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Integrating New Design Features in an Oxygen Concentrator to Improve Patient Outcome

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A thesis submitted to the Center of Biomedical Engineering in partial fulfillment of the requirements for the Degree of Master of Science in Biomedical Engineering

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DECLARATION

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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This MSc. thesis has been submitted for examination with my approval as an advisor.

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CERTIFICATE OF EXAMINATION

This is to certify that the thesis prepared by **Melese Umma Getaneh** entitled *"**Integrating New Design Features in an Oxygen Concentrator to Improve Patient Outcome***" submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering (Bioinstrumentation and Imaging) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Melese Umma

ABSTRACT

Integrating New Design Features in an Oxygen Concentrator to Improve Patient Outcome

By Melese Umma Getaneh

Oxygen therapy has become an integral part of treatment and standard care for childhood pneumonia, surgery, anesthesia, emergency, obstetric care, etc. According to WHO, an oxygen concentrator is a suitable source of medical oxygen in developing-country settings, especially where cylinders and/or piped systems are unavailable. Typically, an oxygen concentrator provides 93±3% pure medical oxygen for oxygen therapy. However, this value may go below the required limit due to several factors such as harsh environment, poor/no maintenance, prolonged operation time, etc. My field assessment in Jimma Zone showed that the oxygen concentrators currently in use in healthcare facilities have no built-in feature(s) to inform clinicians about this low oxygen output. Clinicians often check presence of airflow coming out of an oxygen concentrator before connecting it to a patient. However, presence of airflow does not necessarily guarantee that the oxygen concentration is within the required range as prescribed for oxygen therapy. As a result, patient treatment outcome could be compromised.

In this study, we investigated the existing design features of a typical oxygen concentrator and proposed a modified design that can potentially improve patient outcome. Our design integrates a built-in oxygen sensor that can continuously monitor oxygen concentration and communicate the status to clinicians. In our design, we also integrated a feature for measuring the arterial blood oxygen saturation (SpO_2) of a patient who is receiving oxygen therapy. This information will be used by clinicians to know the clinical response of the patient to oxygen therapy. As a proof of concept, a prototype was developed using the required sensors, actuators and microcontroller. Simulation and testing was done using c^{++}.

In the prototype, an oxygen sensor detects oxygen concentration; the result is compared with the pre-set value, displayed as visual message on a screen, and an audible alarm is produced whenever the output goes below the set value. Moreover, another sensor detects SpO_2 and provides clinical information about the response of the patient to the prescribed oxygen therapy. Our proposed design can not only improve patient outcome but also avoids the need of an external oxygen analyzer and pulse oximeter to measure oxygen concentration of an oxygen concentrator and SpO_2 of a patient respectively. We believe that this novel design can increase the quality of oxygen therapy procedures and save lives.

Key words*: Oxygen concentrator, Sensor, Actuator, Microcontroller.*

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ABBRIVIATIONS AND ACRONYMS

All abbreviations that have been used in this research are listed here unless the abbreviation is well known, has been used only once, or has been used only in tables.

CBA - IDE	Code Blocks Arduino Integrated Development Environment
ED	Emergency Department
FiO2	Fraction of inspired oxygen
HB	Hemoglobin
HbO_2	Oxygenated Hemoglobin
ICU	Intensive Care Unit
IR	Infrared Radiation
JHC	Jimma Higher Clinic
JUSH	Jimma University Specialized Hospital
LCD	Liquid crystal display
LED	Light Emitting Diode
O2	Oxygen
PR	Pulse Rate
SGH	Shenen Gibe Hospital
SpO_2	Amount of arterial blood oxygen saturation measured by pulse oximetry
WHO	World Health Organization

CHAPTER ONE
INTRODUCTION

1.1 Background

World Health Organization (WHO) classifies oxygen as essential medicine with specific biochemical and physiologic actions, a distinct range of affective doses, and well-defined adverse effects at high doses [1]. It is administered to treat hypoxemia and is needed for new borne illnesses & complications, surgery, obstetric case, acute respiratory illnesses such as severe pneumonia, chronic pulmonary diseases, emergencies and cardiovascular diseases, etc.

According to WHO [2], an oxygen concentrator is a suitable source of medical oxygen in developing-country settings, especially where cylinders and/or piped systems are unavailable or inappropriate. A typically oxygen concentrator provides 93±3% pure medical oxygen. Oxygen concentrators use a technology called Pressure Swing Adsorption (PSA) to separate oxygen from room air (mainly nitrogen) and increase its concentration from 21% to somewhere 95%. The limitations related to this technology and presence of other factors related to harsh environment, poor maintenance and prolonged operation time can lead to low oxygen output that has direct negative impact on the treatment outcome

By recognizing the various factors that can affect a typical oxygen concentrator from producing the desired oxygen concentration for oxygen therapy, in this thesis we will be investigating the existing design features and propose novel design ideas which can be incorporated in the existing design in order to improve patient outcome. In the following section (section 1.2), I have presented a brief overview of an oxygen concentrator by highlighting its working principles, main parts & functions, and limitations.

1.2 Overview of an Oxygen Concentrator

1.2.1 Working Principle

An oxygen concentrator is a self-contained, electrically powered medical device designed to concentrate oxygen from ambient air. Utilizing a process known PSA, an oxygen concentrator produces and delivers continuous pure medical oxygen with a concentration of up to 93±3% [3,4].

As shown in Fig 1.1, atmospheric air is drawn through a gross particle and intake filter before moving through a compressor. The pressurized air passes through a heat exchanger to reduce the temperature before entering the two sieve beds that contain zeolite, a mineral material that preferentially adsorbs nitrogen gas (N_2) at high pressures. As each sieve bed is depressurized cyclically, the adsorbed N_2 is released. The purified oxygen is delivered to a reservoir where it accumulates. A regulator and a flow meter are then used to supply a controlled and measured continuous oxygen to the patient at a specified flow rate [5-9].

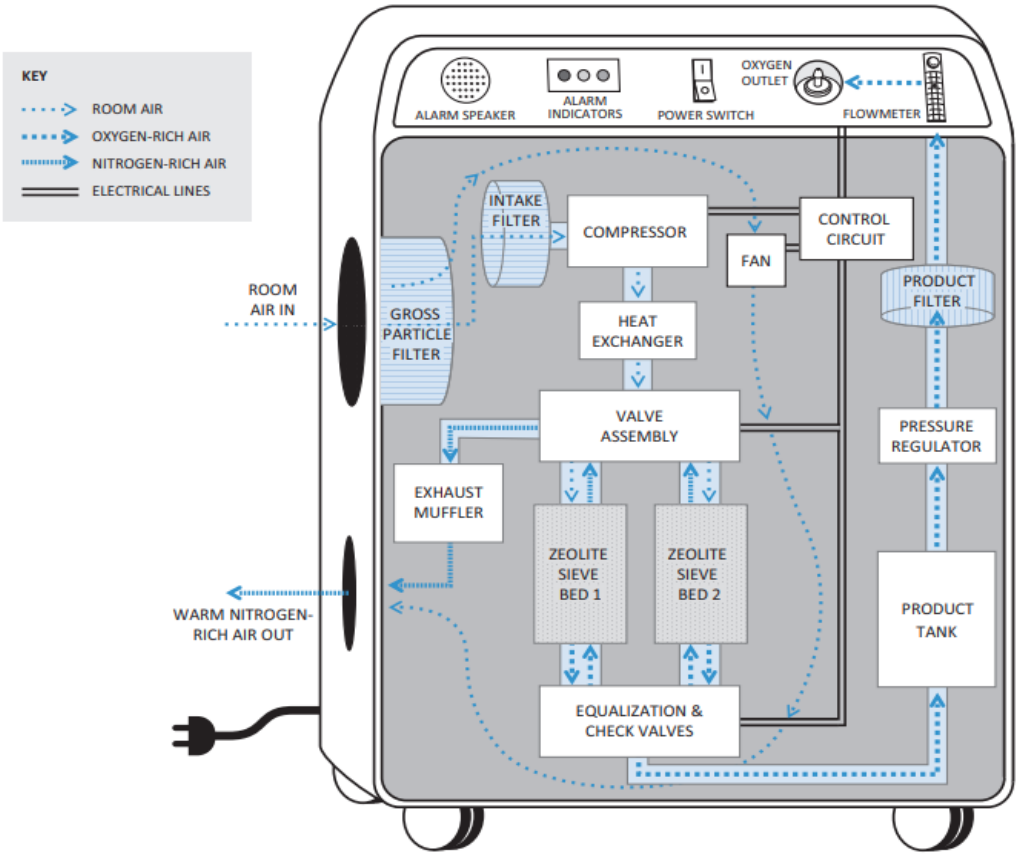


Figure 1.1: Process flow and components of a typical oxygen concentrator [2,3].

In the first half-cycle, the Sieve bed 1 receives a compressed air (~2.5 times atmospheric pressure) from the compressor, which lasts about 3 seconds. During this time, the zeolite becomes saturated with nitrogen. As the first bed reaches near pure oxygen in the first half-cycle, an equalization valve opens and the oxygen-enriched gas flows to the product tank, which connects to the patient's oxygen hose. At the end of the first half of the cycle, there is another

valve position change so that the air from the compressor is directed to the second sieve bed and repeats the half cycle process explained above. At the same time, the pressure in the first cylinder drops as the higher concentrated oxygen moves into the reservoir, allowing the nitrogen to be desorbed and returned into gas.

Partway via the second half of the cycle, there is another valve function change to vent the gas in the first cylinder returned into the ambient atmosphere, preserving the higher enriched quantity of oxygen in the pressure equalizing reservoir from falling below about 90% [10,11].

The main parts and functions of a typical oxygen concentrator are indicated in in Fig.1.1 and described in section 1.2.2.

1.2.2 Main Parts and their Function

Typical components within an oxygen concentrator and their function:

Cart: The cart holds the oxygen tank and makes it easy for a person to move the tank. The cart typically has two wheels and a handle.

Regulator: The regulator is positioned at the top of the cylinder tank. The regulator controls the amount of oxygen leaving the tank.

Pressure Gauge: The pressure gauge is located on the regulator. It is a glass covered dial gauge that shows how much oxygen is in the tank.

Cannula: When using an oxygen tank to assist in breathing, a nasal cannula is attached to the tank. This is a thin tube that runs from the tank to the patient.

Enclosure: Encases internal components of concentrator

Gross particle filter: Filters coarse particulates to extend intake filter life

Compressor intake filter: Filters fine particles to protect compressor and/or valves

Compressor: Pressurizes and pumps air into the system

Fan: Circulates cabinet air and cools the compressor

Heat exchanger: Dissipates heat created by gas compression

Control circuit: Analyses the system state and controls the valves and compressor

Valve assemblies: Controls the flow processes for the sieve and exhaust

Sieve beds: Separates gases as air is moved in and out

Exhaust muffler: Expels and quiets the N2-rich air released back into the room

Product tank: Gas accumulator for providing a steady and continuous flow

Flow meter: Controls the delivered flow rate

Product filter: Removes particulates from the product stream

Humidifier: Humidifies the delivered gas before inhalation

1.3 Statement of the Problem

Even though an oxygen concentrator is a suitable and affordable means of producing medical oxygen and administrating oxygen therapy in healthcare facilities where cylinders and piping system are unavailable and inappropriate, its performance in terms of delivering the desired oxygen concentration can be limited by several factors (such as harsh environment, poor/no maintenance, prolonged operation time, etc). These factors lead to low oxygen concentration output that has direct impact on the clinical outcome. Often times, clinicians check presence of airflow coming out of an oxygen concentrator before connecting it to a patient. However, presence of airflow does not necessarily imply the oxygen concentration is within the required clinical range. As a result, patient treatment outcome could be compromised.

While addressing these factors remains one area of intervention, it is also important to note that the oxygen concentrator itself should be redesigned with feature(s) to mitigate these unintended circumstances. It is therefore the purpose of this study to investigate the existing design features of a typical oxygen concentrator and propose a novel design solution that can potentially improve patient outcome.

1.4 Objective of the Study

1.4.1 General Objective

The general objective of this thesis work is to ***Integrating New Design Features in an Oxygen Concentrator*** in order to fill some of its design gaps and improve patient treatment outcome.

1.4.2 Specific Objectives

- Assess the clinical problems associated with existing oxygen concentrators in selected healthcare facilities.
- Investigate design features of those concentrators being used in healthcare facilities.
- Propose a novel design features that can help improve patient outcome.
- Design and develop prototype as a proof of concept.

1.5 Significance of the Study

We believe that our proposed design will add additional features that can help not only improve patient outcome but also avoid the need of procuring additional standalone devices for analyzing oxygen concentration of the concentrator and measuring SpO_2 of the patient. Our design also improves overall reliability and acceptability of the machine.

1.6 Scope/Delimitation of the Study

As mentioned in the specific objectives section, the scope of this study is limited to proposing a new design and developing a prototype as a proof of concept. Moreover, this study uses oxygen concentrators found in the study area as a baseline to identify clinical drawbacks of the current design.

1.7 Organization of the Study

This manuscript has been divided into five chapters. The first chapter gives a brief introduction and background about the research work to be conducted. Overview of oxygen concentrators, statement of the research problem, research objective has been presented. In chapter two, existing literatures are reviewed and conceptual framework of the research is presented. The third chapter presents the research methodology which will be applied in this thesis. Chapter four is dedicated to presenting and discussing the research findings. Finally, conclusion and recommendation are stated in chapter five.

CHAPTER TWO
LITREATURE REVIEW

In this chapter, some of the available relevant literature has been discussed below to have an insight of the previous work done on the subject. It will specifically focus on theoretical review, past studies on the subject in an effort to highlight the relationship of those researches and this research and a review of some of the literature on the variables of the research. Finally, the literature review is transformed into the appropriate conceptual framework of the study.

2.1. Theoretical Review

2.1.1. Equipment for Providing Oxygen to Patients

Medical oxygen is used for medical reasons, such as oxygen provided to a patient throughout surgery or after an accident until the patient. There are three methods of providing an oxygen supply in patients: Oxygen concentrators, Oxygen cylinders and Liquid oxygen systems. Oxygen Concentrators run off the home electricity supply. They draw-in air from the room, separate out the gases with the aid of extracting nitrogen and supply oxygen at the outlet [13]. Standard concentrators can supply to go with the flow charges ranging from 1 to 5 liters per minute. However, professional machines can provide up to 10 liters per minute for excessive demand users, or low float quotes can run at as little as 0.1 liters per minute [14]. They can deliver around 93±3% oxygen when running at a flat rate of up to 4 liters per minute. The share falls with the growing float rate. Portable battery-driven oxygen concentrators generate up to 5 liters of oxygen per minute and can be splendid for ambulatory use [15].

There are two basic types of oxygen concentrators, stationary and portable. Both of them consist of a cabinet that houses the compressor and filters; tubing; a nasal cannula and/or face mask. Portable units are typically battery operated and lightweight with oxygen output between 1–3 liters per minute (LPM), which is sufficient for one adult. Portable units are generally not considered suitable for clinical settings in low and middle-income countries, as they cannot support multiple patients and are relatively expensive. Stationary units are still portable but are larger and heavier (30–100 pounds) than their portable counterparts and have greater oxygen output capacity (3–12 LPM). A sub-category of stationary concentrators is larger still and capable of output up to 90 LPM.

Oxygen Cylinders contain compressed pure oxygen gas and deliver one hundred percent oxygen [15]. These are reachable in a range of extraordinary sizes. In Scotland, except in any other case specified, cylinders for use in the domestic will be the size AF containing 1360 liters of oxygen [16]. Smaller portable cylinders can additionally be furnished to permit the patient's motion backyard the home for brief periods. In Scotland, these are usually provided with 460-liter ability [16].

Oxygen is stored as a liquid in the house liquid shape [15]. Liquid oxygen passes through a device of tubes that use warmness from the surroundings to convert it to fuel at room temperature. The manner does no longer have any electronic or electrical components and does no longer require an energy supply. The purity of oxygen furnished is over 99 percent [14]. The dealer fills a large storage tank, and this is then used by way of patients to fill smaller transportable devices for ambulatory use [3,4][13][17].

According to Friesen (1992), most oxygen concentrators use a molecular sieve design. In this design, the air is compelled into a chamber containing zeolite. Zeolite absorbs nitrogen, as an end result getting rid of it from the air. Oxygen and any extraordinary gases, small ample to pass by way of the zeolite, are gathered in each other chamber. To preserve a constant oxygen supply, there are two zeolite chambers. While air is pressured into one chamber, the nitrogen is eradicated from the other. The gas in the gathering chamber is about 93% oxygen. At larger glide over rates, oxygen molecules spend much less tune in the molecular sieve chamber, for this cause a lower interest of oxygen is produced [15][16] [18].

2.1.2 Comparative Advantage of Equipment for Providing Oxygen to Patients

Both Oxygen Cylinders and Oxygen Concentrators deliver oxygen to patients who need it. But the methods of delivery are very different. Oxygen concentrators offer several advantages over oxygen cylinders which include:

Consistency –oxygen cylinders can run out of oxygen, whereas, an oxygen concentrator will never run without oxygen as long as it has air available and a power source. An oxygen concentrator filter out oxygen from the air itself, making the supply unlimited and readily available.

Safety – An oxygen cylinder may want to commence to leak and oxygen saturated air will increase the danger of a fire. If a fireplace ignites under these circumstances, it is harder to extinguish because oxygen prompted fires burn hotter than many other sorts of fires. Pulse-dose oxygen concentrators clearly create oxygen as needed, getting rid of the problem of leaks, and consequently the problem of flammability.

Size – An oxygen concentrator is designed for convenience and portability – so it weighs much less. On the contrary, Oxygen Cylinders are bulky and heavy.

Cost – is another factor to consider. For Oxygen Concentrators, the price is largely upfront. For Oxygen Cylinders, costs will be incurred over time e.g. new Oxygen Cylinders purchased periodically as needed. Table 2.1 describes the advantage and disadvantage of the above three types of equipment.

Table 2.1. Advantages and Disadvantages of Different types of Equipment [5].

	Advantages	Disadvantages
Concentrators	Low cost Convenient Widely available No delivery problems Safe	Requires electricity Risk of mechanical failure Frequent maintenance needed Noise and vibration
Cylinders	Widely available High oxygen purity Does not need electricity Reliable Simple maintenance No background noise	High cost Less convenient Frequent deliveries needed , heavy weight Small capacity Regular changes of cylinders require physical effort
Liquid Oxygen	Convenient Very high oxygen purity Portable Most practical for ambulatory use Large capacity Does not need electricity Reliable Simple maintenance	High cost Limited availability Frequent deliveries needed Spontaneous evaporation of oxygen Small risk of finger frostbite May produce hissing noise Different systems may be incompatible

An Oxygen Concentrator is a great choice for all the above reasons. But individuals should also consider having a backup Oxygen Cylinder as well as additional, fully charged batteries for the Oxygen Concentrator in case of a power outage.

Oxygen concentrators can be used as an alternative to compressed gas cylinders. OCs produces 90–95% oxygen from room air, by absorbing nitrogen and provides supplementary oxygen for patients. It is administered to treat hypoxemia and is needed for new borne illnesses & complications, surgery, obstetric case, acute respiratory illnesses such as severe pneumonia, chronic pulmonary diseases, emergencies and cardiovascular diseases, etc.

Oxygen concentrators are typically used as stationary sources to provide long-term oxygen therapy (LTOT) to patients at home [3,12,and18]. All of these devices are electrically operated, so a power failure will result in a failure of oxygen supply unless a standby generator, or a battery backup and power inverter are available.

Research into oxygen concentration is ongoing and modern techniques suggest that the amount of adsorbent required by medical oxygen concentrators can be potentially "reduced by a factor of three while providing ∼10–20% greater oxygen recovery compared to a standard industrial unit" [3,4][16][20].

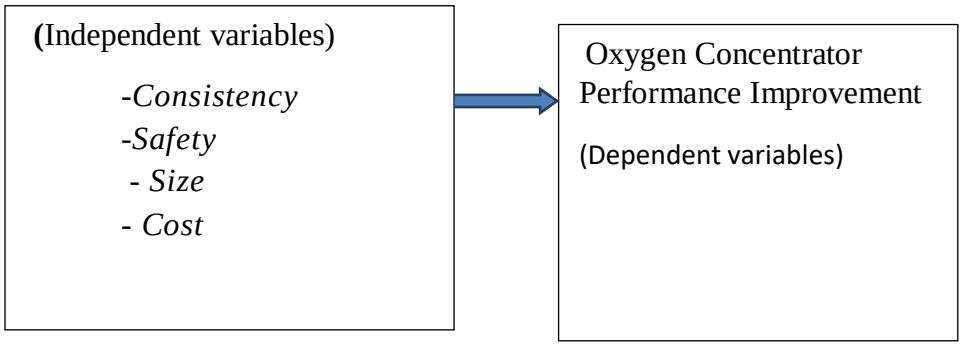
Leveraging global insights along with detailed assessments conducted in four focus countries such as Ethiopia, India, Indonesia, and Kenya—PATH intends to further assess and propose solutions to the unique market challenges for oxygen delivery devices and pulse oximeters in low- and middle-income countries.

Project activities include in-depth assessments of the supply and demand of oxygen delivery devices and pulse oximeters to determine the levels of, and any potential barriers to, product availability, uptake, and use, followed by the development of a global strategy that will include recommendations to overcome identified barriers to access [4][21].

2.2 Conceptual Framework

In this section, the literature review is transformed into a theoretical model. The research study conceptualized out on four categories of independent variables was suggested (Fig. 2.1) to redesign Oxygen Concentrator. The dependent variable in this study is Oxygen Concentrator improvement as illustrated below.

Figure 2.1: Conceptual Framework.



The study has two sub-objectives; firstly the above factors that increase the performance of Oxygen concentrators are to be investigated. Secondly, to improve the control system, which control the output oxygen that is delivered to the patient with the help of oxygen sensor & pulse oximeter via the following methods such as proteus simulation software, c^{++} program, Arduino electronics circuit board, sensors, and actuators.

2.3. On Job or Field Observation

Field visit was conducted from January 19, 2018–February 13, 2018, and it was observed and interviewed by the researcher that the existing medical oxygen delivering device (Oxygen Concentrator) in Ethiopia (Oromia region at Jimma zone such as JUSH, Shenen Gibe hospital and JHC) are Required Design Improvement (Has Design Gaps) so that the patients can face different problems in the health sectors. Therefore, this study was carried out towards the implementation of the new design features of an oxygen concentrator to improve patient outcome in medical oxygen monitoring system of an Oxygen Concentrator.

The prior literature on oxygen concentrator is even more problematic. Two major problems have been recognized during the observation time. First, they did not have any output oxygen control system, LCD display monitor which shows the SpO2 of patient and output Oxygen of the

instrument delivery and pulse ox meter synchronized with the Oxygen Concentrators which helps to extra treatment, and diagnosis. This *Pulse ox meter* is important medical equipment that is needed in conjunction with the oxygen concentrator to safely provide oxygen therapy. It is used to measure the amount of oxygen in the blood. It is an easy, painless measure of how well oxygen is being sent to different area of your body furthest from your heart, such as the fingers and legs [2, 3 ,and12].

Secondly, Oxygen concentrators available in different hospitals may fail to produce therapeutic levels of oxygen (or the reason of low output oxygen) because of the following common problems involving the air-intake system, malfunctioning sieve-control valves, and contaminated sieve materials, small leaks in the internal tubing, low pressure, unplaced the concentrator on a flat surface, abnormality of the zeolite, inadequate maintenance, and the likes [2,3].

The main intention of this thesis to solve these problems mentioned above by using the sensors technology (i.e. oxygen sensor and arterials blood oxygen sensor). It improves the patent out come as well as the effective oxygen treatments in the health sectors.

The first objective of this study was to investigate different factors that increase the performance of the existing Oxygen Concentrator design. Secondly, to improve the patient outcome, to control the output oxygen that is delivered to the patient with the help of pulse oximeter via the following methods such as proteus simulation software, C^{++} program, Arduino electronics circuit board, sensors, and actuator. In doing so, the researcher needs to overcome the problems in both sides the health professionals and the medical instruments of the existing delivering medical oxygen to address the target point.

CHAPTER THREE
RESEARCH METHODOLOGY

This chapter presents a detail discussion about the type of research design approaches which have been employed in this study in acquiring the necessary information to answer the research questions. Moreover, topics related to method of data collection, materials, data analysis and interpretation tools are included.

3.1 Research design and Approaches

The research aimed at evaluating the performance and the design features used in the currently available oxygen concentrator in different hospitals and health centers that investigate the mechanism to control the supplemental oxygen delivery address to the target point.

The study was around the Oromia region at Jimma zone such as JUSH, Shenen Gibe hospital and JHC selected for the study area during the periods scheduled from January 19 – February 13, 2018, in the emergency department or ICU in the case of JUSH only ICU department is selected that includes nurses (BSc and diploma), midwives (BSc and diploma) who were working in ICU/ED and BSc Bio-Medical Engineer as well as Diploma Biomedical Technicians.

This study has the following research approaches:

- ✓ First to apply the new design features in an oxygen concentrator to correct output percentage of oxygen by using (SpO_2 & % of output oxygen) sensors,
- ✓ Second, write the code,
- ✓ Third design, and developed the sensor and Arduino-based electronics circuit, and
- ✓ Finally, design the proper functioning of the prototype according to the patient's needs of arterials blood oxygen level and percentage of output oxygen.

Using those approaches it could be measured the output signals of each device or sensor, simulating the whole circuit, and lastly convert to the hardware prototype to implement on the fields.

3.2. Data Source

In this study, primary and secondary sources of data were used. Primary data was used to get empirical investigation. Thus, this study used physical observation and interviews in order to identify the problems in the existing Oxygen concentrators.

Secondary sources were provided with a theoretical investigation of research problems collected from internet, and procedures of the industries, different researches, literature, books, and journals to know what prior researchers have theorized about the subject.

3.3. Data Analysis and Presentation

The Data Analyses have been done by using different research techniques, so that to round off the study with a summary of findings, and then ways to improve the existing oxygen concentrators have been given.

Experimental research methods are used to successfully conduct the study. In doing so, the following research techniques were conducted:

- ✓ Design of prototype (electronic and development of programming application using C^{++} which simulated on proteus), and
- ✓ Laboratorial experiments/Testing prototypes to measure data by involving volunteer participants.

3.4. Materials

The system is mainly composed of available circuit building materials that used for implementation of the experimental works. Some of these materials are listed below.

I. Arduino Uno processor;
II. Pulse Oximeter (MAX30100) and OXYGEN(MQ-135) sensor;
III. LCD display shield with Arduino and
IV. A buzzer and an LED are added to the system to give out visual and audio warning signals for a low and high level of % of oxygen.

3.4.1. Design Solution

The primary objective of this new design feature was developed a circuit on the bread board that is capable of reading the output coming from patient data as well as the output of the instrument on a short interval of time with the help of SpO_2s & Output oxygen sensor. Both sensors detect the percentage of oxygen and upload it to Arduino for analyzing in order to make the right decision by triggers the alarm automatically through the actuator/relay.

3.4.2. Design Strategy

This section introduces the new design features in an oxygen concentrator to improve patient output, and the control system of the percentage of output medical oxygen delivery devices including the connections of hardware devices, and Arduino software. The system has included Hardware design, and component selection, Software design, circuit construction and Fabrication/assembly of the parts as shown in the following flow chart (Fig.4.1).

3.4.2.1 Component Selection and Hardware Design

Once the system is assembled on the Arduino board, SpO_2 & output Oxygen sensors, Oxygen concentrator, actuator/relay, and the LCD module, the microcontroller shall be coded with a program to:

a) Initialize the ports and shields and

b) Start to repeat the following tasks forever:

- ✓ Reading of the inputs from the sensor
- ✓ Reading the percentage of SpO_2 level from the sensor to the patient finger (ear lobe), and also read the percentage of output Oxygen level from the sensor to the Oxygen concentrator device.
- ✓ Calculating the percentage of SpO_2, in the Patient Body;
- ✓ Display the level and percent of SpO_2 and output Oxygen level from the sensor to the Oxygen concentrator on the LCD module.

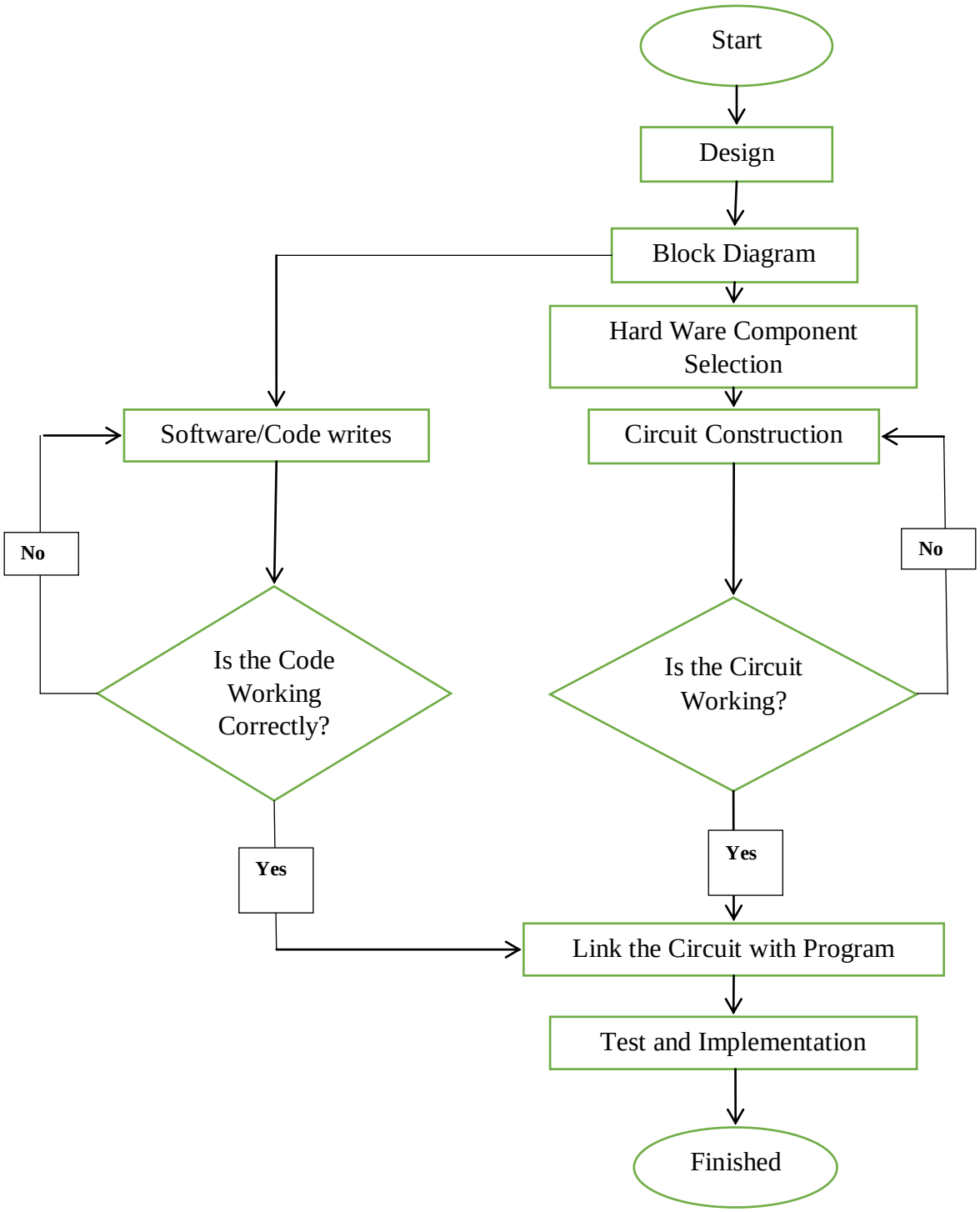


Figure 3.1: Flow Chart for the prototype design process

Fig.3.2 shows how the control of the percentage of oxygen in the new design oxygen concentrator works. The program is written in the special Arduino IDE software in C or C^{++}

programming language and it is transferred to the Arduino program memory using Arduino USB port cable.

After connecting each unit, the functionality of all units was tested in order to be sure that the design was satisfied in all aspects.

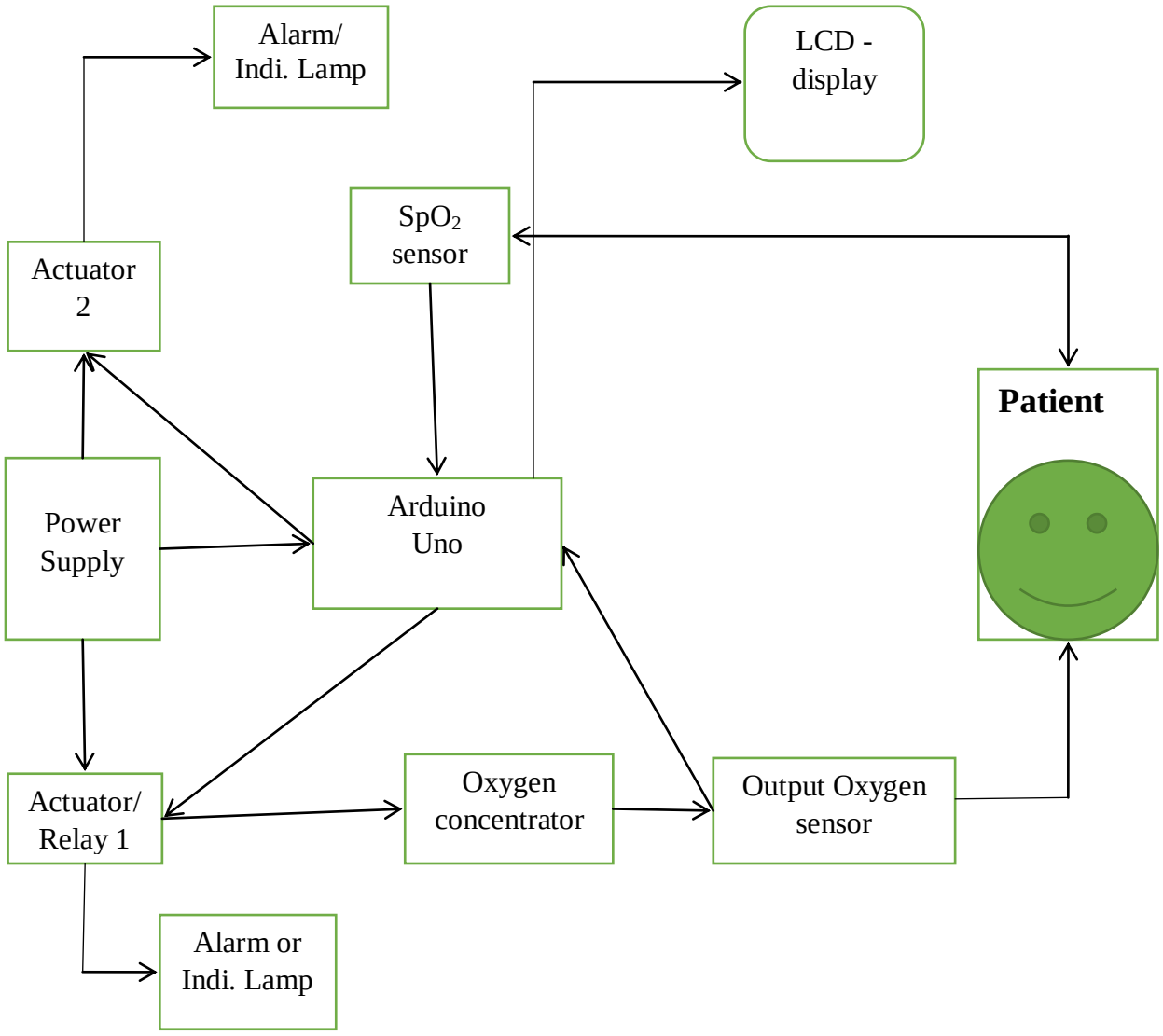


Figure 3.2. Block diagram of new design OC to improve patient outcomes

A practically incremental design procedure was used where the system peripheral units are connected to the system one by one. The assembly of the hardware parts has the following four steps:

Step-1: Arduino software has to be installed and set for the correct port to communicate to the Arduino-Uno board. Port configuration and USB connection of the Arduino-Uno board is tested by transferring a short program to Arduino that blinks a LED.

Step-2: Plug the LCD-keypad shield on the Arduino-Uno, and test the LCD module by writing hello on the LCD screen.

Step-3: Connection of the SpO_2 and Output Oxygen sensor to the LCD-keypad shield. Almost 1cm long, 4 line flexible cable is used to connect the ground (GND) of LCD to the ground (GND) pin of the sensor; 5 V of LCD to the Vcc of the sensor. A_4 of the LCD to SCL pin of the sensor; and A_5 of the LCD to SDA pin of the sensor.

Step-4: Connections with Arduino can start a measurement SpO_2 level by sending a pulse to its A_4 (SCL) pin, and count the duration of the pulse at A_5 (SDA) pin to find out the SpO_2 output in percentage. Similarly Output Oxygen sensor also an almost 1 meter long 4 lines flexible cable is used to connect the ground (GND) of LCD to the ground (GND) pin of the sensor; 5 V of LCD to the Vcc of the sensor. A_1 of the LCD to the trig pin of the sensor.

By the above connections, Arduino can start to measure the percentage of output oxygen from oxygen delivery medical device by sending a pulse to its A_1 (trig) pin to activate the actuator for the right decision or it take action[off/alarm] automatically.

In short, SpO_2 is defined as the ratio of the oxygenated Hemoglobin level over the total Hemoglobin level [Eq. 3.1].

$$spo_2 = \frac{Hbo2}{Total\ Hb} \qquad 3.1$$

Our body tissue absorbs different amounts of light depending on the blood oxygenation level. However, it is important to note, that the characteristic is non-linear. As we know two different wavelengths are used IR (950nm) and RED (650nm). These two wavelengths are emitted towards the finger, earlobe, etc. in an alternating fashion. Once it is turned on, measurement is taken, and then it is turned off. This repeats for the other spectrum. Basically, both of them are not measured simultaneously [12]. The ratio R between these two wavelengths is defined with the following equations [Eq. 3.2 and Eq.3.3]:

$$R = \frac{\left(AC_{RMS\ RED} / DC_{RED} \right)}{\left(AC_{RMS\ IR} / DC_{IR} \right)} \qquad 3.2$$

Or it can also be expressed like as:

$$R = \frac{\log(I_{AC}) \times \lambda_1}{\log(I_{AC}) \times \lambda_2} \qquad 3.3$$

I_{AC} is the light intensity where only the AC is present. And λ_1 is for 650nm wavelength and λ_2 is for 950nm wavelength of light. The Output Oxygen sensor complete Arduino code of the prototype is listed in Appendix B. Fig. 3.3 shows photograph of the complete prototype of the system.

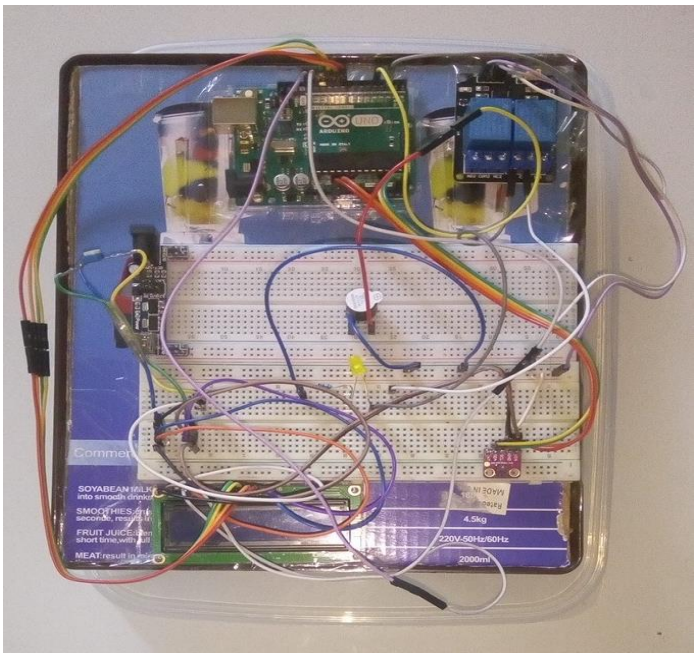


Figure 3.3: SpO_2 sensor output circuit

The pins of the sensor were connected to GND, 5V, A_4 (SCL), and A_5 (SDA) of the LCD to receive the signal from the controller. GND is connected to GND, V cc to 5V, SCL to A_4, and DATA to A_5.

The MQ-135 sensor module was selected to serve the purpose of sensing the AIR QUALITY. It has the capability of sensing the amount of oxygen and other combustible gases. The following

are the reasons as to why it was selected: Wide detecting scope, Fast response and high sensitivity, Stable and long life and it has simple drive circuit. Fig.3.4 shows photograph of the oxygen sensor output circuits.

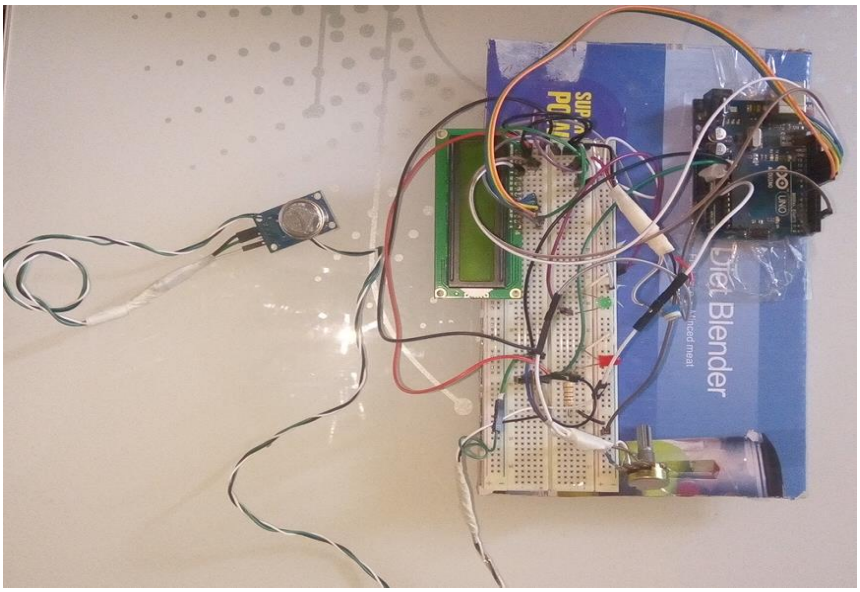


Figure 3.4: Oxygen sensor output circuit

The pins of the Led were then connected to GND, and output pin 2 of the LCD to receive the signal from the controller. (-) terminal is connected to GND, and (+) terminal to output pin 2.
The pins of the Buzzer were connected to output pin number 4 of digital pins of the LCD to receive the signal from the controller. (-) terminal is connected to GND, and (+) terminal to pin number 4.

3.4.2.2 Software Design

For the microcontroller to interface the sensor and the alarms and the LCD, it had to be programmed, hence necessitating software design. The following flowchart (Fig.3.5) indicates the functionality of the circuit and was used as a guide in the software design.

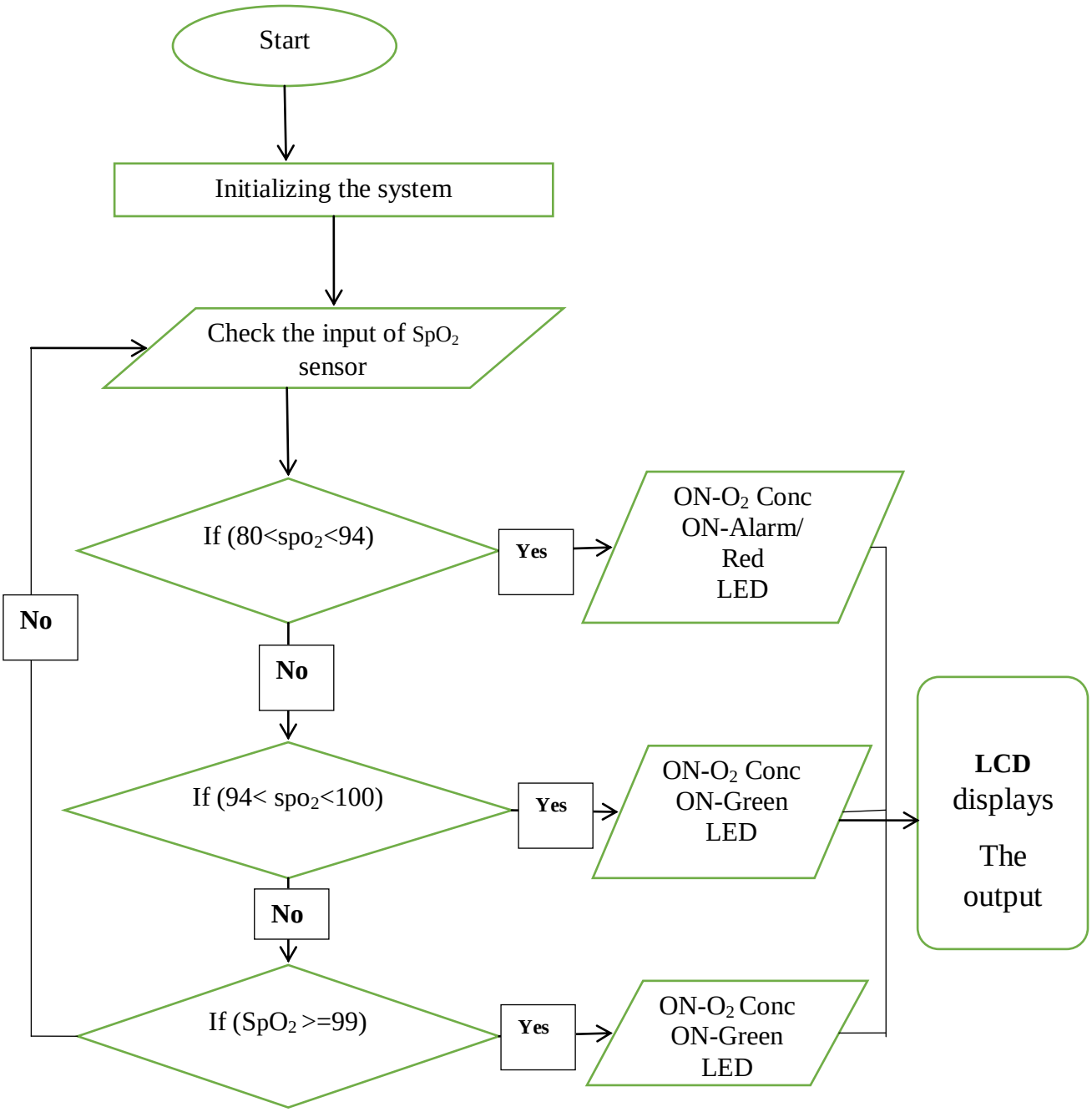


Figure 3.5: Flowchart for software design for spo_2 sensor

3.5. Testing of Arduino Program

The Arduino is a small computer that you can program to read information from the world around you and send commands to the outside world. In this study, instead of developing Arduino software directly on an Arduino board, programs have been developed and simulated on

the Code Blocks Arduino, Integrated Development Environment (CBA-IDE), which allows the code developer to trace the codes on an Arduino simulator.

The simulation of Arduino provides a powerful tool for debugging and testing the developed codes before building the prototype. In this paper, all codes were developed and tested in the CBA-IDE environment, to obtain the highest coding quality and correctness of the code functionality [24].

The last version (2014) contains very useful tools such as:

- ✓ Arduino Builder and compiler, Standard Arduino libraries,
- ✓ Core files, Serial terminal, AVR tool chain, and, an Arduino simulator at API-level.

The Code Blocks Arduino IDE allows chip simulation and in-circuit emulation for the Arduino family of microcontrollers. The IDE provides important information to the user by several windows. Some of these windows are the *Workspace*, *Source Code*, *Output*, and *Watch* windows as seen in Fig. 3.6 below.

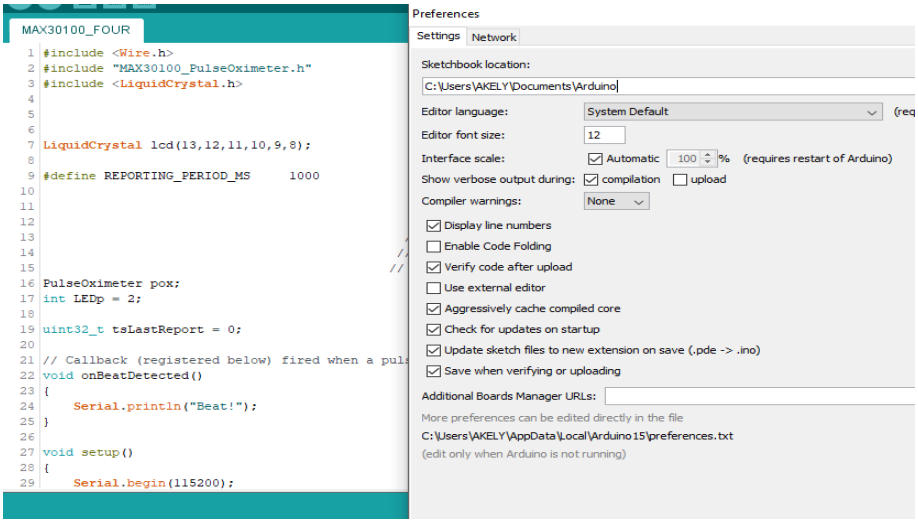


Figure 3.6: A sample of IDE windows when a program is simulated.

Fig. 3.7 and Fig. 3.8, show how to choose the right Arduino board. And then, Arduino is made connected to its sensors and electronic part and communicates with programs on the computer, such as processing program and MATLAB.

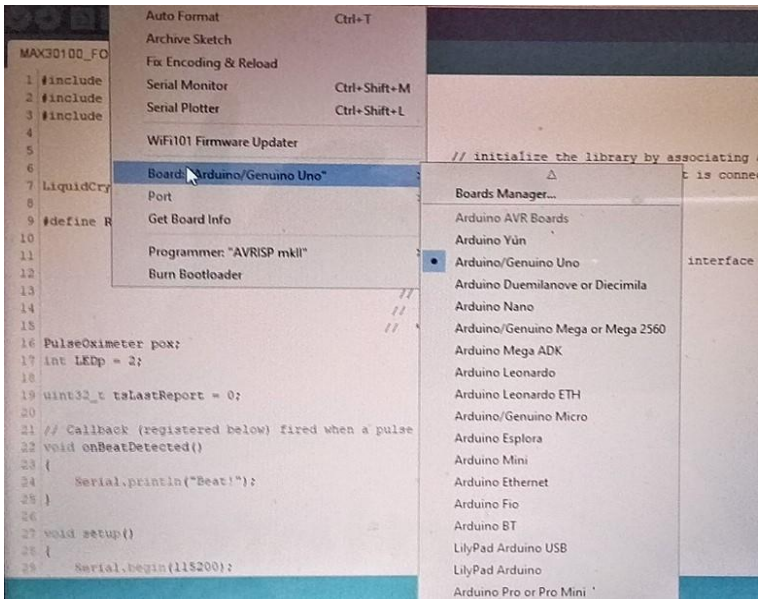


Figure 3.7: A snapshot of choosing the right arduino board.

And then click "tool", pick up relevant Arduino board, and relevant com. Then click "Serial Monitor", on the new open up window's bottom right, choose the relevant rate.

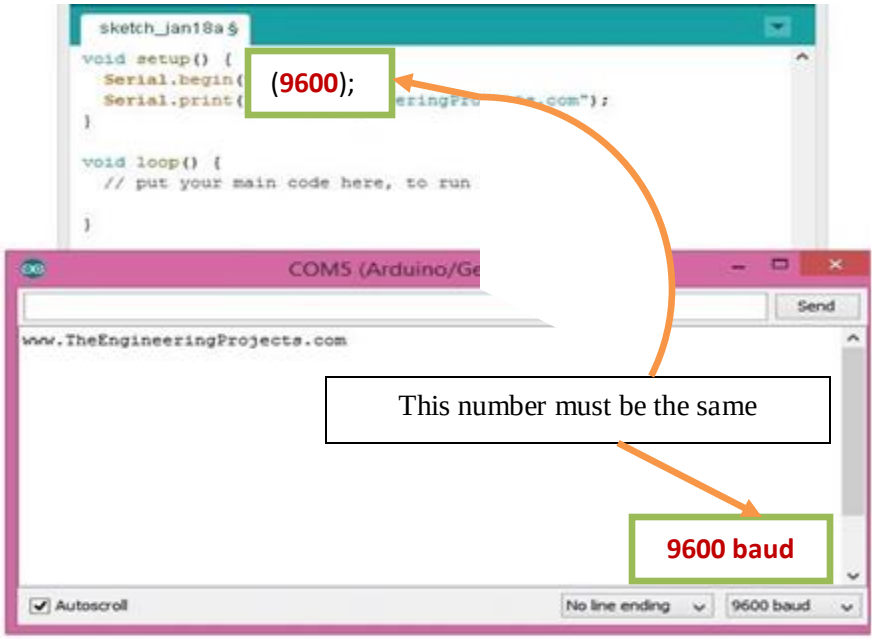


Figure 3.8: A snapshot of choosing the right Arduino serial port.

In the Fig.3.9, one can see an Arduino board labeled which is used in this study and Table 3.1 shows the specification of Arduino-Uno

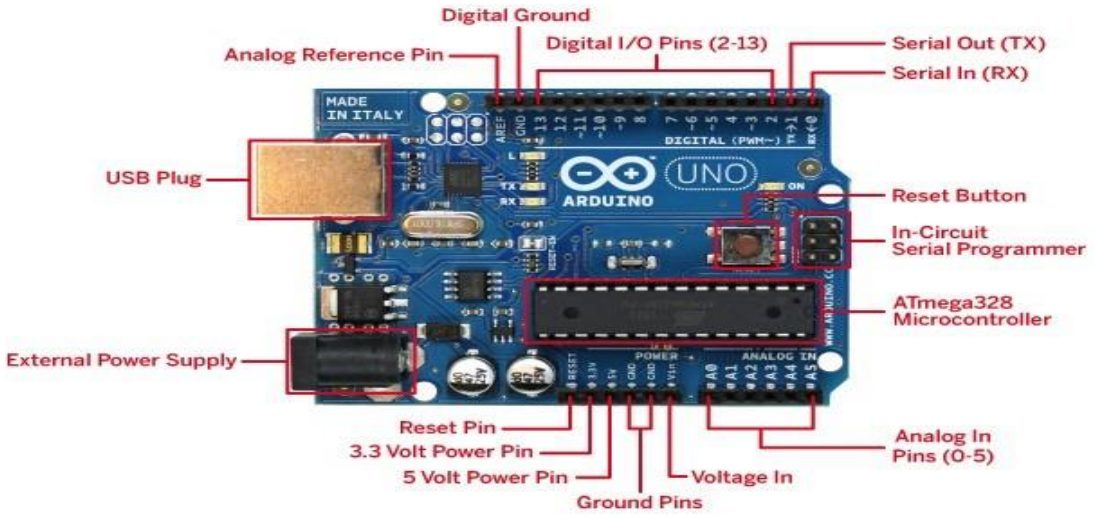


Figure 3.9: In the Arduino board each part labeled [25].

Table 3.1: Arduino-Uno specifications [25].

Arduino Uno board contain	**Description**
Microcontroller	ATmega328
Operating Voltage	5V
Recommended Input Voltage	7V - 12V
Digital I/O Pins	14
PWM Channels	6 Provides PWM output
Analog Input Channels	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
SRAM	2 KB (ATMaga 328)
EEPROM	1 KB (ATMaga 328)
Clock Speed	16 MHz
Length, Width, Weight	68.6mm, 53.4mm, 25gm

3.6. Sensors Program

The sensor is integrated pulse oximetry and heart-rate monitor sensor solution. It combines two LED's, a photodetector, optimized optics, and low-noise analog signal processing to detect pulse and heart-rate signals. It operates from 1.8V and 3.3V power supplies and can be powered down through software with negligible standby current, permitting the power supply to remain connected at all times, but the MQ-135 gas sensor applies SnO2 which has lower conductivity in the clear air as a gas sensing material.

In an atmosphere where there may be polluting gas, the conductivity of the gas sensor raises along with the concentration of the polluting gas increases. MQ-135 performs a good detection of smoke and other harmful gas, especially sensitive to ammonia, sulfide, and benzene steam. Its ability to detect various harmful gas and lower cost make MQ-135 an ideal choice for different applications of gas detection [2][26][27].

3.7. LCD Program

A liquid-crystal display (LCD) is a flat-panel display or another electronically modulated optical device that uses the light-modulating properties of liquid crystals.

LCD was implemented in the 4-bit mode as opposed to the 8-bit mode. The advantage of using the 4-bit mode is the utilization of fewer pins for interfacing with the microcontroller. However, in the 4-bit mode, data must be sent one nibble at a time, so execution time is twice that of 8-bit mode. Displaying data using a 4-bit interface consists of sending the high-order nibble followed by the lower-order nibble through the LCD 4-high-order-data lines. The pulsing of the E-line follows the last nibble sent [28].

The software must provide a way of reading and write to the appropriate port lines, the ones used in data transfer, without altering the value stored in the port bits dedicated to other uses. The R/W pin is always low since data is always written into the LCD. The RS pin was connected to PD0 and was used to control the instructions or characters sent to the LCD. The Enable pin was connected to PD1 and it was used to enable the LCD to either feed instruction into the register or write the character into it [28][29].

3.8. Alarm Activation Program

A buzzer is an audio signaling device that may be used in alarm devices, timers, and other forms of alerts. When the output oxygen(air quality) detected exceeds the rated value, the buzzer is activated, the green LED is switched off and the red LEDs are switched on in addition to the status indication of output oxygen(air quality) detected on the LCD.

As long as the circuit is powered, the sensor keeps checking for the presence of output oxygen (air quality). For the purpose of the demonstration, the preset value was 3800 particles per million (ppm). It has the following Specifications and Features: Rated Voltage: 5V, Operating Voltage: 4 - 8V, Rated Current (MAX): 30mA, Min Sound Output at 10cm: 80dB [24][29].

3.9. PCB Design

The circuit was first tested on a breadboard and found to be functioning and the next step was a fabrication. This was to facilitate to fit of the whole design on a small board and in a compact manner. It also helps in improving the organization of the whole design as well make it neat and presentable.

The first step involved drawing the whole layout on proteus software to determine how the components will be arranged on the board before replicating the same on the PCB. The layout of copper wires was drawn on express PCB and the drawing was then printed on a transparent paper before the paper was laid on the PCB board and UV lights passed on it. It was then passed through a developing solution of Sodium Hydroxide where only the needed copper lines were outlined.

The next step involved the etching process where the weakened copper was removed from the board, leaving only the needed copper lines. The final step involved the drilling of holes for the needed components and soldering of components on the board.

In order to start reading the data from SpO_2 the following two things have to be done:
Set the mode, on heart rate mode and secondly set the current for IR led. This enables us to measure arterial blood oxygen, once we are done with filtering. You can check how the researcher did it, by looking at three functions in the library: set Mode (), set LED Currents (), and read FIFO () [28].

CHAPTER FOUR
RESULT AND DISCUSSION

4.1. Overview

The proposed novel design features of medical oxygen delivery system in this study is developed and simulated in proteus software, and the circuit design control circuit was constructed in the laboratory on the breadboard. The circuit was built and assembled into one module and connected to a computer in order to upload the control algorithm and run the simulation software.

The new design is able to upload the code and activated the circuit constructed on the breadboard to measure data from the LCD display by using both arterials blood oxygen (SpO_2) sensors (SpO_2s) and oxygen sensor.

SpO_2 sensor senses the signal from the patient and sends the data to the microcontroller. The data will be analyzed by the microcontroller and the decision will be displayed on the LCD screen. The output oxygen sensor also senses data from the instrument/oxygen delivering device send to the Arduino just like the (SPO_2s). In order to measure and quantify the proposed integrating new design features of an oxygen concentrator control system as a control means, the result made to show higher performance with slow time elapsing. This is the time that takes the whole system to report a fault/correct result that comes from the patient to the Arduino microcontrollers and then sent to the LCD display automatically.

The SpO_2 sensor is dependent on the patient blood oxygen output situation to process the data by the Arduino microcontroller, login to the module and transmit it over the actuator interface.

Generally, the integrating new design features of an oxygen concentrator had more advantages than the existing system for real-time activity. Therefore, the integrating new design features of an oxygen concentrator can be control the situation of the patient in a good performance than the existing system. Hence, choosing to, the integrating new design features of an oxygen concentrator to improve patient treatment outcome as a control option is quite reasonable.

4.2 Test Results of the Developed Circuit

The modules which were built are evaluated one at a time and were compiled them all together into one component. First of all, the sensing modules were built. Each of these modules was tested using a digital multimeter (DMM) and an oscilloscope. The output oxygen measuring module from the device was the starting point. Secondly, the percentage of arterials blood oxygen control sensing modules was built.

Finally, a combination of both sensing modules built together to synchronized. After synchronization of the modules, the data uploaded to the Arduino, then reading on the Arduino serial monitor was first seen and the readings were displayed each second simultaneously also displayed on LCD screen. The SpO_2 sensor readings were displayed in percentages. While the oxygen sensor is displayed in percent. At this point, it is possible to access the data numerically.

The designed Arduino-based system is found out to be capable of reading the output coming from patient data as well as the output of the instrument on a short interval of time and uploads it to Arduino microcontroller.

The Output Oxygen sensor senses the output signal comes from the oxygen delivery device to send to the microcontroller that can be analyzing the data and send back to the actuator for the right decision based on the coming information.

Similarly, the signal sensed from the patient is uploaded to a specific data stream using a max 30100 sensor (SpO_2) and feed to the microcontroller that processed the data and sends it to the actuator that can take action based on the required level. This is important to keep the system automatically respond and prevent unnecessary faults that made by the human being (health professionals) as well as the instrument itself. Using this system, average working capacity up to one year can be saved.

4.3 Percentage of Output Oxygen Sensor.

The following results (Table 4.1, Fig.4.1) have been obtained after simulation on Proteus software. Since the oxygen output sensor gives an output of analog voltage, this was simulated by giving a corresponding voltage to the input of the microcontroller which was to be connected to the sensor.

Table 4.1: Output of oxygen sensor

O_2 Output in V	O2 Output	O_2 Concentrator	Green LED	Red LED	Buzzer	LCD Display
0.00	0.00	OFF	OFF	OFF	OFF	Standby mode qua=0%
0.50	<= 80	OFF	OFF	ON	ON	Satisfactory
1.50	85	ON	ON	OFF	OFF	Good
2.50	90	ON	ON	OFF	OFF	Very Good
3.50	95	ON	ON	OFF	OFF	Excellent

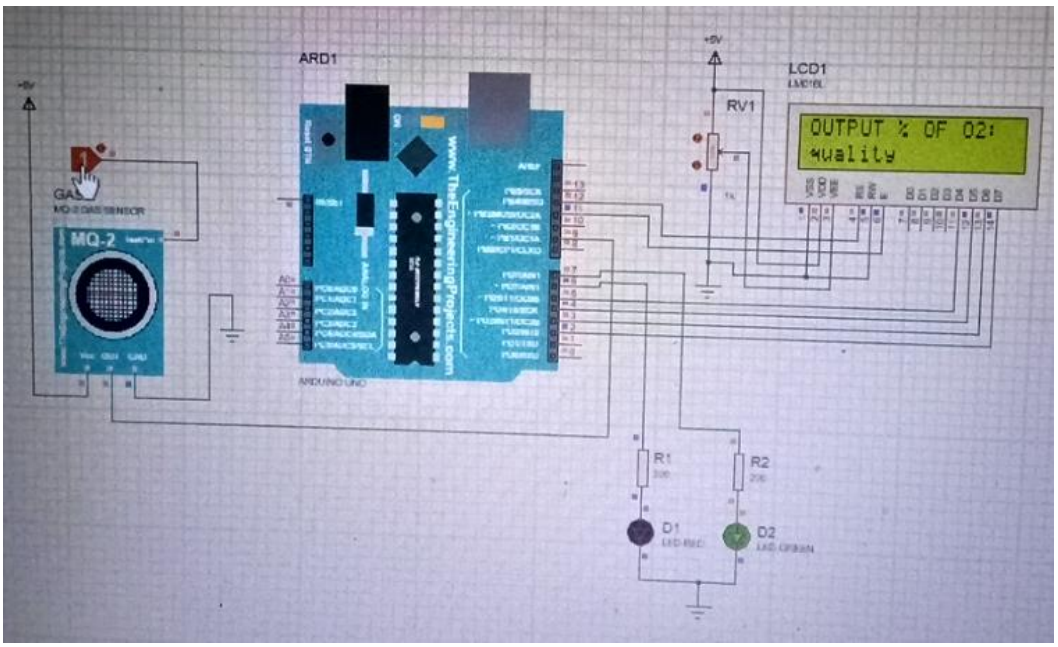


Figure 4.1: LCD display percentage of output oxygen detected ON mode simulation.

The critical value for output oxygen detection was (80%) 3800ppm. It was a preset value and could be changed in the code. From the simulated results (Fig.4.2), it was observed that the immediately output of oxygen quantity was greater than the pre-set value of (80%)3800ppm, the audio and visual alarms were triggered appropriately. From the observations, the system achieves the functionality of an output oxygen detector device.

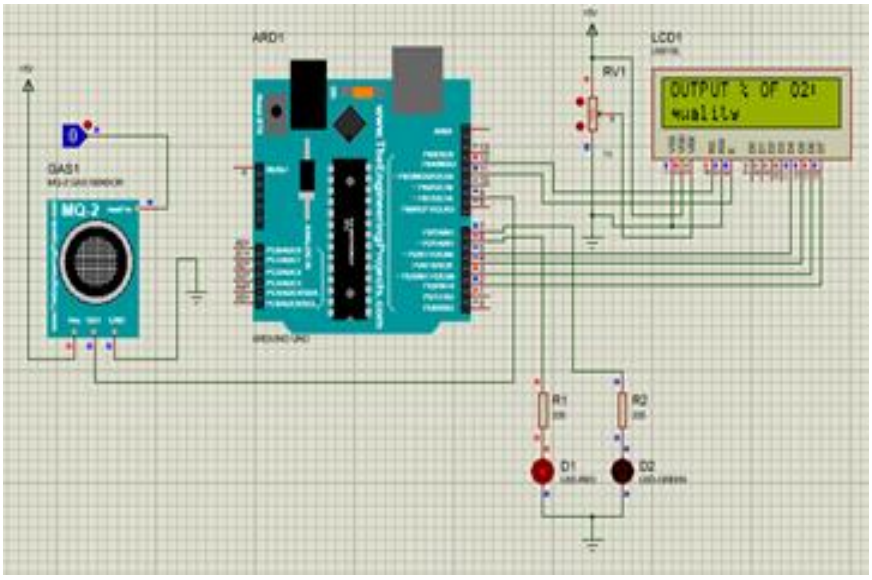


Figure 4.2: LCD display percentage of output oxygen detected OFF mode simulation.

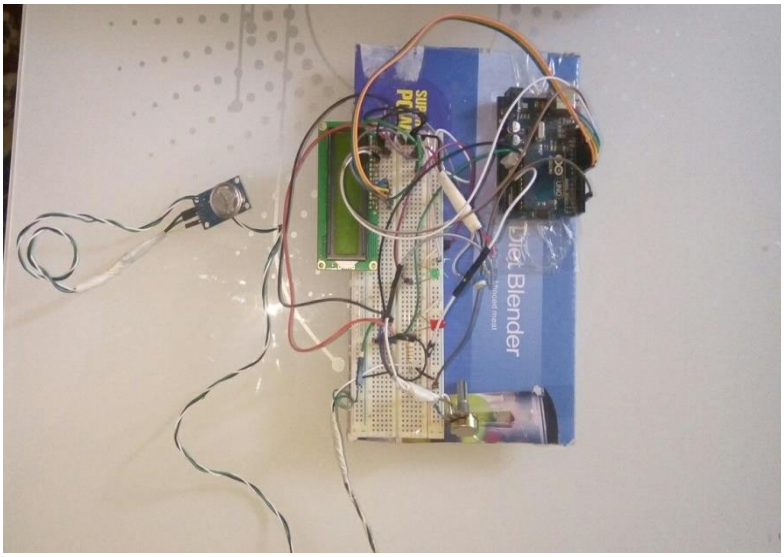


Figure 4.3: Final module with the power switched off

Fig.4.3 shows the final module after develops, but with the power supply switched off. As expected, all the Arduino, Sensor, LEDs, buzzer, and LCD were off regardless of the output oxygen from the device conditions.

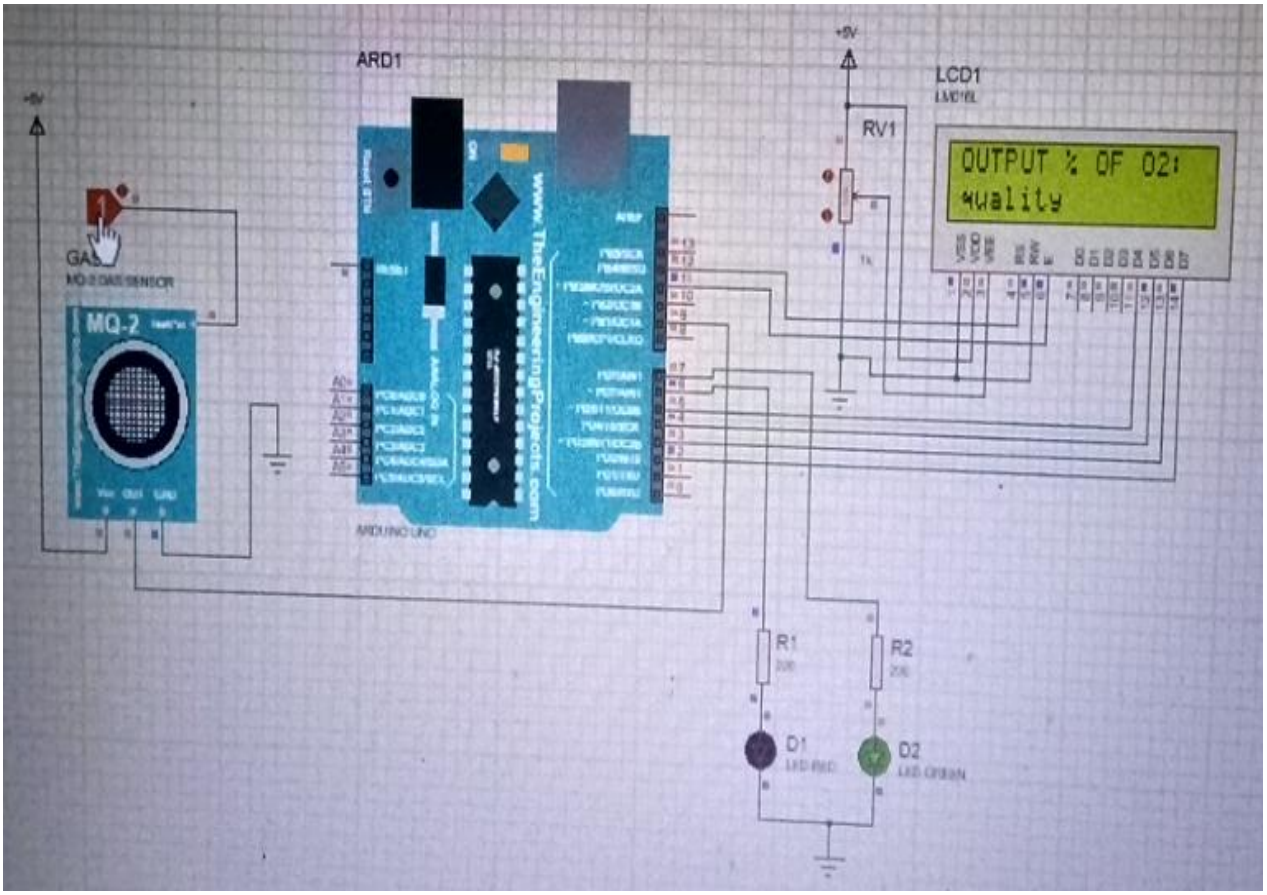


Figure 4.4: LCD display percentage of output oxygen detected ON mode simulation.

The above Fig.4.4 was taken while the circuit was being tested while mounted on a breadboard. The preset critical value was (80%) 3800ppm but the output oxygen detected was (92%) 4550ppm. Hence, the system had not met the threshold for triggering an alarm.

The buzzer and red LEDs were off, while the green LED was on, as expected. The LCD indicated ‘’standby mode‟, which was an indicator of an insignificant quantity of output oxygen.

4.4. Output of SpO_2 Sensor.

The following results have been obtained after simulation on Proteus software. Since the blood oxygen level sensor gives an output of analog voltage, it was simulated by giving a corresponding voltage to the input of the microcontroller which was to be connected to the blood oxygen sensor.

Table 4.2: Output of SpO_2 sensor

SpO_2 Output in V	SpO_2	O_2 Concentrator	Green LED	Red LED	Buzzer	LCD display
0.00	0.00	OFF	OFF	OFF	OFF	Off
5.00	80	ON	OFF	ON	ON	High Risk
5.00	84	ON	OFF	ON	ON	Very Low
5.00	88	ON	OFF	ON	ON	Low
5.00	90	ON	OFF	ON	ON	Moderately Low
5.00	94	ON	ON	OFF	OFF	Normal
5.00	96	ON	ON	OFF	OFF	Very Good
5.00	98	ON	ON	OFF	OFF	Excellent
5.00 - 0.00	99	ON	ON	OFF	OFF	Saturating

As can be seen from the result (shown in Table 4.2, Fig. 4.5, Fig.4.6), the critical value for SpO_2 level detection was 94%. It was a preset value and could be changed in the code. From the simulated results, it was observed that immediately the arterial blood oxygen level quantity was greater than the pre-set value of 94%, the audio and visual alarms were triggered appropriately. From the observations, the system achieves the functionality of SpO_2 level detector device.

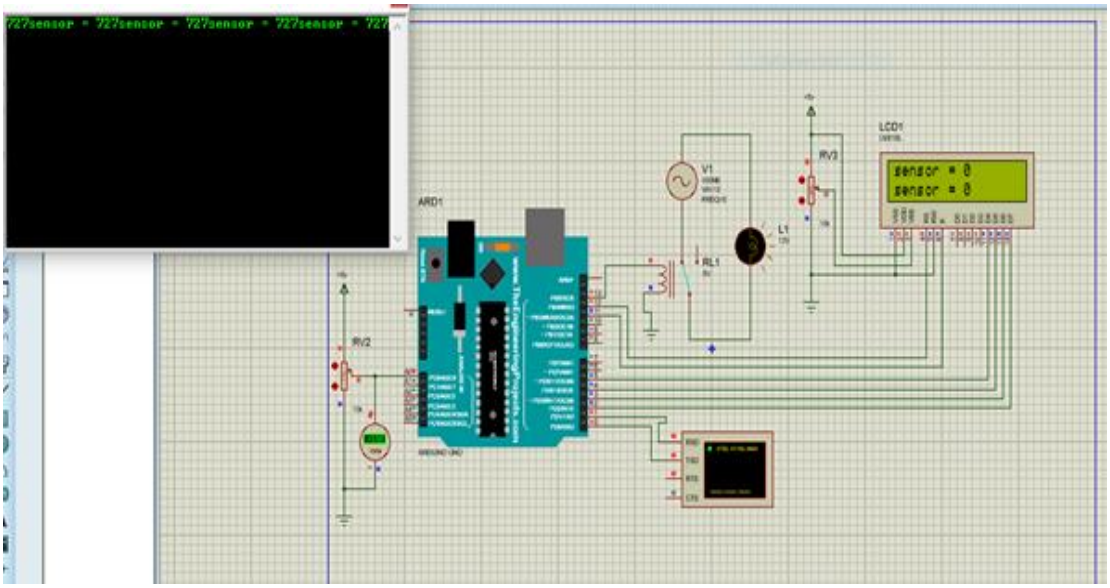


Figure 4.5: LCD display the SpO_2 output ON state condition.

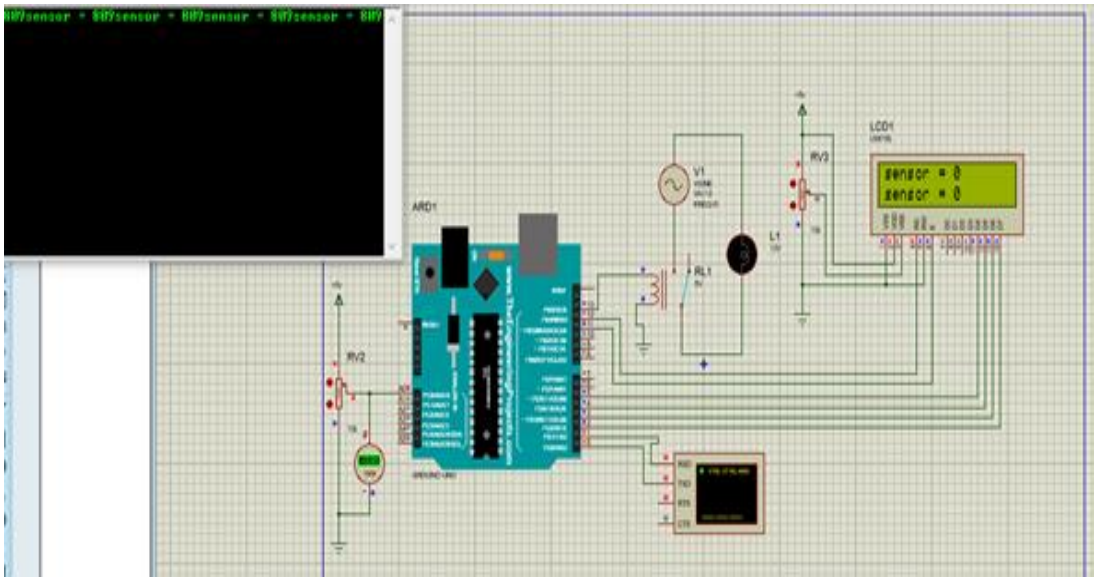


Figure 4.6: LCD displays the SpO_2 output OFF state condition.

Fig. 4.7 shows Photograph of SpO2 sensing module which is the final module after developed, but with the power supply switched off. As expected, all hardware implementation of the device which includes the Arduino microcontroller, two light-emitting diodes (LEDs), photo detector (infrared diode), liquid crystal display (LCD) and variable resistance to control the LCD light, and buzzer/ALARM were off regardless of the arterials blood oxygen level of the patient conditions.

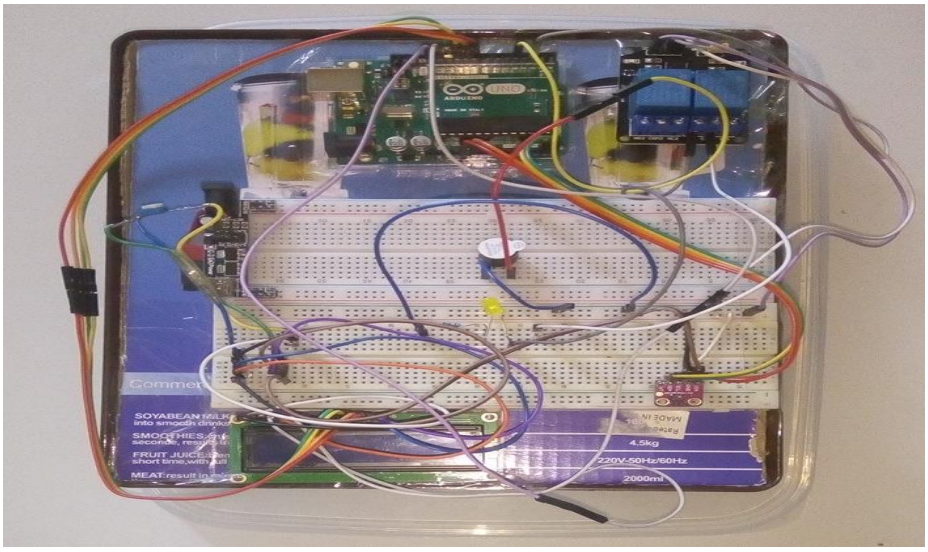


Figure 4.7: SpO_2 sensing module

Figure 4.8: On Breadboard a SpO_2 sensing module

As shown in Fig.4.8, the image was taken while the circuit was being tested while mounted on a breadboard. The preset critical value was 94%, but the arterials blood oxygen detected was 96% hence, it had not met the threshold for triggering an alarm. The buzzer and red LEDs were off, while the green LED was on, as expected. The LCD display indicated ‘’standby mode‟, which was an indicator of an insignificant quantity of arterials blood oxygen level.

Figure 4.9: Circuit on breadboard with a significant quantity of SpO2 detected

As seen in Fig. 4.9, the RED LEDs were blinking, the GREEN LED was off, the buzzer was activated and the LCD display indicated ‘’not SATISFACTORY‟ and a quantity of 90%. This was as expected since the quantity of arterial blood oxygen levels had surpassed the preset value of 94%.

Moreover, the developed system is capable of measuring the oxygen from the arterial blood of the patient through the SpO_2 sensor which is directly displayed on the serial monitor as well as the LCD display simultaneously, this indicates the present information of the patient's condition. Hence, the integrating new design feature of an oxygen concentrator takes the right measure or action accordingly. These activities can give relives for both the patient as well as the health professional's burden.

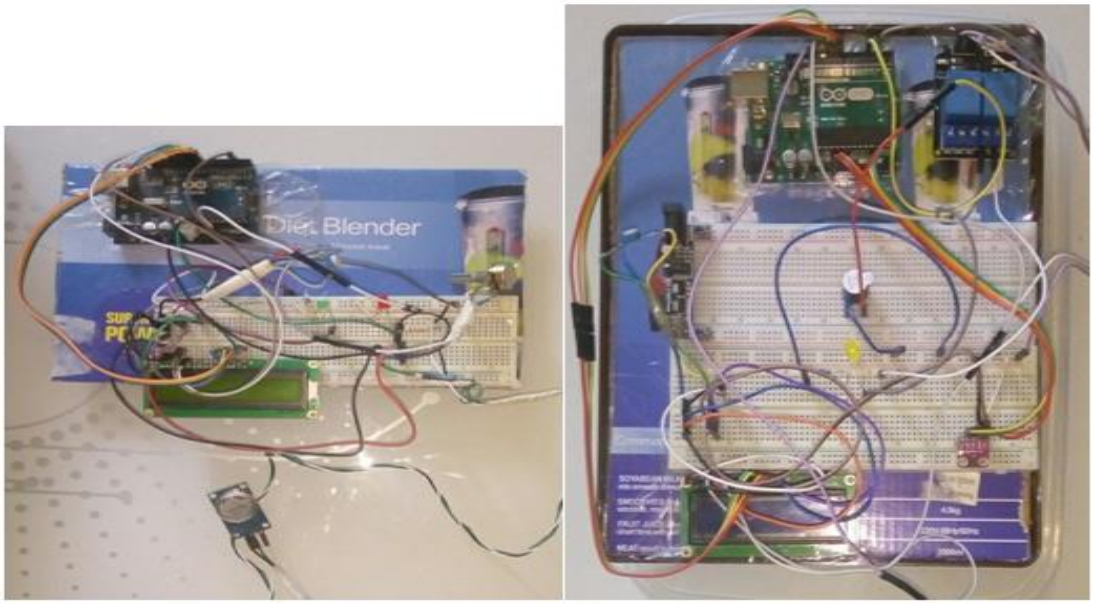


Figure 4.10: Final module with a significant quantity of percentage of output oxygen detected.

From the above Fig.4.10, the oxygen level was not good enough or under the level. The RED LEDs were blinking, the GREEN LED was off, the buzzer was activated and the LCD display indicated ‘’UNDER THE PRESET VALUE’’ and a quantity of 75%. This was as expected since the quantity of output oxygen level had surpassed the preset value of 80%.

All the above aforementioned observations were in accordance with the design specifications for the project. The only major limitation while taking the observations is the positioning of the

sensor and the direct contact of the index finger since detection would not occur unless the SpO_2 sensor comes directly in contact with the finger (or earlobe). The LCD display also indicates the quantity of arterial blood oxygen level from 94% up to 100%, since that is the only range within which the sensor operates linearly.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Oxygen therapy has become an integral part of treatment and standard care for various life treating diseases such as childhood pneumonia, surgery, anesthesia, emergency, obstetric care, etc, and an oxygen concentrator is indicated by WHO as a suitable source of medical oxygen in low-resource settings, especially where cylinders and/or piped systems are unavailable. Typically, an oxygen concentrator provides 93±3% pure medical oxygen for oxygen therapy. However, this value may go below the required limit due to several factors such as harsh environment, poor/no maintenance, prolonged operation time, etc.

In this study, clinical problems associated with existing typical oxygen concentrators used in Hospitals in Jimma Zone have been assessed. I have noticed patents who are connected to oxygen concentrators having oxygen output that is less than the clinically recommended value. My technical assessment on the design features showed that these concentrators on patient use did not have built-in feature(s) to inform clinicians about this low oxygen output. Clinicians told me that they often check presence of airflow coming out of an oxygen concentrator before connecting it to a patient. But as we know, presence of airflow does not necessarily guarantee that the oxygen concentration is within the required range as prescribed for oxygen therapy. As a result, patient treatment outcome could be compromised.

The aim of this thesis was therefore to propose a modified design of the oxygen concentrator that can potentially improve patient outcome. The proposed design integrates a built-in oxygen sensor that can continuously monitor oxygen concentration and communicate the status to clinicians. In the design, a feature for measuring the arterial blood oxygen saturation (SpO_2) of a patient is also integrated. This information will be used by clinicians to know the clinical response of the patient to oxygen therapy.

As a proof of concept, a prototype was developed using the required sensors and actuators. Simulation and demonstration were done using proteus simulation software and Arduino microcontroller. In the prototype, an oxygen sensor detects oxygen concentration at the output side of an oxygen concentrator; the result is compared with the pre-set value, displayed as visual

message on a screen, and an audible alarm is produced whenever the output goes below the preset value. Moreover, another sensor detects SpO_2 of the patient and provides clinical information about the response of the patient connected to the oxygen concentrator for a prescribed oxygen therapy.

The proposed design can not only improve patient outcome but also avoids the need of an external oxygen analyzer and pulse oximeter to measure oxygen concentration of an oxygen concentrator and SpO_2 of a patient respectively. Hence in this thesis, we came with a novel idea of using an oxygen concentrator for diagnosis and treatment applications beyond treatment which do not exist in the exist concentrator. We believe that this novel design can increase the quality of oxygen therapy procedures and save lives.

5.2 Recommendations and Future Work

In this thesis, a prototype for measuring and controlling oxygen concentration in an oxygen concentrator and SpO_2 of the patient was developed in order to demonstrate the concept. I strongly believe that integrating these two features in the actual oxygen concentrator will significantly improve patient outcome. Therefore, I recommend collaborating with a manufacturer of an oxygen concentrator and including these two important features as a future work.

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1.8. Definition of terms

In order to create a common thoughtful between the researcher and various readers of the research paper, the operational and conceptual definition of some words and phrases are presented:

- **Hypoxemia:-**An abnormal deficiency in the concentration of oxygen in arterial blood. Itisamajorcauseofmorbidityandmortalityassociatedwithacuteandchroniclungdiseaseinadults&canleadtodeathirrespectiveofage, sex, etiology, geographic region or clinical presentation of a patient.
- **Hypoxia: -** Inadequate supply of oxygen to tissues or cells.
- **Oxygen saturation:** The amount of oxygen carried in the blood (that is, the average amount of oxygen bound to each hemoglobin molecule), expressed as a percentage of the maximal binding capacity. Normal saturation is 95 to 100%.
- **Oxygen therapy:** A medically supervised use/provision of pure oxygen, (also hydrogen peroxide, or ozone) in greater inspired concentration than the ambient/room air (that is, the fraction of inspired oxygen [FiO2] is greater than 21%), to treat a wide range of health problems.
- **Pulse oximetry:** A non-invasive method that uses infrared technology to measure the oxygen saturation of capillary blood (SpO2), which provides a good estimate of the oxygen saturation of arterial blood (SaO2); 100% is the maximum reading possible.
- **Hyperoxemia: -**Increased oxygen content of the blood; refers to the increased partial pressure of oxygen in arterial blood (PaO2) to above the normal range.
- **Hyperoxia:** An increased amount of oxygen in tissues and organs; a greater oxygen tension than normal.
- **COPD:** Chronic obstructive pulmonary disease (includes emphysema, chronic bronchitis, and some chronic severe asthma).
- **Supplemental oxygen**: is a well-established therapy with clear evidence for the benefit of patients with COPD
- **Patient Outcome:** refers to the treatment and diagnostic outcome of the patient

APPENDIX

Appendix-A: Arduino Code for Arterial Blood Oxygen (SPO_2) Sensor:

```
#include <Wire.h>
#include "MAX30100_PulseOximeter.h"
#include <LiquidCrystal.h>

                                    // initialize the library by associating any needed LCD interface
pin
                                   // with the arduino pin number it is connected to
LiquidCrystal lcd(13,12,11,10,9,8);

#define REPORTING_PERIOD_MS     1000

                                     // PulseOximeter is the higher level interface to the sensor
                                    // it offers:
                                   //  * beat detection reporting
                                  //  * heart rate calculation
                                 //  * SpO2 (oxidation level) calculation
PulseOximeter pox;
int LEDp = 2;

uint32_t tsLastReport = 0;

// Callback (registered below) fired when a pulse is detected
void onBeatDetected()
{
```

```
    Serial.println("Beat!");
}

void setup()
{
    Serial.begin(115200);

    Serial.print("Initializing pulse oximeter..");
    pinMode(LEDp,OUTPUT);

    lcd.begin(16,2);
                                    // Turn on  and print a message.
    lcd.setCursor(0,0);
    lcd.print("Initializing...");
    delay(1000);
    lcd.setCursor(0,1);

                                     // Initialize the PulseOximeter instance
                                     // Failures are generally due to an improper I2C wiring, missing
power supply
                                    // or wrong target chip
    if (!pox.begin()) {
        Serial.println("FAILED");

        lcd.print("FAILED");
        for(;;);
    } else {
```

```
        Serial.println("SUCCESS");


        lcd.print("SUCCESS");
    }


                                    // The default current for the IR LED is 50mA and it could be
changed
                                    //   by uncommenting the following line. Check
MAX30100_Registers.h for all the
                                    //   available options.
    pox.setIRLedCurrent(MAX30100_LED_CURR_7_6MA);


                                   // Register a callback for the beat detection
    pox.setOnBeatDetectedCallback(onBeatDetected);
       delay(1000);
}
void loop()
{
                                  // Make sure to call update as fast as possible
    pox.update();



                                  // Asynchronously dump heart rate and oxidation levels to the serial
                                   // For both, a value of 0 means "invalid"
    if (millis() - tsLastReport > REPORTING_PERIOD_MS) {


        Serial.print("SpO2:");
        Serial.print(pox.getSpO2());
```

```
        Serial.println("%");

        lcd.clear();
        lcd.setCursor(0,0);
        lcd.print("SpO2: ");
        lcd.print(pox.getSpO2());
        lcd.print("%");


        tsLastReport = millis();

        if(pox.getSpO2() >= 93 && pox.getSpO2() <= 100){

          digitalWrite(LEDp, HIGH);
          lcd.setCursor(0,1);
          lcd.print("O2 IS SUPLYING TO.....: ");
            delay(1000);
           }else{
             digitalWrite(LEDp, LOW);
            }
    }
}
```

Appendix-B: Arduino Code for Percentage of output oxygen Sensing:

```
// include the library code:
#include <LiquidCrystal.h>
// initialize the library by associating any needed LCD interface pin
// with the arduino pin number it is connected to
LiquidCrystal lcd(12,11,5,4,3,2);
// These constants won't change:
int sensorPin = 9;    // pin that the sensor is attached to po2pin
int ledpin1 = 7;      // pin that the GREEN LED is attached to
int ledpin2 = 6;      // bezzer/red LED
// These variables will change:
int sensorValue = 0;        // the sensor value
String quality ="";
void setup() {
   Serial.begin(9600);                    // initialize serial communications:
  pinMode(sensorPin,INPUT);                  //set p.opin as an input orset digitalpinA0as input:
  pinMode(ledpin1, OUTPUT);                  // initialize the LED pin as an output:
  pinMode(ledpin2, OUTPUT);                    // initialize the LED pin as an output:
 lcd.begin(16,2);
lcd.setCursor(0,0);
lcd.print("               ");
lcd.setCursor(0,1);
lcd.print("               ");
lcd.setCursor(0,0);
lcd.print("  Air sensor             ");
lcd.setCursor(0,1);
```

```
lcd.print("   Warming up              ");
delay(2000);                                  // delay in between reads for stability
lcd.setCursor(0,0);
lcd.print("                 ");
lcd.setCursor(0,1);
lcd.print("                 ");
}
void loop() {
   // read the value of the sensor:
  int sensorValue = digitalRead(sensorPin);
    // if the analog value is high enough, turn on the LED:
  if (sensorValue == HIGH){
       quality = "GOOD:                    ";
      digitalWrite(ledpin1,HIGH); //set the GREEN LED ledpin ON:
      digitalWrite(ledpin2, LOW);   //ledpin OFF:
  }
  else {
     quality = "BELOW THE LEVEL:                    ";
       digitalWrite(ledpin1,LOW);  //set the GREEN LED ledpin OFF:
      digitalWrite(ledpin2, HIGH);   //RED LED ledpin ON:
  }
   lcd.setCursor(0,0);
   lcd.print("OUTPUT % OF O2:");
   lcd.setCursor(0,1);
   lcd.print("quality");
}
```

Appendix-C: Flow chart of Output O2 System.