygen decrease Pujary (2004).

Pulse oximeters perform a significant technological progress the last decade. The applications of pulse oximeters are still expanding. However, the problem of motion artifacts does not been solved completely.

The pulse oximeter was recommended as a standard of care for basic intraoperative monitoring by the American Society of Anesthesiologists in 1986. Furthermore, in 1988, the Society for Critical Care Medicine recommended that pulse oximetry be used to monitor patients receiving oxygen therapy. The use of pulse oximeters by other professional and regulatory organizations, whether mandatory or voluntary, is likely to continue.Mendelson (1992).Because noninvasive pulse oximetry allows effective oxygen monitoring without the time, risk, and high cost associated with clinical laboratory analysis of blood samples, it is an essential tool for everyone today. This research provides a low-cost implementation of an accurate pulse oximeter. As a result, everyone can monitor his or her body's oxygen saturation.

Project description

Materials and Methods

The main components are an Arduino microcontroller, a red led, an infrared led, a photodiode, an OLED display and a power supply. The table 1 describes analytically the components, which are used, in order to implement the oximeter. The system was designed firstly in Tinkercard and then in was implemented in order to measure oxygen saturation in 10 volunteers.

Table 1 Table of components

	Name of component
1	Arduino UNO
2	OLED display
3	Red led
4	Infrared led
5	Photodiode
6	Finger clip
7	npn Transistor BC547
8	Resistors: 80ohm, 50ohm and 1Mohm
9	9V Battery
10	Battery Cap
11	Wires
12	Breadboard

As it was described before, the principal components of a pulse oxymeter are a Red led, an Infrared led and a photodiode. Moreover, this system is also capable of measuring the heart rates. Arduino microcontroller is used in order to process the data and use calibration methods and signal processing techniques to calculate oxygen saturation. The battery power supply unit of 9V supplies the required current to the microcontroller, the system of leds-photodetector and the OLED display unit. Furthermore, the finger-clip was made by a 3D-printer.

Firstly, the leds-photodetector system detects signals related to the oxygen saturation parameter from the fingertips, which are flanked by an optical transmitter (made up of two LEDs, one red and the other infrared) and an optical detector (only one photodiode capable of detecting both red and infrared light).

Because of its low power consumption, higher efficiency, built-in ADC, and USART mode communication capability, the Arduino Uno R3 microcontroller is used here. This microcontroller converts the analog signal to digital with the aim of signal processing techniques.

The Arduino microcontroller interprets and processes the sensor signal received at its input port before calculating the oxygen saturation level in percentage using the developed assembly language program supplied to it via the personal computer. The measured SpO2 level is then sent to the OLED display unit, which displays it in the layout specified in the microcontroller's program. Although some components are not available in Tinkercard, an equivalent hardware circuit is designed and used in the circuit of Fig. 1.

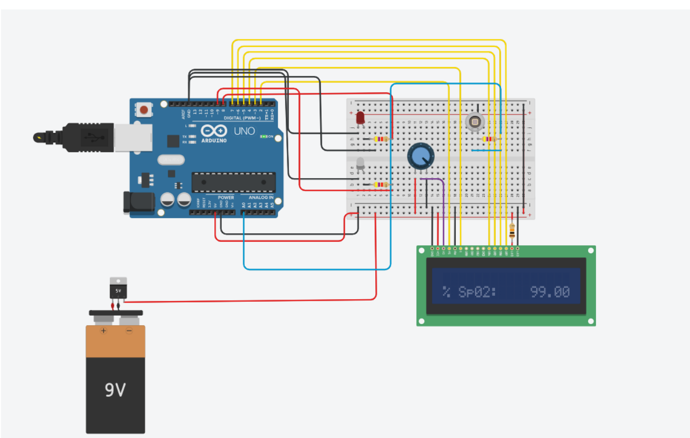

Figure 1 Tinkercad simulation

Program description

An assembly language program was essential in order for the Arduino Uno microcontroller to function properly. Assembly language programming is divided into two levels: device and application. The first can control the system's hardware, while the second can calculate the pulse oxygen saturation level in percentage and display it on the selected display device in the appropriate format.

It should be noted that programming a microcontroller necessitates the use of an integrated software development platform. The flow chart of the developed assembly language program is shown in Figure 2. This program continuously scans the serial port for the pulse oxygen sensor signal, which is connected to the microcontroller's serial input pin. To synchronize the data between the two units, the sensor and Arduino clock signals are also linked. Thus, the digital data are transferred to the microcontroller's memory, where they are processed according to the assembly program's instruction sets, converted into the appropriate percentage format, and finally sent to the microcontroller's output port to display the measured pulse oxygen saturation level data in text format on the system's OLED screen.

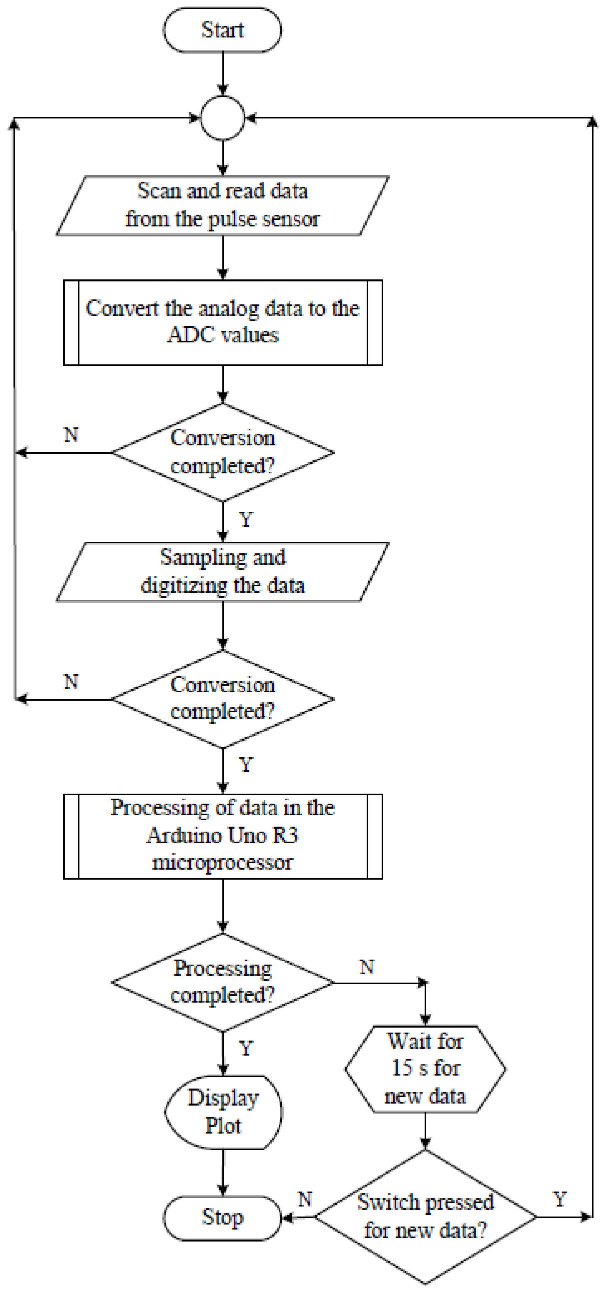

Figure 2 Flow chart of the designed digital oxygen measuring device's microcontroller program

The software has been designed properly to display the pulse oxygen saturation level at the designated display unit (here, an OLED screen). The functions of this software include data processing and displaying it in the appropriate percentage format. The output ports have been properly initialized to send data to the input ports of the OLED screen, which are connected to the microcontroller's output ports. When the output port receives available data at any time, the oxygen saturation value in percentage is displayed on the OLED screen immediately.

Results and discussion

Figure 3 depicts the breadboard-implemented system. The power supply required is 5 V. (DC). This result was obtained at the system's OLED display.

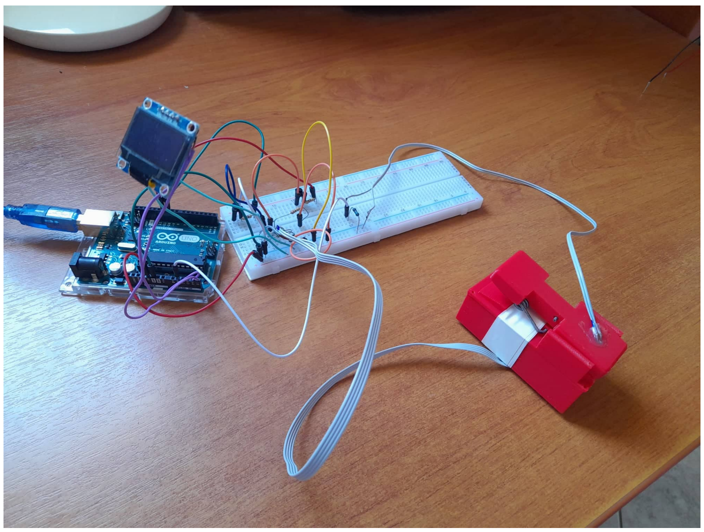

Figure 3 Implemented pulse oximeter system on a breadboard.

Data are collected using both the designed digital oxygen meter and a market-purchased pulse oxygen saturation level measurement device. Figures 4 and 5 show two such measured values for the same person at the same time.

The pulse oxygen saturation level is measured for 10 people of various ages simultaneously using our designed oximeter and a standard oximeter purchased from the market. Table 2 shows the data for various ages of people. The percentages of error between the two oximeters' data are calculated using the following equation:

$$e = |DO - PO|/(PO) * 100\% \tag{7}$$

where DO indicates the data measured by the designed digital oximeter in percentage and PO indicates the data measured by the purchased pulse oximeter in percentage.

The Table 2 introduces the experimental data. The percentage of errors varies from 0% to 2.1% . However, the average percentage of error is very less, only 0.52%.

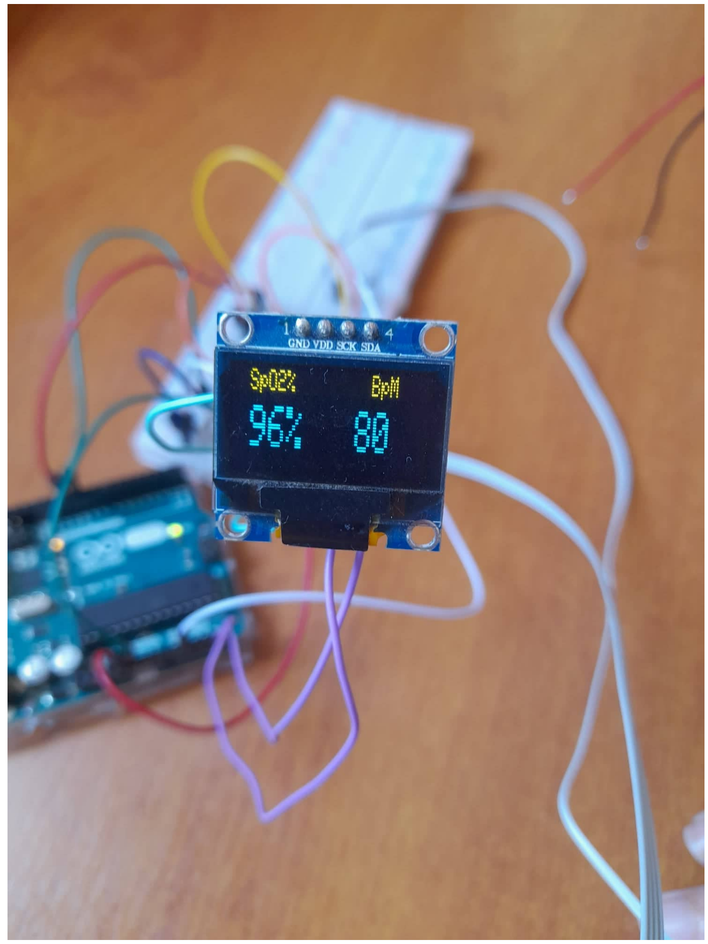

Figure 4 Measured data by the designed pulse oximeter

Table 2 Experimental data

Patient	Designed oximeter	Purchased oximeter	e%
1	96	96	0
2	98	96	2.1
3	97	98	1
4	95	96	1
5	95	97	2.1
6	96	98	2
7	98	97	1
8	95	97	2.1
9	95	96	1
10	98	97	2.1
Average values	96.4	96.9	0.52

Table 3 concludes with the cost analysis. Table 3 shows that the total cost of implementation is only EUR45,69. The cost of implementation would be significantly reduced if we were to implement it on a large amount.

Figure 5 Measured data by the purchased pulse oximeter

Table 3 Table of cost

	Component	Quantity	Price(in EUR)
1	Arduino UNO	1	24
2	OLED display	1	8.90
3	Red led	1	0.08
4	Infrared led	1	0.12
5	Photodiode	1	0.86
6	npn Transistor BC547	2	0.08
7	9V Battery	1	1.45
8	Battery Cap	1	0.4
9	Wires	20	1.8
10	Breadboard	1	2.60
11	Resistor 1 Mohm	1	0.80
12	Resistor 80 ohm	2	0.80
13	Resistor 50 ohm	2	0.80
14	Finger-clip	1	3
	Total cost		45.69

Conclusions

Using a microcontroller and a system of leds-photodetector, a simple and low-cost pulse oximeter was designed, simulated, implemented and tested. The patient can easily measure the oxygen saturation with the aim of this device.

In the future, power consumption and costs should be reduced by replacing the power supply with a rechargeable battery and developing an application for real-time data analysis on smartphones.

Overall, the main goal of providing a simple, portable, and affordable solution for measuring pulse oxygen saturation levels for people in intermediate income countries was achieved.

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