UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

IoT-BASED MEDICAL OXYGEN MONITORING SYSTEM IN ICU
(case study: Rwandan hospitals with ICUs)

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A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by:

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DECLARATION

I, MUCYURABUHORO Philemon, declare that this dissertation entitled "IoT BASED MEDICAL OXYGEN MONITORING SYSTEM IN ICU" is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

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CERTIFICATE

This is to certify that the project entitled "IoT BASED MEDICAL OXYGEN MONITORING SYSTEM IN ICU" is a record of original work done by MUCYURABUHORO Philemon (Reference number: 220020530), a MSc. Degree student in Biomedical Engineering. This work has been submitted under the guidance of Assoc. Prof. Damien HANYURWIMFURA and Dr. Philibert NSENGIYUMVA

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ABSTRACT

Globally, oxygen is among the most important medication provided to patients especially the ones with breathing problems. The management of oxygen supply in ICU is very crucial for being aware of oxygen pressure level being supplied from the source. In many hospitals, the oxygen is not distributed directly from the oxygen plant to ICU oxygen outlets. Full oxygen cylinders are installed on oxygen manifold which distributes the oxygen in different room oxygen outlets. Currently, biomedical engineers (BME) must be at the nearest place of the manifold of central distribution (oxygen supply), to observe and control the manifold pressure gauge, for being aware of medical oxygen pressure remaining in installed cylinders for clinical staff**.** The absence and availability of oxygen is recognized on oxygen flowmeters and other related medical equipment observation such as pulse oximeter and patient monitoring systems. When oxygen is not available and given in the appropriate manner and at the appropriate time in ICU regions, it immediately affects patient's medical conditions. The main goal of this research project is to design an IoT-based medical oxygen monitoring system in ICU hospitalization area that uses IoT devices to check oxygen pressure in installed cylinders and produce an alarm when the oxygen pressure is reaching nearby critical level. The biomedical engineers dealing with the oxygen supply system are frequently moving and checking the oxygen pressure level at the manifold pressure gauges, where this takes their time while they can be doing other activities and get the oxygen pressure level information wherever they are. This medical oxygen alarm system project is intended to be utilized for monitoring oxygen pressure level that is still present in installed O2 cylinders on the manifold, for the benefit of patients in intensive care unit (ICU) who are experiencing respiratory system issues. The system is composed of Arduino board that contains the color sensor, and GSM module. The color sensor senses the red LED bulb light, which turns on when the oxygen pressure is 20 bars or below. Through Arduino, the warning signal is generated after the light becomes red, and it sends mobile phone SMS and calls alerts to selected clinical staff and biomedical engineers wherever they are. In brief, an automatic SMS and call via GSM/GPRS in real-time is used to alert when the oxygen pressure level has not yet reached the unsafe pressure level. The proposed system will help the engineers and clinical staff to be aware of what is happening on the oxygen supply system (manifold) and engineers will only attend to such place only when in need. The system will send an SMS to him/her when the oxygen level reaches the critical level for saving the patient's life rapidly. The oxygen level data will be maintained for further records analysis, and future decision-making.

Key words: Oxygen, ICU, LED, Pressure switch, Manifold, BME, SpO_2

LIST OF ACRONYMS

3D: 3 Dimension

BME: Biomedical Engineer

BMET: Biomedical Equipment

GSM: Global System for Mobile Communications

ICU: Intensive Care unity

LED: Light Emitting Diode

MOH: Ministry of Health

O2: Oxygen

PCB: Printed Circuit Board

SD Card: Secure Digital Card

SDM: System Development Method

SpO_2: Oxygen saturation

TTL: Transistor Transistor Logic

UR: University of Rwanda

WHO: Word Health Organization

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CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

This chapter is a set of brief information about how the proposed information will look like. It includes discussion of current systems' problems, hypothesis, objectives of the research, and it discusses also to the study scope, significancy of the study, organization of this research work and the summary of the whole chapter indeed.

A hospitalization area is a location within a healthcare facility where patients are constantly admitted for a day or more in order to get medical treatment. The intensive care unit (ICU) is one of the hospitalization locations where patients who are injured, critically respiratory ill, or in need of emergency medical attention receive specialized care[1]. Due to the patients' issues, it is impossible to deliver the critical care and life support that these patients need in this setting without an external oxygen supply[2]

For the lifesaving treatment of these critical patients to be achieved, a controlled external medical oxygen supply pipeline circuit to normalize oxygen pressure level coming to patient may be provided [3]. For making a credible and trusted lifesaving of such patients, a central oxygen supply source may be equipped with alarm systems that can alert occupants and oxygen supply system's source point to remember that oxygen depletion will occur in ICU in soonest possible time and set quick intervention for this coming incident to save patient's life without reaching the lowest level of O2 that may cause serious accidents [4].

In healthcare facility where quick response time is critically considered, this medical oxygen alarm system may enable rapid patients' lifesaving in easy and comfortable way, by receiving immediate medical assistance as quick as possible. For reaching this purpose, a clinical staff who is in ICU, must share equal information related to oxygen pressure supply status on manifold, in the same time with biomedical engineering staff, as they must work as a team to save patient life. In most of hospitalization areas, clinical staff determines wards oxygen status by patient monitoring system or oxygen flowmeters observation [5].

Oxygen pressure sensor on the manifold device will release analogue information for oxygen pressure level status. Once the oxygen pressure is equal or below to 20 bars, the electrical signal generated by oxygen pressure sensor will cause the LED red bulb to light [6]. Thereafter, a digital color sensor, microcontroller and GSM module will be used to process the analogue signal (light) to digital signals and to deliver digital information to concerned clinical staff and biomedical engineers [7].

1.2 Problem statement

An IoT-based medical oxygen monitoring system facilitates communication between healthcare providers and biomedical engineering team in charge of oxygen supply of known critical areas. It is understandable as system that is capable of sensing (air) oxygen pressure level and alarming when necessary. The importance of this system is highly found in ICU, where admitted patients with respiratory problem are located. Indeed, an uninterrupted and fully monitored oxygen supply pressure level must be in place to transmit oxygen pressure level information in the same time to clinical staff and biomedical engineer and make intervention related to low oxygen pressure on the manifold when it is required. While this critical patient is not supported in breathing, he/she can have the hypoxic problem that can cause brain injury, and even death [8]. The severity of respiratory problems is determined by the measurement of the amount of oxygen in the body, known as oxygen saturation (SpO_2). According to WHO's respiratory patient classification severity, when patients with COVID-19 are considered, useful definitions are shown in Figure 1.1 [9].

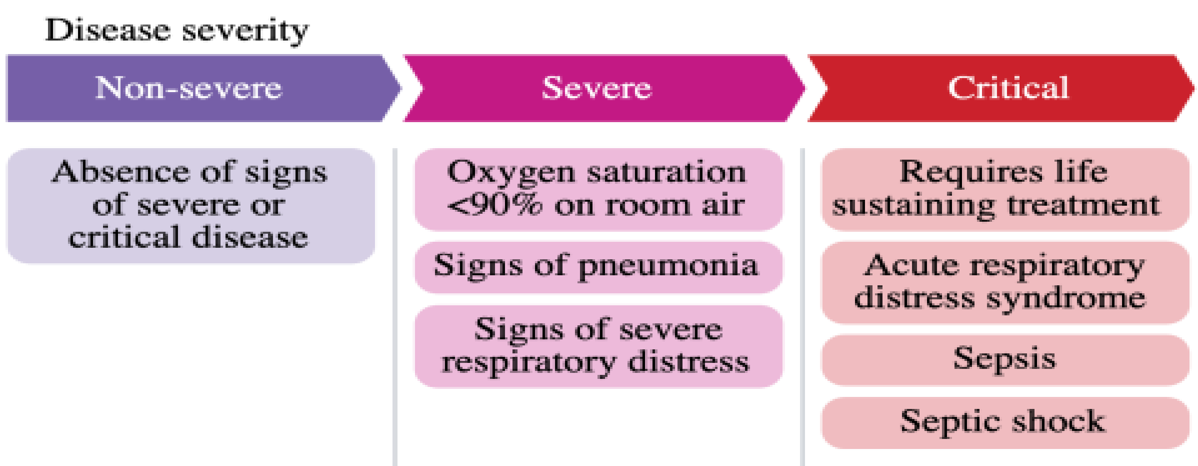


Figure 1.1.WHO severity definitions of all patients with COVID-19

Indeed, considering critical patients, they require life sustaining treatment which is basing on the oxygen central distribution supply from the manifold. When we have such kind of hospitalized patients in the room, the control of external oxygen supply must be made seriously, because such kind of external oxygen interruption can cause lung corruption, brain injury and other serious problems. By current situation, the system can't be fruitful when manifold pressure gauge observation and buzzer systems are only used. An advanced system that will use SMS for oxygen level information and call dissemination will be used.

The paragraph below illustrates different problems that are challenging for users in the existing system.

As the Intensive Care Unit is where critical patients are admited, the principal treatment is done using medical oxygen.This medical oxygen is supposed to be delivered in accurate and adequate way , and oxygen alarm system plays a key role in delivering this medical oxygen.

1º.Today, it is so difficult for clinical and biomedical engineering staff to share informations related to oxygen pressure level on external central oxygen supply.

2º Currently, a biomedical engineer must stand or sit near the central distribution manifold (oxygen supply) to monitor the manifold pressure gauge and keep track of the remaining medical oxygen pressure in installed cylinders.

3º. For clinical staff side, such kind of medical oxygen interruption is recognized by oxygen flowmeter and other related medical equipment observation such as pulse oximeter and patient monitor.

4º. For those who have oxygen monitoring system with sound alarm, the distance between the alarm source and biomedical engineering department may be so long for BMEs to hear the alarm voice.

5º. Due to a shortage of biomedical engineers in many hospitals, dealing with this oxygen supply system does not become easy, because it requires a frequent checkup of oxygen pressure level at the manifold pressure gauges, and this takes idle time for biomedical engineers to be moving around for checkup, while those engineers are supposed to be dealing with other activities.

The entire set of these challenges yields stressful situation to **c**linical staff and biomedical engineers that can cause different risks to ICU patients.

1.3 Research Questions (Hypotheses)

1. How is the medical oxygen monitoring system in ICU oxygen central supplies of Rwandan hospitals?
2. What gaps and challenges are in the medical oxygen monitoring **s**ystem in ICU oxygen central supplies of Rwandan Hospitals?
3. What should be done to improve the current medical oxygen monitoring **s**ystem in ICU oxygen central supplies and management in Rwandan hospitals?
4. Is the current system functions productively?

1.4 Objectives

1.4.1 General Objective

The objective of this project is to design and prototype an IoT-based medical oxygen monitoring **s**ystem for ICU oxygen central supplies.

1.4.2 Specific Objectives

To achieve the general objective of this project, the following specific objectives are used as guiding points:

- To understand the features of the current system used;
- To design the hardware part, develop the software to control the system functionality, integrate the hardware part with software and make the system based on users ‘requirements;
- Build a system that delivers real-time low oxygen pressure alarms to system users and store event information for future analysis;
- To check the proposed system for its accurate functionality.

1.5 Study Scope

This study focuses on Rwandan hospitals’ medical oxygen monitoring system in ICU oxygen central supplies monitoring and will alarm when the targeted oxygen low level measurement is recognized. Thus, it will concentrate on Rwandan hospitals that currently have ICU hospitalization zones and for limited financial resources and time constraints the used oxygen manifold will be for one oxygen cylinder.

1.6 Significance of the Study

This thesis aims to contribute to medical oxygen alarm system in intensive care unit hospitalizations in Rwandan hospitals by sensing, monitoring, and alarming oxygen low pressure status on the central oxygen supply system for ICU. The data gathered through this research will help various health-related organizations, project shareholders, and policy makers to enhance the management and operation of Rwandan hospitals' medical oxygen alarm systems. Based on the availability and functionality of the current systems, this study will attempt to determine how current medical oxygen alarm system might be improved. This study will also help in filling a gap in the management and monitoring of low oxygen pressure in Rwandan hospitals' current medical oxygen alarm systems, particularly on ICU's manifold and its maintenance.

The management team and operators of the medical oxygen alarm system will benefit from the study's findings as they improve maintenance of the system's faulty sensors, bulbs, and other components. In order to better understand the issues surrounding the development and usage of medical oxygen alarm system in ICU, policymakers, biomedical engineering department that manages this system, Rwandan hospitals, and MOH partners will all make use of this information. The findings from this research will also be used by the utilities to improve healthcare service delivery through the reduction of time taken to receive oxygen low pressure status information and reducing the time taken in intervention measures, when necessary, too.

1.7 Organization

This presents how the rest of this research is structured: Chapter 2 discusses a descriptive literature of this research. Chapter 3 summarizes the research methodology. Chapter 4 explains system project design results. Chapter 5 presents the conclusions and recommendations.

1.8 Summary

In order to provide health support and specialized healthcare where patients who are injured, critically ill, or in need of emergency medical attention are located, IoT based medical oxygen monitoring system in ICU hospitalization area will be used where Oxygen pressure sensor on the manifold device will release analogue information for oxygen pressure level status. Once the oxygen pressure is equal or below 20 bars, Oxygen monitoring monitoring system’s LED light bulb will be switched on. A digital color sensor, microcontroller, and GSM module will then process the analog signal (light) to digital signals and send SMS and call to concerned staff for quick intervention, ICU patient risks reduction and patient safety improvement.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter contains a number of studies on the design and implementation of the IoT-based medical oxygen monitoring system in ICU hospitalization areas. The design, implementation, operation and maintenance of the medical oxygen monitoring system in the ICU hospitalization area are theoretically and experimentally analyzed. This evaluation of the literature will be based on a selection of carefully picked books, papers, and other relevant published works.

2.2 Medical oxygen monitoring systems

In the last decade, the Manifold Control Systems project has been done and the author made it with different components. For the system to operate, those components such as pressure gauges must indicate oxygen pressure content of installed oxygen cylinders and the user must ensure that full gas cylinder pressure is shown on the cylinder content gauges, and spends there several times to see if the oxygen pressure level is not low to generate different incidents to patients[10] .

Different gaps in this system have been recognized as looking up to different alarm visions where the oxygen level of cylinders on central supply is shown by different colors on cylinder content pressure gauge and all required information is known while moving from the office to the specific place where central oxygen supply manifold is installed. This is the lowest technological way used here, where clinical staff and biomedical engineers are not able to share information to this oxygen pressure level status, and when this is in critical condition, these concerned persons are not going to receive real time information, which can cause lot of risks to ICU patients, without forgetting ICU and biomedical engineering staff.

The project called Alarm Management System [11] has been also worked on, where the manifold central supply system has been used to channel the oxygen flow to dedicated destinations. The alarm management system is incorporated in the used central oxygen supply system in the fact that when the low oxygen pressure is recognized, sensing system transmits the information to GSM and via local area network, the information is transmitted to display monitors as a text displaying for showing clear information.

Here, the color-coded signal lights are easily used where operating alarms are indicated in yellow while emergency alarms are indicated in red. During normal operation, when no alarms are active, a green LED remains on. It is used to display the location of the alarm and telephone number of the technician to be called.

This system shows different challenges where it is so expensive, requires many components and requires a huge number of staff to be always on display screens, for being aware of where the problem is also the maintenance cost of the system is so high [11].

The Ohio Medical Corporation Medical Gas Alarm System has been also designed to continuously monitor the status of source equipment and gas line pressure of medical gases [12]. The system is comprised of Area Alarm Modules which monitor and indicate the gas pressure level of a specific gas at a specific point in the hospital and Master Alarm Modules which monitor source equipment such as oxygen systems. The Alarm System monitors gas line pressure with sensors. The Annunciator alarm determines the status of pressure and it is displayed on an area alarm module. The alarm module also has trend LEDs light to show that the displayed pressure is either in a normal, caution, high or low alarm condition.

The function of sensor module is to sense pressure level in the line and transmit data to specific (annunciate) panel which is the main processing board for Medical Gas Alarm System. When the oxygen pressure decreases below a specified set-point, an alarm condition is detected, an audible alarm will sound and the appropriate red LED will illuminate from the corresponding area or Master Alarm Module[12].

This system reveals different challenges where it requires many components and requires a huge number of staff to be always near display Modules and sound devices for being aware of oxygen alarms status is, data analysis for different alarm events is impossible, alarm signals are transmitted through cables, the alarm system is pure analogue, also maintenance cost of the system is so high.

Tony et al. [13] implemented also a Centralized Medical Gas Monitoring System project**.** It has been also implemented by using a central oxygen supply system incorporating an oxygen pressure sensor, that measures the level of oxygen pressure in mobile oxygen Cylinders located in central distribution. Digital data from sensor is processed in data signal processing Unit and when this sensor detects oxygen pressure value lower than pre-set value in the system, the buzzer sound is given to technician side and also the information signal is transmitted through wireless monitoring system to monitoring station to display this current information[13].

The recognized gaps in this project are that the system works only using internet to the monitoring station and storing data in the work station. A permanent staff to be at the nearest alarm device is required to hear, and lookout status of oxygen pressure level and react when necessary. If internet is not there the technician will not receive low pressure alarm information and different incidents may be happening.

Another good project named “Centralized Medical Gas Monitoring Solution for Medical Piping Gases in The Hospitals” has also been developed and is also called “Medical Gas Operation Center[14]. It is an integration box to be installed in each site, linked to the gas pressure sensors and is equipped with a proprietary integrated circuit powered by a secure GSM connection, thus allowing it to work from the site’s Internet connection availability. The basic idea was to design a complete system to monitor medical gases in the hospital, collect real-time readings, which are securely uploaded to the cloud, displaying the output pressures on a desktop computer or any smart phone using the internet at any place away from this medical gas stations of the hospital[14].

As gaps recognized, the system has the option of being used only when local area network is available, which means that when there is oxygen low pressure in ICU manifold, it is very difficult to be aware of this event. Other thing that we can say is that this system is much expensive and needs lot of components to fulfill the user requirements.

2.3 Summary

Various previous studies have attempted to address medical oxygen monitoring system problems and management in in hospital settings**.** Thus, as mentioned above**,** numerous gaps have been recognized as not being able to transmit oxygen low pressure alarm information to dedicated staff at the real time, others are built in the way of not being able to be controlled remotely, use of vision and acoustic alarms used in the way that additional and permanent staff is needed to manage those kind of systems, Clinical and biomedical engineering staff is not actually sharing real information of centralized oxygen supply manifold, others don’t have even acoustic, vision panels ,problem of alarm data storage and analysis, and automatic information transmission by internet or phone SMS which is the case of Rwandan hospitals.

Some other advanced systems are so expensive by using lot of components, materials and also while there is no internet above systems cannot work at all.

Therefore, as a contribution this study is more concerning to Rwandan Hospitals. Indeed, IoT-based medical oxygen monitoring system in ICU where improving healthcare service delivery, staff security and patient safety in Rwandan hospitals has been proposed.

CHAPTER 3. RESEARCH METHODOLOGY

3.1. Introduction

This chapter outlines various methods and techniques employed in the gathering, processing, and analysis of data obtained from various respondents in this research. The chapter discusses on research and design approach, scientific research approaches, system development, bloc diagram and data flow diagram of new system, components of proposed system integrated development selection and summary [15].

This chapter presents hardware and software designs, which together make up the overall design of my suggested solution. The identified methodological methods cover both physical designs, which reflect the choice and design of hardware components, and logical designs, which also reflect the choice of software components used in my project design.

3.2 Research and design approach

A summary of the research and system development process is shown in Figure 3.2, from the concept collection stage through prototype and results stage.

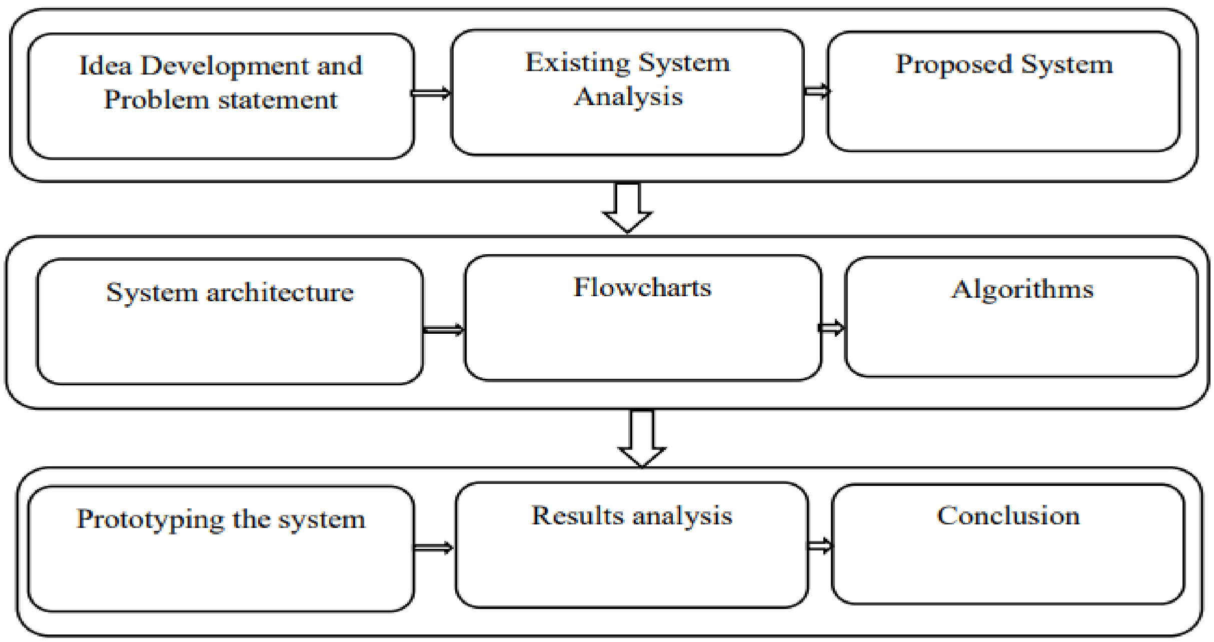


Figure3.2. Research Approach

Firstly, the idea development and problem statement for this research departed from conducting a literature review to identify current problem and limitations of the existing works. After analysis of the existing system and identification of the gaps, we proposed a system to address identified gaps. Secondly, the system architecture, flowcharts, and algorithms for proposed system were made, and finally, we did system prototyping and analyzed the obtained results to conclude[16].

3.3 Scientific research approach

In this research, qualitative research including observation of the existing related projects has been used, and document consultancy by reading journal papers. The goal was to investigate the existing system and to find its merits and weaknesses to find a way to improve it by applying new, innovative and cheapest technology[17] [16].

3.3.1 Preliminary review and analysis of technical and design needs

In this stage, we used questionnaires to collect information from hospital workers in Rwanda who were dealing with the medical oxygen alert in the ICU. A thorough study of the data gathered at this point led to the demands and technical requirements that informed the design of the system enhancements. I was able to learn enough about the current state of the existing medical oxygen alarm systems, how they are utilized, their difficulties, and the need for change thanks to the study I conducted.

3.3.2 Research design

First of all, this study concentrated on gathering qualitative information. We created and revised questions to make sure that they would be effective in obtaining information we needed from Rwandan hospital staff who oversee medical oxygen monitoring systems in ICU O2 centralized Manifold Supply, current systems used, different approaches used to prevent low oxygen pressure presented on the ICU centralized manifold, and different challenges that they face in their daily responsibilities information related to medical oxygen monitoring system and medical oxygen pressure low level alarms.

Respondents were able to provide accurate information based on their knowledge and experiences because the research surveys were nameless. As a result, this enabled us to obtain additional information we need and ensured that the data given accurately represented the state of the current used systems.

3.3.3 Target and study population

There were two types of study participants. Users of medical oxygen monitoring systems made up the research population's first category (Nurses, Doctors, Biomedical Technicians and Biomedical engineers). Users of medical oxygen monitoring systems are hospital staff who work on a permanent basis in ICUs. The medical oxygen monitoring systems in ICUs of Rwandan hospitals were the second target population.

3.3.4 Sample size

During data collection, only 18 medical oxygen monitoring system users and 6 medical oxygen monitoring systems were taken into consideration as samples. The selection of such a sample was influenced by the difficulties encountered during this data collection phase, which were mostly due to financial limitations. As a result, I decided to gather data in locations where it is feasible to do so.

3.3.5 Data analysis

The respondents' knowledge of medical oxygen monitoring systems standards, monitoring instruments, and the current system's quality were assessed using twelve (12) separate questions. Every question included a Yes or No response option, and the final one asked about any additional suggestions the respondent may have had.

The responses obtained demonstrated that all respondents (BIOMEDICAL engineers and technicians, Nurses and doctors) work in ICUs and ICU-related hospitals staff, use centralized O2 wall supply by manifold systems to supply medical oxygen in ICUs. Respondents also indicated that the oxygen pressure level of their employed system is controlled.

According to 66.7% of respondents, the current control system they are using relies on pressure gauges on the manifold as a visual aid, which presents challenges because it necessitates regular moving to the manifold's existing location for pressure gauge maintenance. On the other hand, 33.3% of respondents utilize sound systems as oxygen monitoring alarms, which presents difficulties for them because it necessitates staying near the current sound source in order to be informed about the status of oxygen alarm. The existence of additional risks that are connected to the current difficulties have been also confirmed by 100% respondents.

For overcoming all challenges presented by users of current system, a new system will be developed. Instead of leaving their working place and traveling long distance to check the oxygen pressure level on the manifold pressure gauge and staying near the current alarm sound source for not missing the oxygen alarm sound, a new system is a response of all those challenges. For reaching the objectives, the design of the hardware part of IoT-based medical **o**xygen monitoring system for the ICU, the development of the software to control the system functionality and integration of hardware parts with software, to make the system that is based on user requirements will be done. By the end, the proposed system will be tested for its functionality. The developed software, oxygen pressure and color sensors together with GSM will allow users to control and receive low oxygen pressure level alarms remotely wherever they are.

Considering the current system, the new system will transmit information quickly and the intervention will be done in shortest time, also the information storage will be another new system improvement. Thus, the new system will be beneficial to users in their day-to-day operations and will be able to enhance the provision of healthcare services at their health facilities, according to Figure 4.38 and 4.39.

3.4 System Development

In the context of research methodology, software development life cycle is a prototyping model with a system development method (SDM) in which a prototype is built, tested, and then reworked on as necessarily until an acceptable prototype is finally achieved from which a complete system or product can now be developed [18]

The System Development Method employed includes the following steps**:**

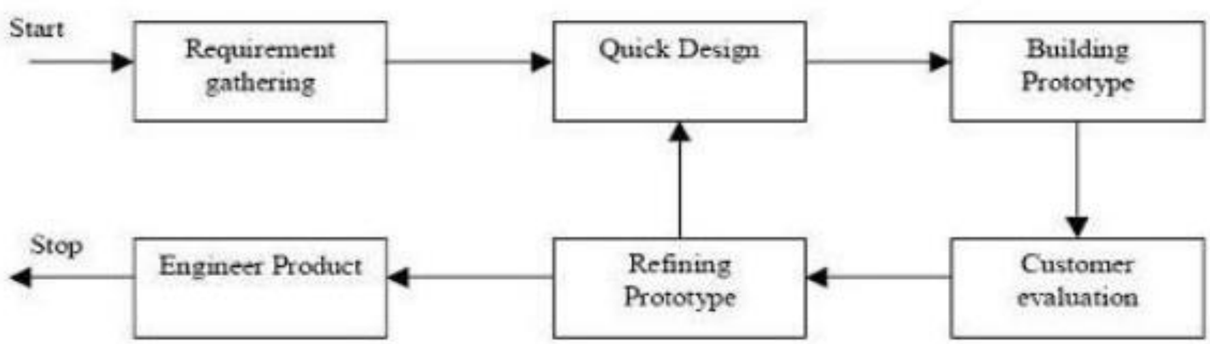


Figure 3.3 System development model adapted from

For my research project, two blocks have been adopted, namely requirements gathering, analysis, and building prototype according to the Figure 3.3.

In order to obtain the necessary information, we first went to Rwandan hospitals with ICU hospitalization units and looked into how the present medical oxygen alarms on Centralized supply manifold are used, running from the time the oxygen pressure drops until the action is taken. We looked at the current system's conditions through observation and questionnaires, and we studied a variety of publications, particularly [13] those that were pertinent to my research, in order to analyze the data we collected.

After all steps, prototyping as one of the most critical activities in new product development has been started which is the main key that play an important role in my product development from the requirement gathering up to the final product [19]. By monitoring oxygen pressure low level in ICU centralized manifold and generating phone alarm by SMS and call, a system with three main parts namely oxygen source, sensing devices (Sensors), controlling part (Microcontroller) with alarm transmission to dedicated receivers has been thought on.

3.5 Block diagram of the system developed

A block diagram is a system diagram in which the main components or functions are represented by blocks linked together by lines that highlight the connections between the blocks.

The system design is illustrated by Figure 3.4

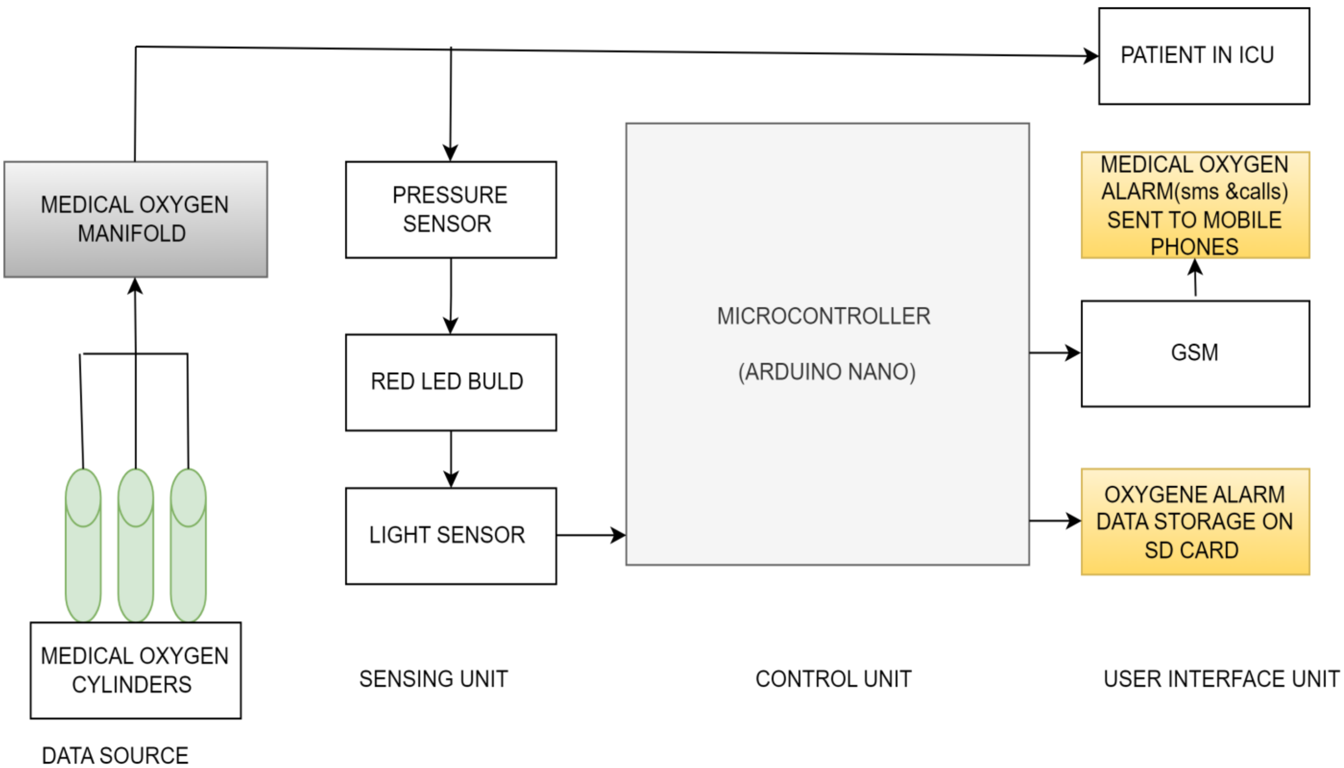


Figure 3.4 Block diagram of proposed system

Depending on the cost, availability and system component compatibility the analogue pressure sensor has been used to read the oxygen pressure level. As the output signal of oxygen pressure sensor is analogue (light), the light sensor detects and converts analogue signal into digital signal for being processed in the microcontroller.

3.6 System functional algorithm

The functional algorithm is a set of instructions for carrying out certain tasks while taking into consideration the relationship between inputs and outputs, where each input results in exactly one output and this algorithm is set to solve a general, well-specified problem[20].

As presented in Figure 3.5, the functional system medical oxygen monitoring system ICU starts by checking oxygen pressure level of the oxygen cylinders installed on the central supply manifold. After reading pressure level, when it finds that the pressure is above 20 bars no alarm is generated.

The time when it finds the oxygen pressure equal or below to 20 bars the color sensor reads the red-light color from the bulb, and after signal processing, depending to the microcontroller processing instruction, the alarm signal is generated. After that, the information generated is stored in SD card for farther view and analysis and Global System for Mobile communication **(GSM)** transmits SMS alarm and call to a biomedical engineer, and a clinical staff member for information and reaction to the action required to save ICU patient.

3.7 Flowchart of the designed system

In data flow diagram is the highest-level view of the system and is known as context diagram.

According to Figure 3.5, data flow diagram in this system's architecture shows how information moves via a process or system. Data inputs, outputs, data repositories, as well as the multiple subprocesses that the data goes through are also included. Certain established symbols and notation are used to describe a variety of elements and their relationships [21].

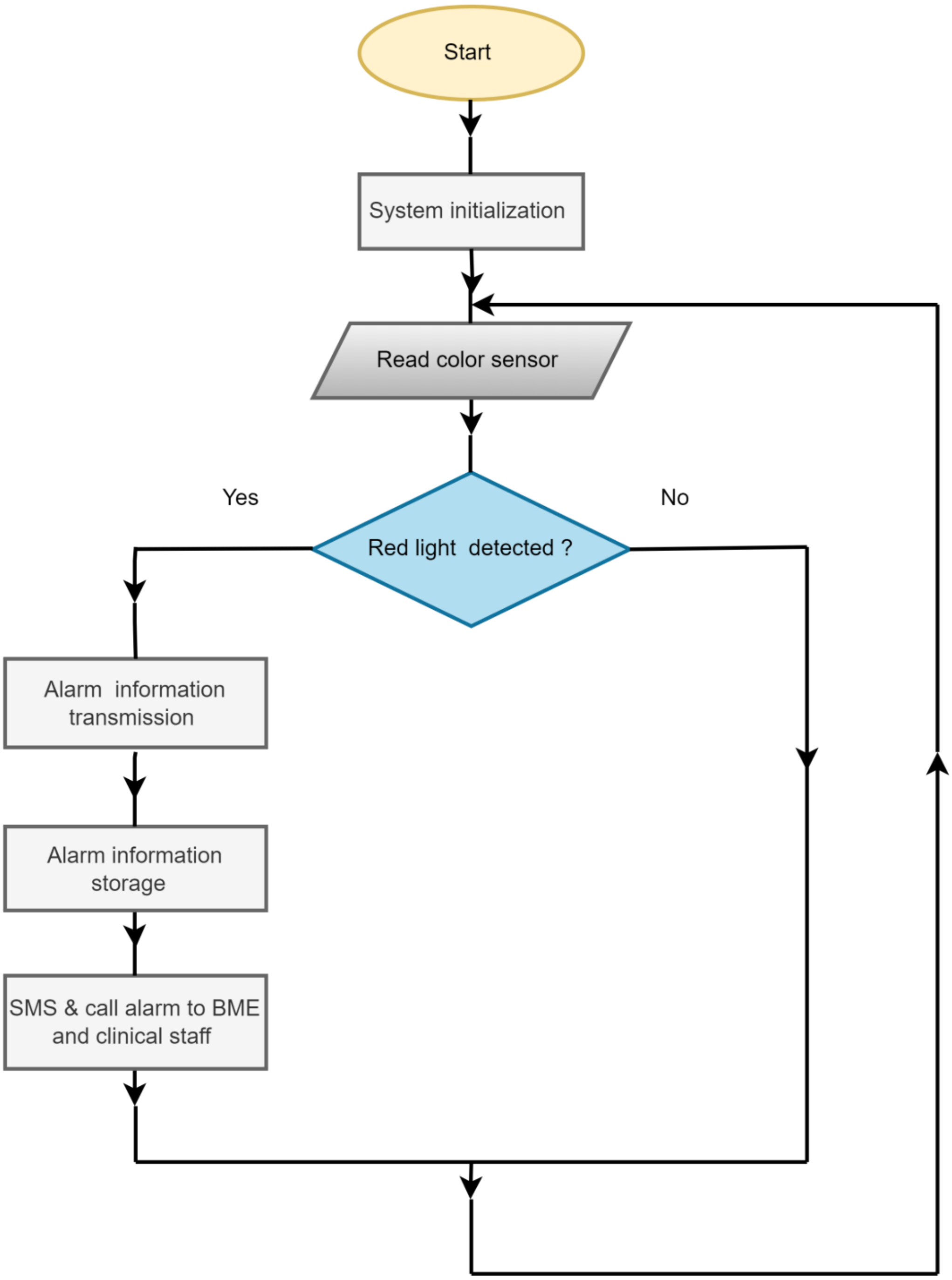


Figure 3.5 Flowchart of the designed system

3.8 Components of the proposed system

For the designed system to be able to provide the most effective way of monitoring medical oxygen pressure being supplied by centralized manifold, the project is made by combination of hardware system and software system. As the Figure 3.5 shows, low oxygen pressure alarm is sent through SMS (Short Message Service) and call to biomedical engineers and selected clinical staff. The necessary hardware parts for the prototype consist of the following materials:

N^{O}	MATERIALS	QUANTITY
1	Oxygen manifold	1
2	Oxygen pressure sensor	1
3	Electrical cable (2.5 mm2)	5 m
4	Electrical L bulb	1
5	Bulb socket	1
6	Color Sensor	1
7	Microcontroller	1
8	GSM Module	1
9	SD card	1
10	3D box	1
11	5v DC charger (USB PORT)	1
12	PCB board and accessories	1
13	Software coding and installation	1

Table 3.1 List of materials comprising the system

3.8.1. Used hardware

Oxygen central manifold

It is utilized to provide a continuous flow of medical gas to a pipeline system in a medical facility. Figure 3.6 shows an image of a typical central oxygen supply manifold.

Figure3.6: Central Oxygen supply Manifold

Oxygen pressure sensor

This pressure sensor has the role of sensing any lowest pressure of oxygen supplied from central manifold.

Electrical cable (2.5 mm^2)

This is the electrical cable that is used to supply the light generator after lowest oxygen pressure on the manifold is reached.

Electrical Red LED bulb

This is the 5W electrical light bulb that generates light once the once lowest oxygen pressure on the manifold is reached.

Bulb socket

To insure connection of pressure sensor and the LED bulb.

TSC3200 Color Sensor

Is a type of "photoelectric sensor" which emits light from a transmitter and then detects the light reflected back from the object detected.

The TCS3200 and TCS3210 programmable color light-to-frequency converters that combine configurable silicon photodiodes and a current-to-frequency converter on a single monolithic CMOS integrated circuit. The output is a square wave (50% duty cycle) with frequency directly proportional to light intensity.

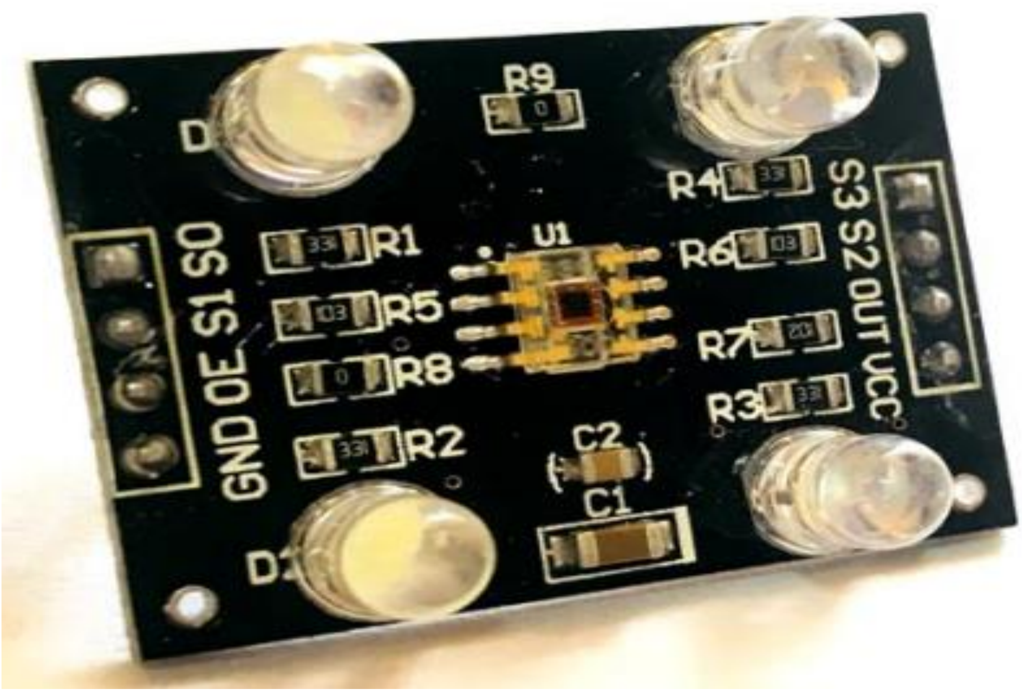


Figure 3.7 TSC3200 color sensor

TSC 3200 color sensor

It is Programmable Color and Full-Scale Output Frequency

• Communicates Directly with a Microcontroller

• Single-Supply Operation (2.7V to 5.5V [22] [23].

Microcontroller

A Microcontroller is a programmable digital processor with necessary peripherals. Both microcontrollers and microprocessors are complex sequential digital circuits meant to carry out job according to the program / instructions given. A microcontroller can be compared to a Swiss knife with multiple functions incorporated in the same Integrated Circuits [24].

During prototyping of this project this microcontroller ATmega328 has been used and is the heart of the system and is programmed using Arduino NANO [25][26]. The data from used sensors are its input signal and after being processed the output signal is sent to the GSM for sending current information to the receiver and to SD CARD for storage and analytics.

Figure 3.8 Microcontroller ATmega328

SIM900A GSM Module

It is second generation cellular standard generated to cater voice services and data delivery using digital modulation[27]. Modem is SIM900A Dual-band GSM / GPRS device, works on frequencies 900 MHZ and 1800 MHZ. It is very compact in size and easy to use as plug in GSM Modem. The Modem is designed with 3V3 and 5V DC TTL interfacing circuitry, which allows the user to directly interface with 5V Microcontrollers (PIC, AVR, Arduino, 8051 etc.) as well as 3V3 Microcontrollers (ARM, ARM Cortex XX, etc.) [28]. In my project SIM900A GSM Module has been used[29].

Figure 3.9 SIM900A GSM Module

3D box

It is a smart box that is used to cover and protect the control and transmission circuit of this project.

Printed circuit board

This board essential in connecting different components and allowing for communication between them. Additionally, PCBs help protects these components from damage and interference.

3.9 Integrated Development Environment Selection

Across-platform program the Arduino Integrated Development Environment (IDE) is also include as an official software introduced by Arduino.cc, that is mainly used for editing, compiling and uploading the code in the Arduino Device. Almost all Arduino modules are compatible with this software that is an open source and is readily available to install and start compiling the code on the go [30]. The boards feature serial communications interfaces, including USB on some models, for loading programs from personal computers. For programming the microcontrollers, the Arduino project provides an integrated development environment (IDE) based on the Processing project, which includes support for the C and C++ programming languages[31].

The Arduino board must be programmed using the Arduino IDE open-source software. Sketch is the name of the program created with the Arduino IDE. It has been used in this study too bulk.

3.10 Summary

This chapter starts by the introduction of the research methodology, research design and approaches used to conduct this research, scientific research approach used up to the physical components and software selected for the new system design. Indeed, selected physical and software components have been chosen depending on flexibility and compatibility between them in order to fulfill the targeted objectives and user requirements as they have been expressed while I was conducting this research. Considering the new system and current one, it has been realized that there is a significant discrepancy between them. Considering the new system design, it is done in the way to give solutions to the problems caused by the current used one as show by the respondents.

In fact, during my research journey, it has been realized that Rwandan hospitals with ICUs now employ advance less old system to monitor oxygen low pressure on ICU oxygen manifold centralized supply, such as visual and acoustic systems which do not facilitate hospital staff in their working process.

I also learned that the hospital staff who provide healthcare services in the intensive care unit (ICU), biomedical engineers and technicians are dissatisfied with the alarm systems currently in use. They listed various difficulties and associated risks produced by current medical oxygen monitoring systems and emphasized the need for a new advanced, reliable, and trustworthy medical oxygen alarm system in their responses 9, 10, 11, and 12.

CHAPTER 4. THE PROJECT RESULTS FROM SIMULATION AND IMPLEMENTATION

4.1 Introduction

This research project's prototype design is made up of a number of hardware and software components. Nevertheless, this chapter provides a summary of the system architecture that was developed for this investigation. It offers details on the creation of the new medical oxygen monitoring system and its use in ICU settings. The architecture of the upgraded new medical oxygen monitoring in ICU situations basically refered to previously utilized structures. These include the structure of the control unit, the database, the user interface, and wireless communication structure. The paragraphs that follow provide a description of the prototype design model block diagram.

4.2 Prototype design

According to the new system's prototype design model, the improvement in medical oxygen alarm in ICU and monitoring of low oxygen pressure level in ICU centralized Manifold of O2 supply are made by a microcontroller as a fundamental component. The low oxygen pressure data were gathered by several sensor nodes and input into the microcontroller of the circuit. After data processing, an accurate and better monitored alert signal was produced, sent to designated receivers (clinical staff and Biomedical Engineer), and is also stored on SD card disk.

Figure 4.10 shows the full organizational shape of my designed system as it is shown below:

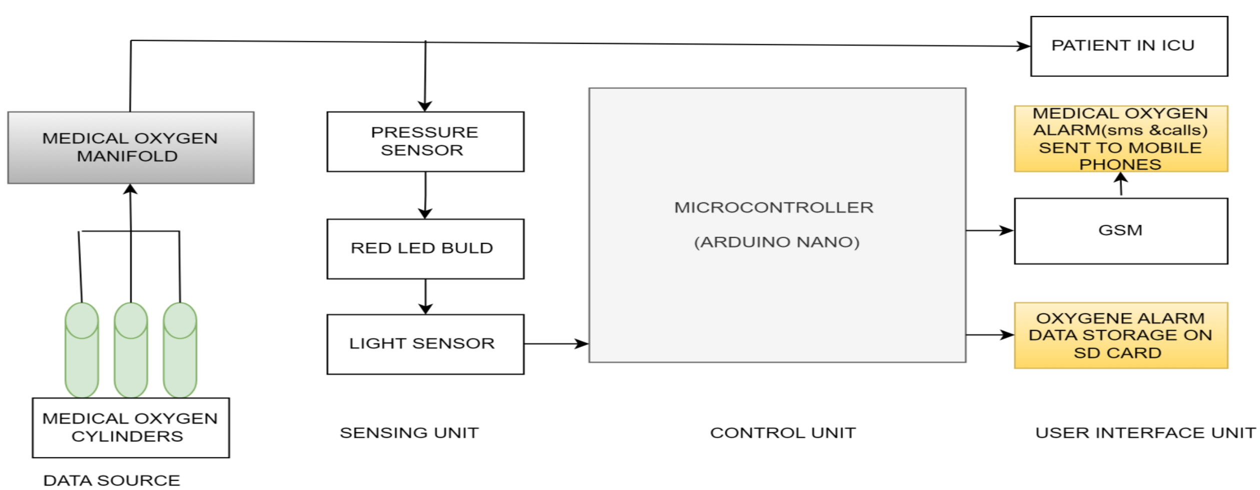


Figure 4.10 Block diagram of improved medical oxygen alarm system in ICU Hospitalization

As Figure 4.10 shows, functional system of IoT-based medical oxygen system in ICU starts by checking oxygen pressure level of the oxygen cylinders installed on the central supply manifold. After reading the pressure level, when it finds that the pressure is above 20 bars no alarm is generated. The time when it finds the oxygen pressure equal or below to 20 bars the color sensor reads the red-light color from the bulb, and after signal processing, depending to the Microcontroller processing instruction the alarm signal is generated. After that, the information generated is stored in SD card for farther view and analysis and Global System for Mobile communication **(GSM)** transmits SMS and call alarm to BME and clinical for information and reaction to the action required to save ICU patient.

4.3 Prototype results

After system prototyping to be processed, different system tests have been processed and different system results have been gotten as presented in the Figures 4.11 up to 4.18.

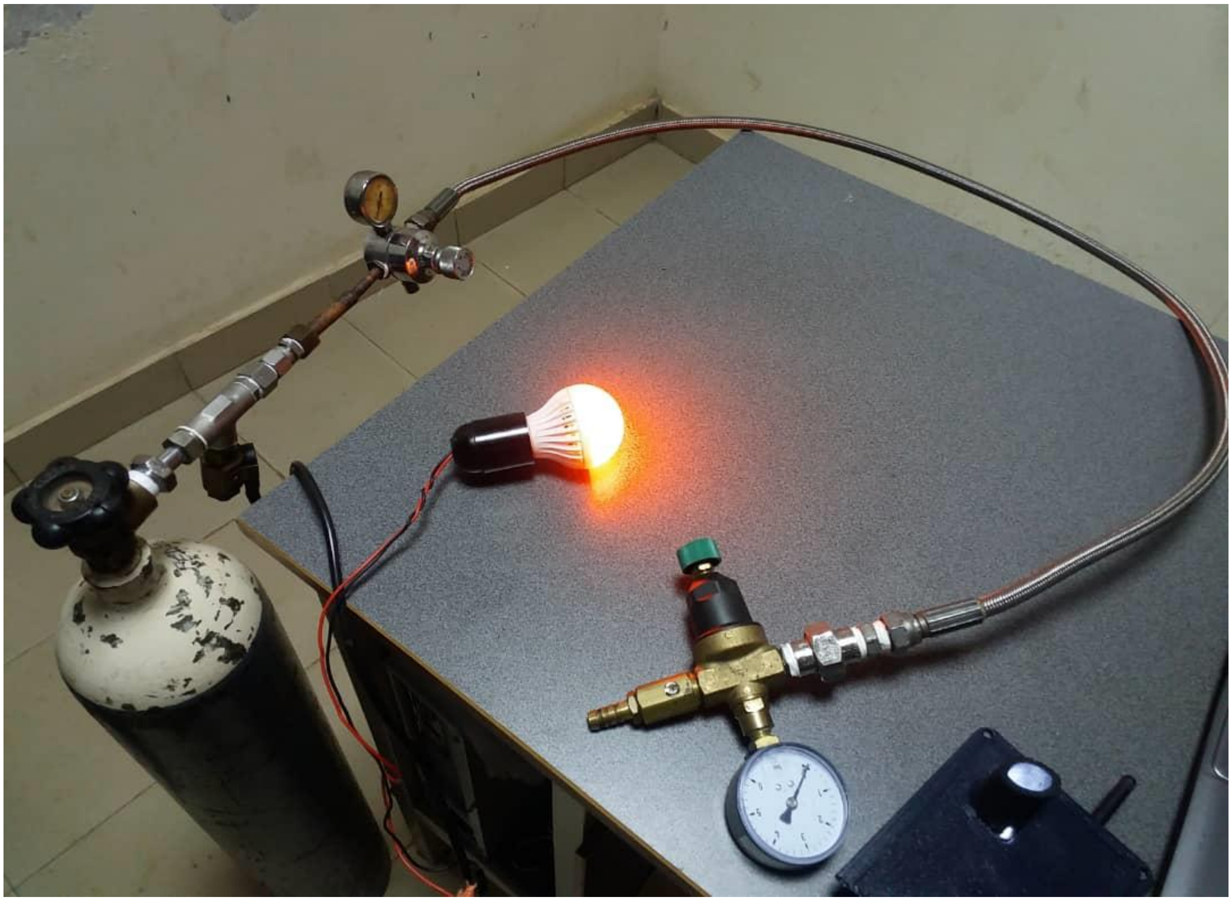


Figure 4.11 Prototype and testing of medical oxygen low pressure sensing unit.

Figure 4.11 shows how the device is prototyped from the oxygen cylinder up to the red bulb ON as sign of oxygen low pressure on the manifold.

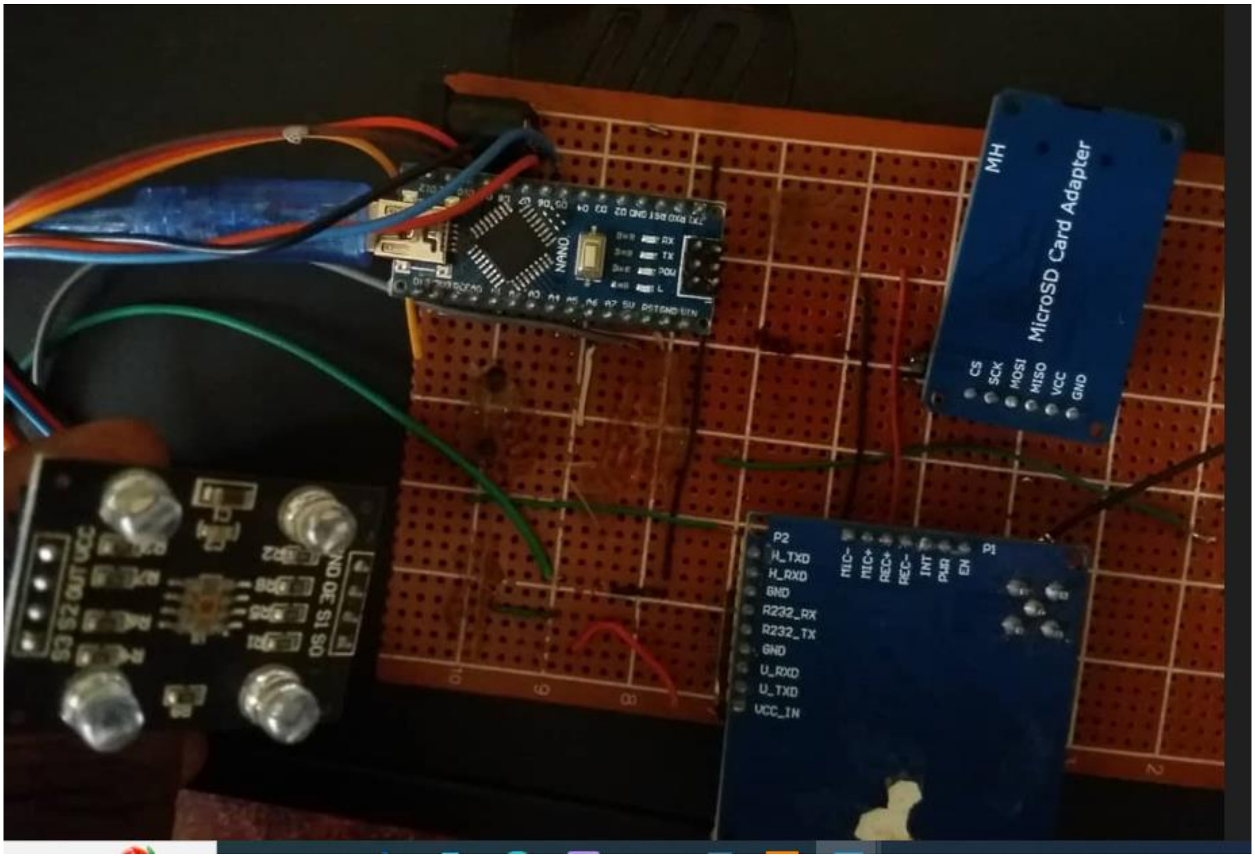


Figure 4.12 Control system components assimbling

Figure 4.12 show the control system assembling while device prototyping process

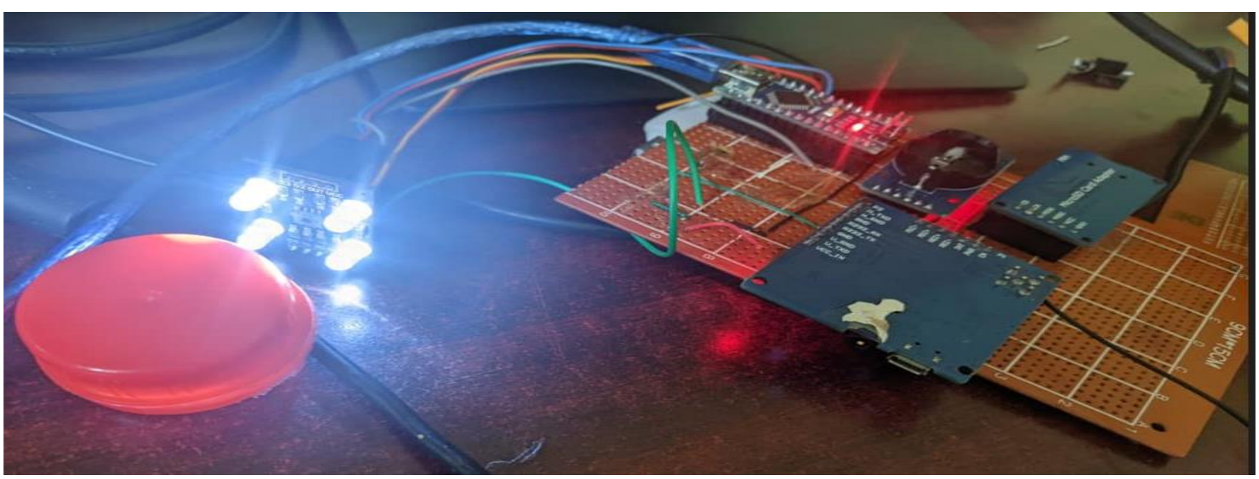


Figure 4.13 control system test on 5v DC

Figure 4.13 show the control system that was tested and supplied by 5v dc in device prototyping process.

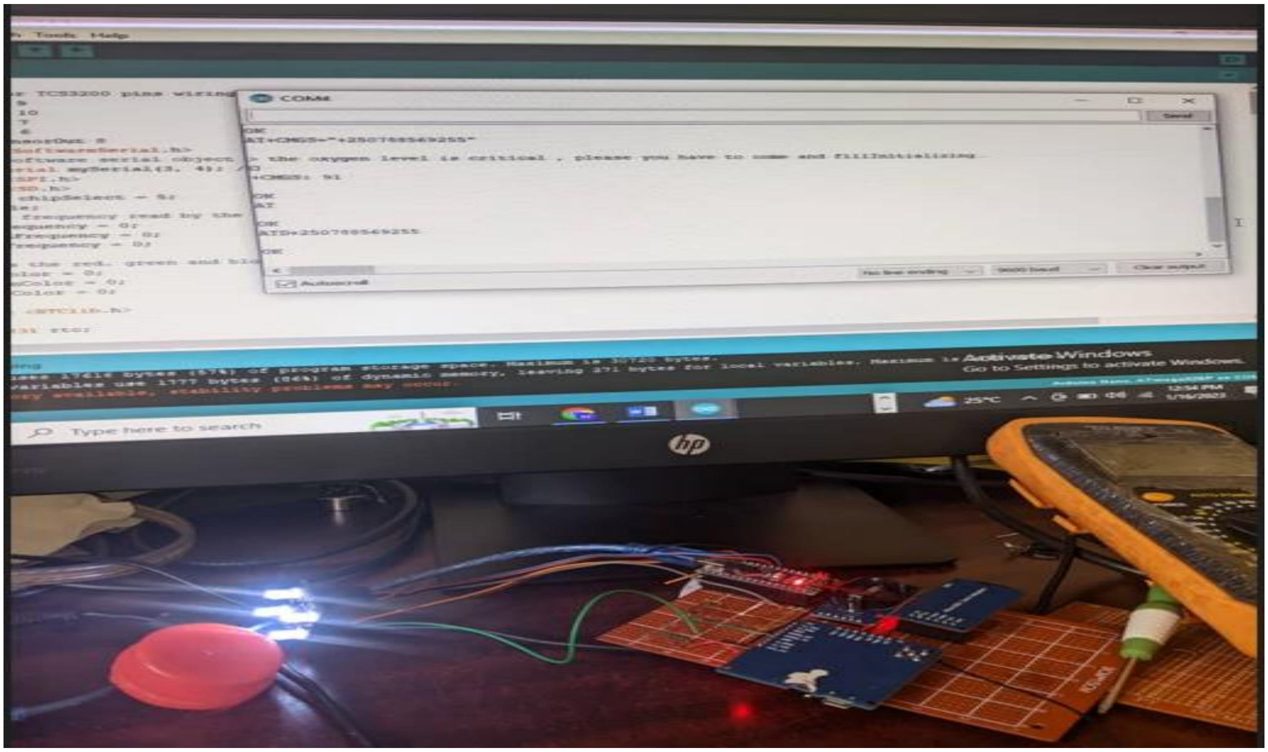


Figure 4.14 control unit testing using the developed programing codes

Figure 4.14 show the control system was tested using the developed programing codes on red color components

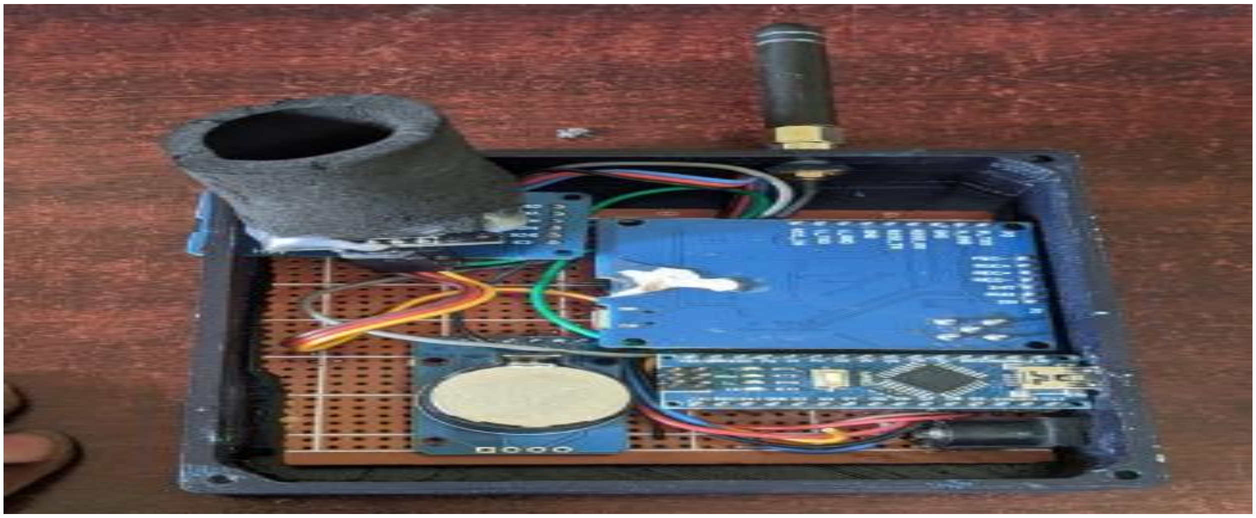


Figure 4.15 control system cuvering process

Figure 4.15 show the control system covering process with 3D box

Figure 4.16 Control system boxing

Figure 4.16 show the control system well covered with 3D box.

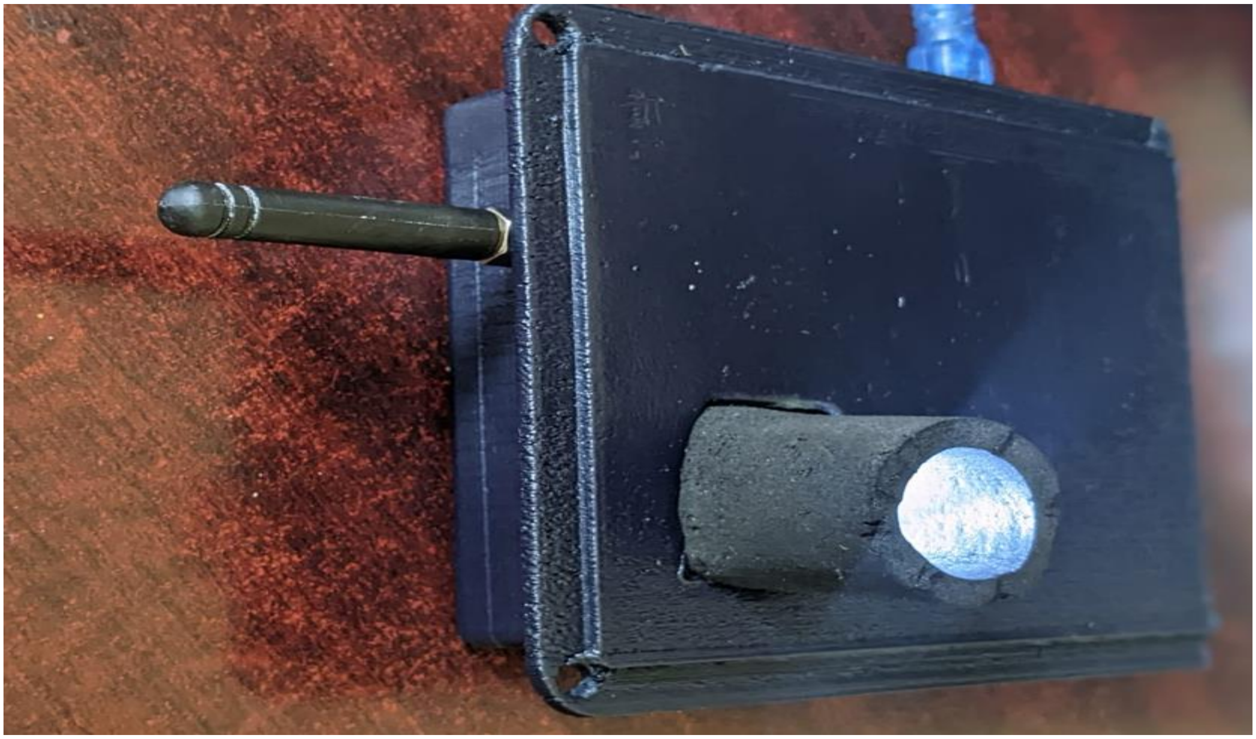


Figure 4.17 color sensor and control system ON an covered in 3D box

Figure 4.17 show the control system ON and well covered with 3D box.

Figure 4.18 Entire functional circuit of IoT based medical oxygen monitoring system in ICU

Figure 4.18 show the entire prototyped system with the program running but the light is not On, and bulb is placed in the way that the light sensor can detect the light once pressure is low.

Working principle of prototiped system

The system has two different power supplies, the one of 220 V AC that supplies the oxygen pressure sensor to monitor the oxygen pressure level with the LED bulb , and 5v dc that supplies the data processing and control unit as the Figure 4.18 shows. As the role of this system, after realizing that the pressure of cylinders on the manifold is below or equal to 20 bars the oxygen pressure sensor switches ON the red LED bulb for the red-light presence, then, color sensor reads the red-light color as the Figure 4.20 shows, and after signal processing, depending to the microcontroller processing instruction the alarm signal is generated as presented in the Figures 21 and 22.

After that, the information generated is stored in SD card for farther view and analysis as Figure 25 and 26 show and Global System for Mobile communication **(GSM)** transmits SMS alarm to biomedical engineer and clinical as presented in the Figure 4.28. After sending SMS the system also calls the BME twice and clinical staff or highlighting the alarm transmitted previously and reminding them to react to the action required to save ICU patient life as the Figure 4.28 shows.

The cycle process of storing information on SD Card, sending 2 SMS and 3 calls (2 for BME and 1 for ICU clinical staff) takes 30 seconds.

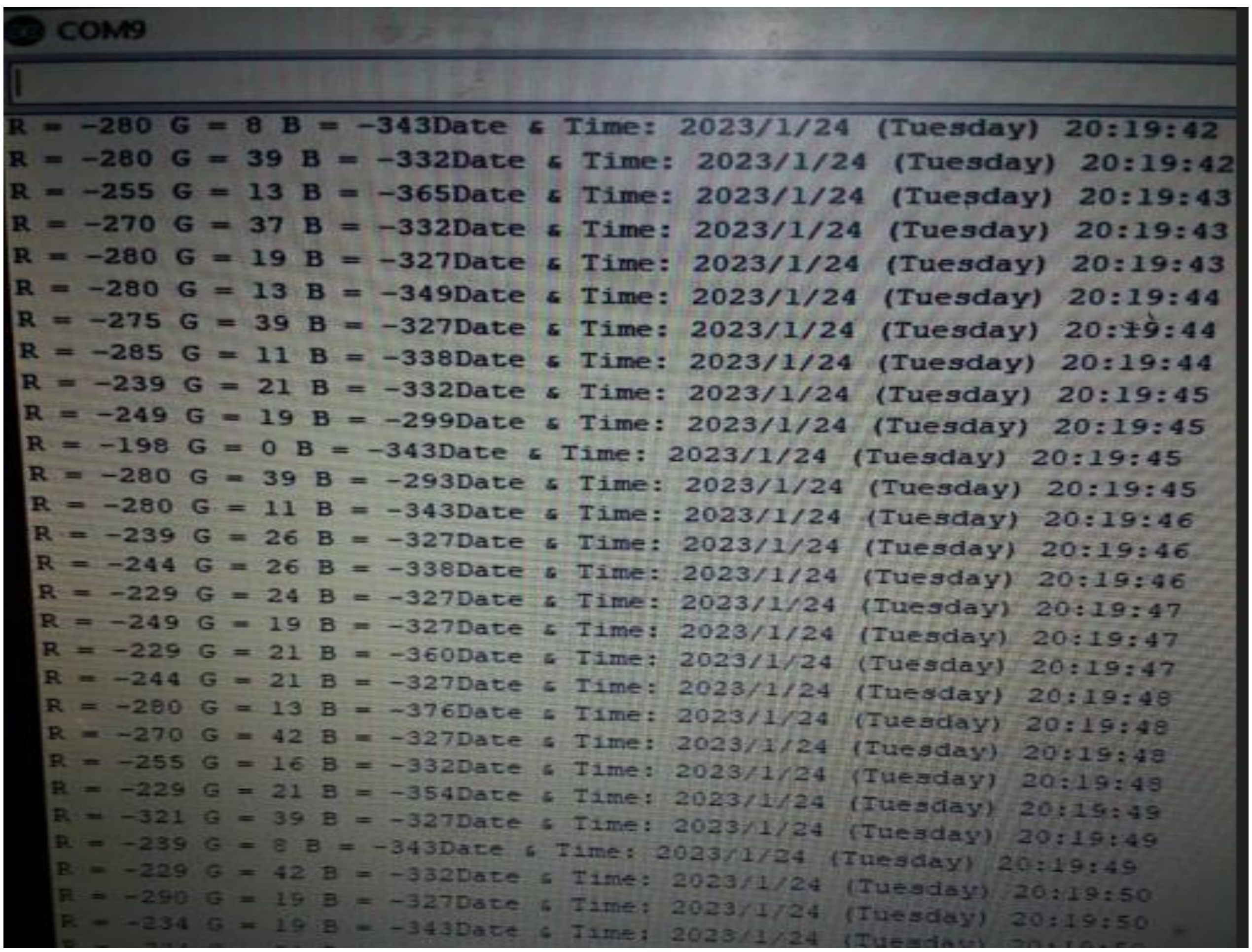


Figure 4.19 The system runs normally before detecting oxygen low pressure

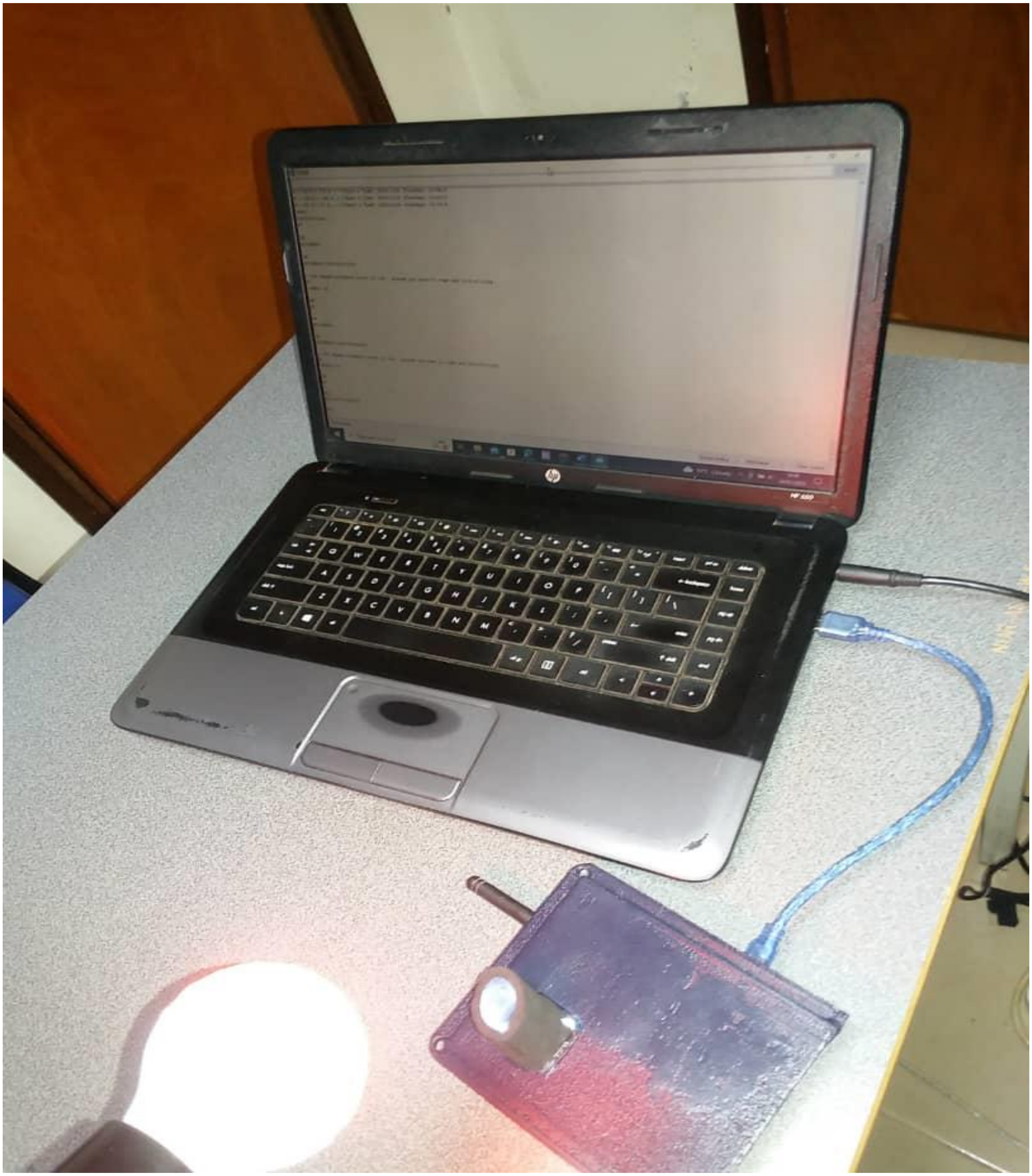


Figure 4.20 The light sensor connected to the control system detects red light (O2 low pressure)

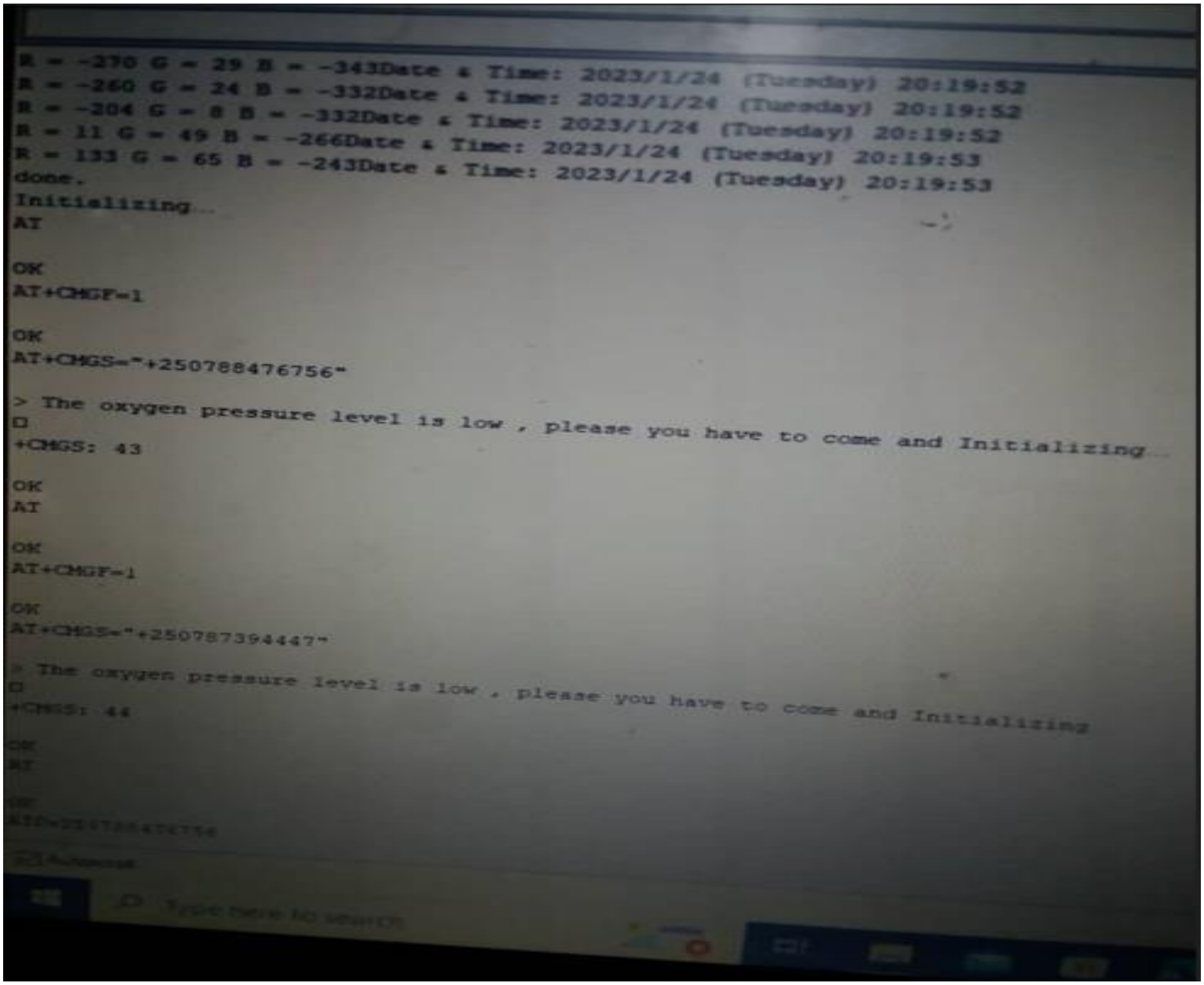


Figure 4.21 GSM sends Mobile SMS to BME and clinical staff

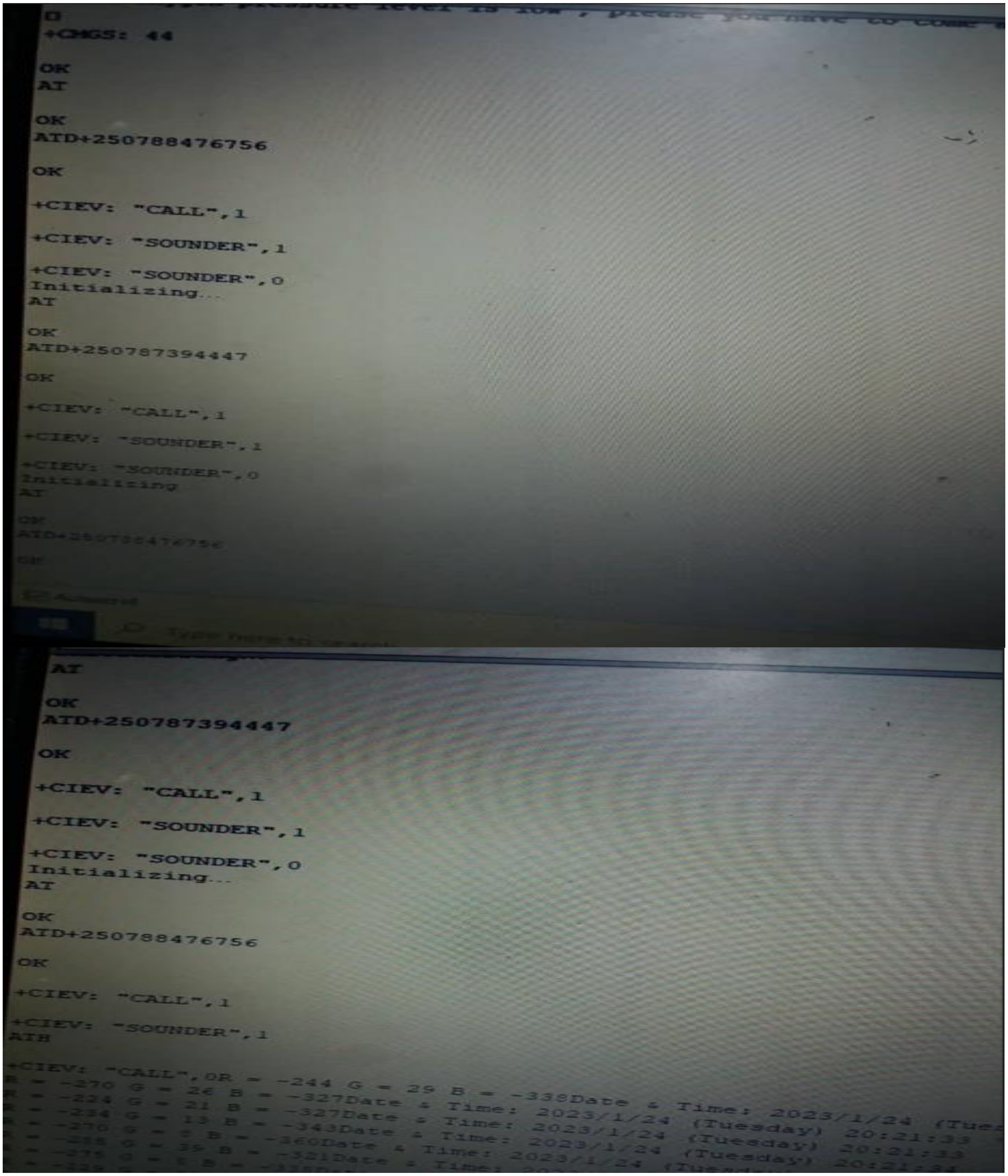


Figure 4.22 GSM is calling BME(tuice) and Clinical staff for action required

4.3.1 Data sensing structure

The real-time monitoring of medical oxygen on centralized manifold in ICU is the primary objective of this improved medical oxygen alarm system in ICU setting. Different sensors such as oxygen pressure sensor and light sensor have been used to reach the objectives of this Thesis.

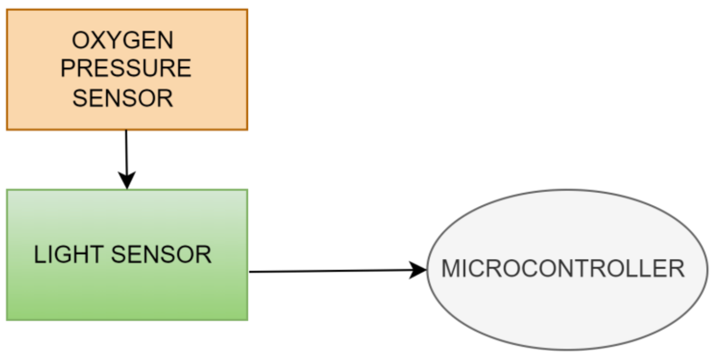


Figure 4.23 The oxygen pressure sensor, colour sensor connections to the microcontroller

The oxygen pressure sensor and colour sensor that is connected to the microcontroller, together are among the main components of this prototyping work as the Figure 4.10 shows. As the output signal of oxygen pressure sensor is analogue (light), the color sensor detects and converts analogue signal into digital signal for being processed in the microcontroller and delivering convenient output response.

4.3.2 Schematic connection of medical oxygen monitoring system control circuit

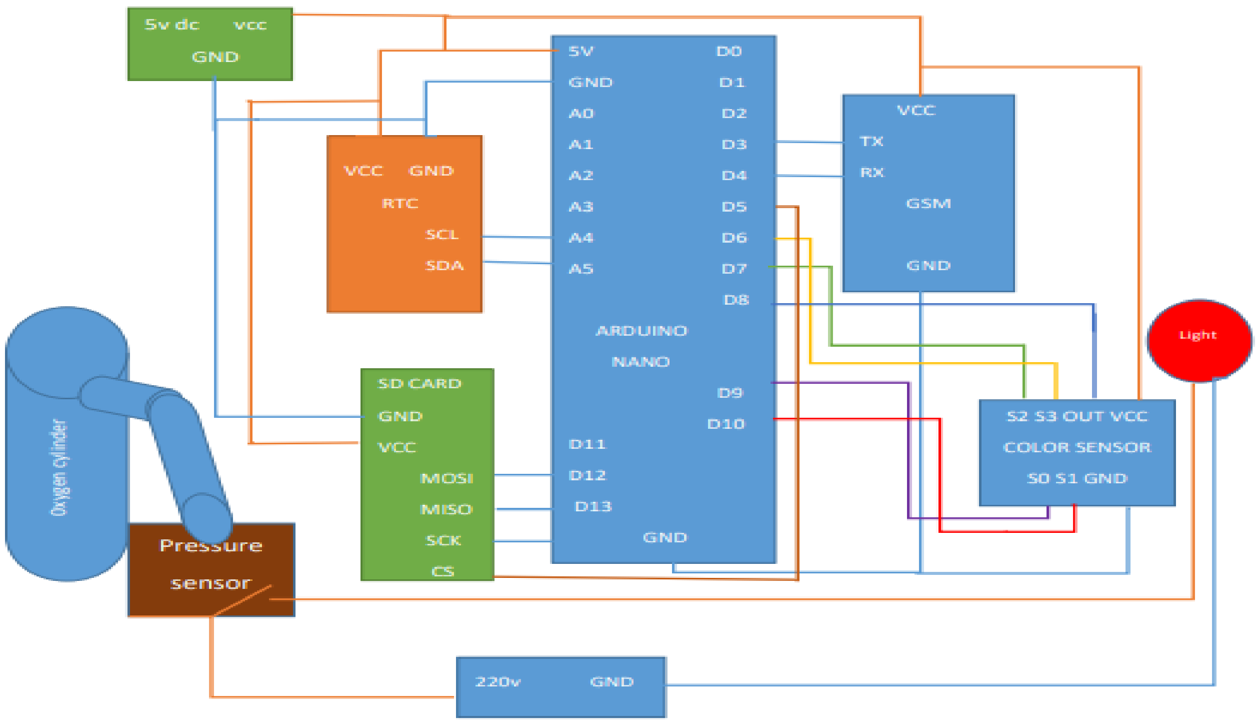


Figure 4.24 Schematic connection of medical alarm system control circuit

Working principles

Color Sensor Module has 4 LEDs with **TCS3200** Color Sensor IC.

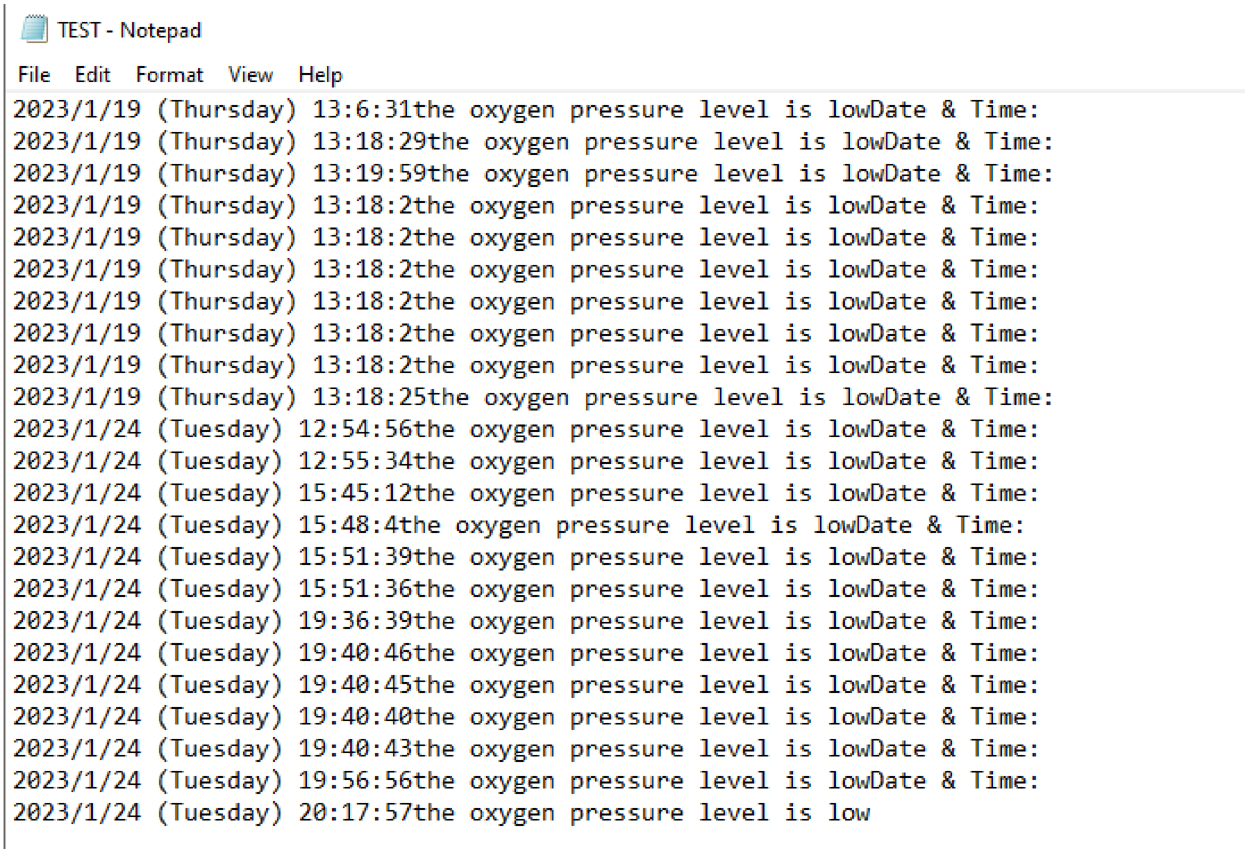
Module is designed in such way that 4 bright LEDs will light the object after oxygen low pressure level detection and reflections from that red bulb will strike the **TCS3200** Color Sensor IC to detect the color of an object. When oxygen pressure level is below 20 bars the re LED light is ON, the color sensor detects the reflection of led color and send the signal to the controller and after GSM sends SMS and calls to concerned stat. Microcontroller is the heart of the circuit and has the purpose of making analysis and deciding what to do based on the program stored inside it as shown by Figure 4.24.

4.4 Other Prototype results

*TEST - Notepad
File Edit Format View Help

```
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:5:32
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:6:48
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:8:6
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:8:5
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:11:9
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:11:3
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:25:21
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:52:20
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 19:54:58
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 20:0:55
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 20:0:57
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 20:0:55
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 20:8:3
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 20:12:52
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 20:21:15
the oxygen pressure level is low
Date & Time: 2023/1/17 (Tuesday) 20:35:9
```

Figure 4.25 First image of information stored on SD Card



TEST - Notepad

File Edit Format View Help

2023/1/19 (Thursday) 13:6:31the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:29the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:19:59the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:2the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:2the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:2the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:2the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:2the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:2the oxygen pressure level is lowDate & Time:
2023/1/19 (Thursday) 13:18:25the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 12:54:56the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 12:55:34the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 15:45:12the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 15:48:4the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 15:51:39the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 15:51:36the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 19:36:39the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 19:40:46the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 19:40:45the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 19:40:40the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 19:40:43the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 19:56:56the oxygen pressure level is lowDate & Time:
2023/1/24 (Tuesday) 20:17:57the oxygen pressure level is low

Figure 4.26 Second image of information stored on SD Card

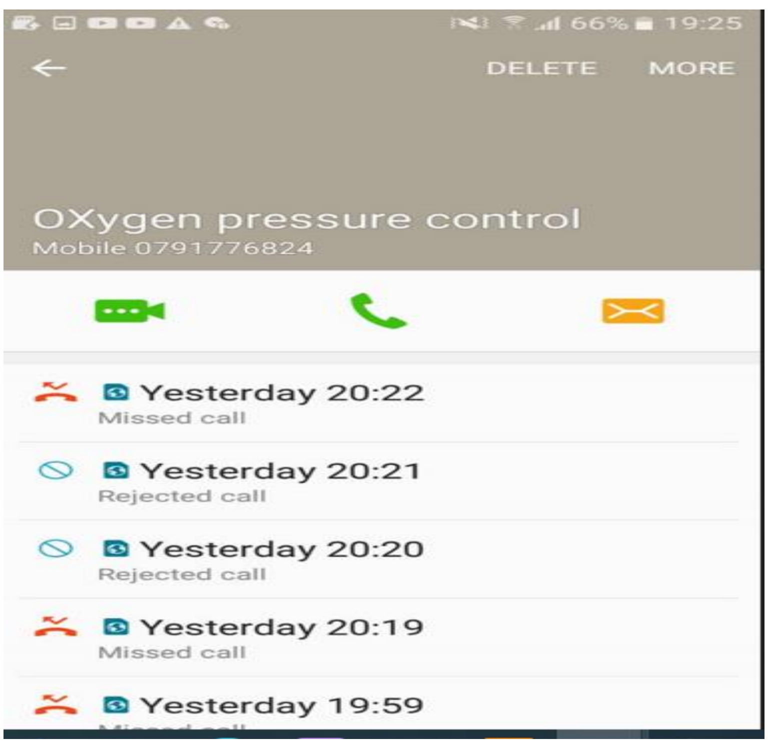


Figure 4.27 Image for missed call from GSM used number in case of O_2 low pressure

After oxygen monitoring and realizing oxygen low pressure on the manifold, GSM send 2 mobile SMS as alarm on 2 staff registerd in the system which says that:" ***The oxygen pressure level is low , please you have to come and fill the oxygen pressure at maximum for avoiding ICU patients risks***". The image here below shows mobile phone SMS received as alarms, on one of receivers' Mobile phone.

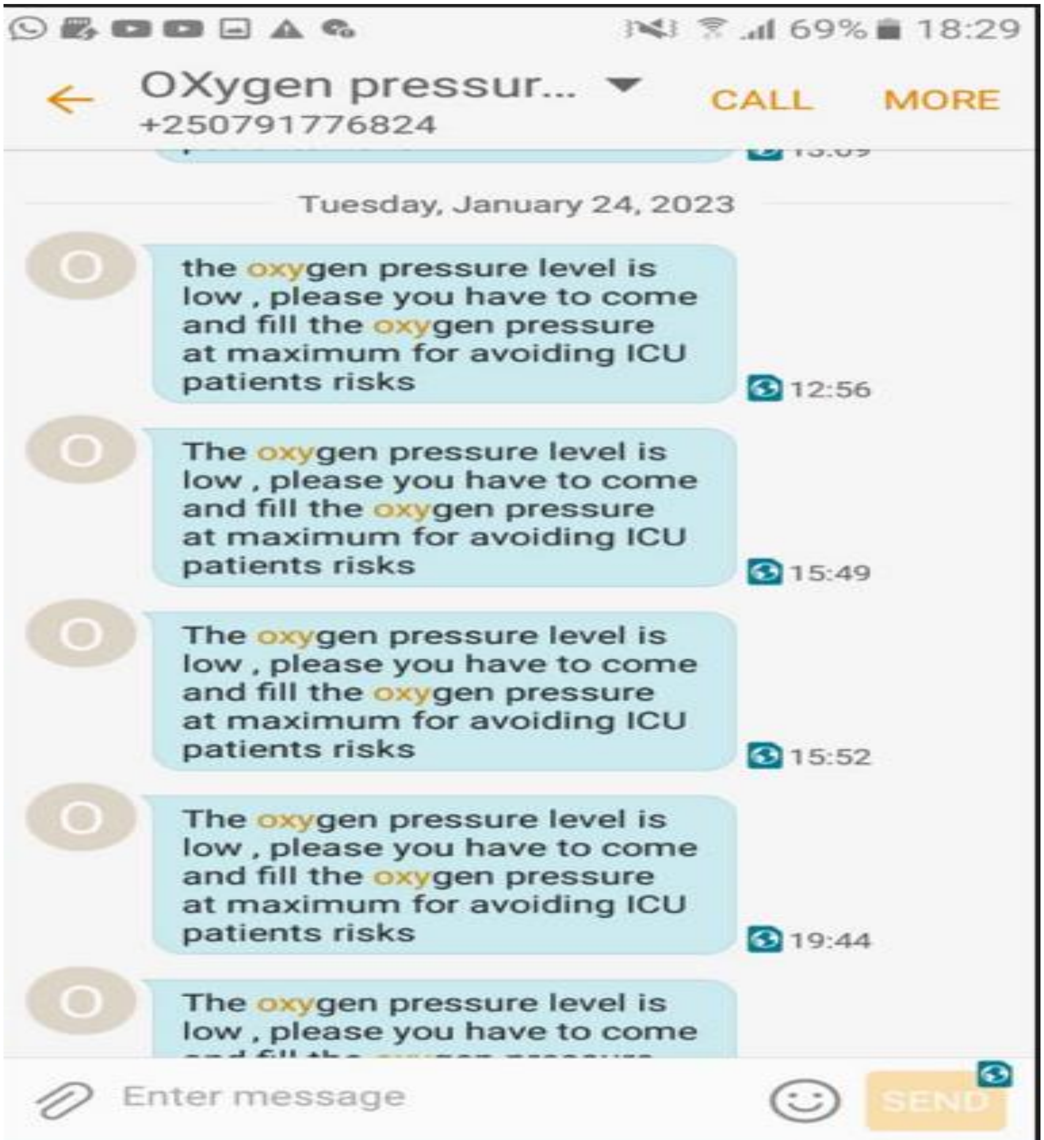


Figure 4.28 Mobile phone SMS sent to BME/BMET and clinical staff after O2 low pressure detection

4.5 Summary

This research project's prototype design is made up of a number of hardware and software components. Nevertheless, this chapter provides a summary of the system architecture that was developed for this investigation. It offers details on the creation of the new medical oxygen alarm system and its use in ICU settings.

Various potential impacts of this research successfulness to the society have been identified such as:

- Show the correct and affordable way to manage medical oxygen pressure level on centralized oxygen distribution manifold system in ICU;
- Provide better management of medical oxygen alarm data generated periodically;
- Reduce professional conflict between clinical staff and biomedical engineering staff;
- Reduction of frequent interruption of centralized oxygen flow to Patients of ICU;
- Reduction of ICU Patients injuries related to frequent oxygen interruption due to uncontrolled oxygen low pressure level;
- Population’s better health due to qualitative healthcare services delivery;
- Increase health financing and support health workforce in developing country.

CHAPTER 5. CONCLUSION AND RECOMMANDATIONS

5.1 Conclusion

The results of this study's data collection and analysis revealed that the medical oxygen monitoring systems now in use, particularly in Rwandan hospitals with ICU settings, have significant functional weaknesses.

The availability of newly created, highly modern IoT based medical oxygen monitoring system and their innovative technology shown their capacity to address the issues with present systems utilized in Rwandan ICU hospital settings. The proposed IoT based medical oxygen monitoring system can detect any oxygen pressure level and produce alarm when detected pressure is equal to or lower than 20 bars. This signal is identified as low oxygen pressure, and the involved staff are informed by phone SMS and call the situation of O2 pressure level, so they can take appropriate action before the ICU's minimal (0) O2 pressure level is achieved.

When using the manifold as the major source for oxygen, especially in the clinical area, WHO advises employing an alarm to let nurses and clinicians know when they are running low on oxygen[32].

Beyond WHO's recommendation the new system is able to disseminate information without forgetting the hospital biomedical engineer /biomedical technician and store all alarm events for further analysis and decisions. This new system shows the ability to overcome all problems presented by current medical oxygen alarm system used, improve healthcare service delivery, clinical and biomedical engineering researches on medical oxygen alarm system.

5.2 Recommendations and future work

For improving patient safety and hospital staff safety security, oxygen alarms data storage analysis and reporting in general, we recommend the Ministry of Health of Rwanda to use this medical oxygen alarm in ICUs of Rwandan hospitals.

- It is advised that future researchers to develop a hybrid system that can send double notifications by email, SMS and on display objects to increase the number of options for receiving information about medical oxygen alarms in ICU.
- The future researchers also have to work on medical oxygen monitoring in other clinical department like neonatology and accident& emergency department focussing in monitoring medical oxygen alarm on high pressure level of oxygen.

- The future researchers also have to use digital pressure sensor to link directly the manifold to the microprocessor and monitor continuous level of oxygen pressure in manifold cylinders.

REFERENCES

[1] D. K. Rose, R. J. Byrick, M. M. Cohen, G. M. Caskennette, and K. K. Tan, “Postoperative Ventilation,” *Anesthesiology*, vol. 81, no. SUPPLEMENT, p. A324, 1994, doi: 10.1097/00000542-199409001-00323.

[2] B. R. O’driscoll and R. Smith, “Oxygen use in critical illness,” *Respir. Care*, vol. 64, no. 10, pp. 1293–1307, 2019, doi: 10.4187/respcare.07044.

[3] National Institutes of Health, “Treatment Guidelines Panel. Coronavirus Disease 2019 (COVID-19),” *Nih*, vol. 2019, pp. 1–243, 2021, [Online]. Available: https://www.covid19treatmentguidelines.nih.gov/.%0Ahttps://www.covid19treatmentguidelines.nih.gov/.

[4] “Central oxygen pipeline failure by Lelanè Mostert MB ChB (Stell), DA(SA), FCA(SA),” 2014, [Online]. Available: http://scholar.sun.ac.za.

[5] A. Tavaré and E. Ahsn, “COVID-19: Patient Assessment the role of physiology and oximetry - AHSN NENC AHSN NENC,” [Online]. Available: https://www.ahsn-nenc.org.uk/covid-19-patient-assessment-the-role-of-physiology-and-oximetry/.

[6] F. Each, “Technical explanations for mechanical pressure switches.”

[7] H. Nozaki and T. Adachi, “Color sensor,” pp. 1–9, 1987, [Online]. Available: https://www.google.com/patents/US4677289.

[8] P. Kotagiri *et al.*, “The impact of hypoxia on B cells in COVID-19,” *eBioMedicine*, vol. 77, pp. 1–11, 2022, doi: 10.1016/j.ebiom.2022.103878.

[9] W. H. Organization, “Therapeutics and COVID-19,” pp. 1–98.

[10] M. Instructions, “Operation and Maintenance Instructions Manifold Control Systems Manual Manfiold Operation and Maintenance Manual Manual Manifold,” no. 2006230, 2019.

[11] “From a pure alarm system to active monitoring Alarm Management Systems for the central medical gas supply.”

[12] M. Halsey, “Installation and Restore,” *Wind. 10 Troubl.*, vol. 255098, pp. 475–482, 2016, doi: 10.1007/978-1-4842-0925-7_30.

[13] T. Tony, R. E. G. No, M. Simon, and A. Reg, “CENTRALIZED MEDICAL GAS MONITORING,” no. 1131110067, 2015.

[14] M. Hisham, “Centralized Medical Gas Monitoring Solution For Medical Piping Gases In The Hospitals,” no. May, 2019.

[15] Chinelo Igwenagu, “Fundamentals of Research Methodology and Data Collection,” *L. Lambert Acad. Publ.*, no. May, pp. 4–5, 2016, [Online]. Available: https://www.researchgate.net/publication/303381524_Fundamentals_of_research_methodology_and_data_collection#:~:text=1.1 Methodology is the systematic,a branch of knowledge.

[16] D. Mukanyiligira, N. Jean, and D. La Croix, “College of Science and Technology African Center of Excellence in Internet of Things Master of Science in Internet of Things - Embedded Computing Systems "A FUZZY INFERENCE MODEL FO...,” no. May, 2022.

[17] F. S. Downs, “Handbook of Research Methodology,” *Dimens. Crit. Care Nurs.*, vol. 9, no. 1, p. 60, 1990, doi: 10.1097/00003465-199001000-00018.

[18] T. M. Tuan *et al.*, “M-CFIS-R: Mamdani complex fuzzy inference system with rule reduction using complex fuzzy measures in granular computing,” *Mathematics*, vol. 8, no. 5, 2020, doi: 10.3390/MATH8050707.

[19] C. A. Lauff and D. Kotys-schwartz, “What is a Prototype ? What are the Roles of Prototypes in Companies ?,” no. October, 2018, doi: 10.1115/1.4039340.

[20] S. S. Skiena, *The algorithm design manual: Second edition*. 2008.

[21] R. Ibrahim and S. Y. Yen, “Formalization of the Data Flow Diagram Rules for Consistency Check,” *Int. J. Softw. Eng. Appl.*, vol. 1, no. 4, pp. 95–111, 2010, doi: 10.5121/ijsea.2010.1406.

[22] M. A. R. Joy, B. Sarkar, J. Sen, and M. A. Hossain, “Design and Development of Product Sorter Using TSC3200 Color Sensor,” *Glob. Sci. Jorunals*, vol. 8, no. 4, pp. 1–7, 2020.

[23] TAOS, “Tcs3200, Tcs3210 Programmable Color Light-To-Frequency Converter,” *The LUMENOLOGY*, no. 972, pp. 1–10, 2017, [Online]. Available: www.taosinc.com.

[24] “www.getmyuni.com.”

[25] J. A. Langbridge, “Introduction to Arduino,” *Arduino^{TM} Sketches*, pp. 01–24, 2015, doi: 10.1002/9781119183716.ch1.

[26] S. Alike, “Arduino Nano V2.3 User Manual,” *Arduino*, pp. 1–5, 2008, [Online]. Available: https://www.arduino.cc/en/Main/ArduinoBoardUno.

[27] W. Diamond and A. Third, “Global System for Mobile Communications (GSM) What is GSM ?,” no. 301.

[28] C. C. Pvt, “GSM Interfacing Board Campus Component,” 2011, [Online]. Available: www.campuscomponent.com.

[29] U. Manual, “SIM900A GSM / GPRS Module User Manual,” pp. 1–6.

[30] M. Fezari and A. A. D. Al Zaytoona, “Integrated Development Environment ‘IDE’ For Arduino Integrated Development Environment ‘IDE’ For Arduino Introduction to Arduino IDE,” *ResearchGate*, no. October, 2018, [Online]. Available: https://www.researchgate.net/publication/328615543.

[31] N. Zlatanov, “Arduino and Open Source Computer Hardware and Software,” *J. Water, Sanit. Hyg. Dev.*, vol. 10, no. 11, pp. 1–8, 2016, doi: 10.13140/RG.2.1.1071.7849.

[32] WHO, *WHO Technical Consultation On Oxygen Access Scale-Up For COVID-19*. 2020.

APPENDICES

Appendix 1: Questionnaire used in Data Collection

Investigation questionnaire on Medical Oxygen Alarm System in ICU Hospitalisation Area

I, Philemon MUCYURABUHORO a Master's student in Biomedical Engineering, Canter of Excellence in Biomedical Engineering and e-Health from University of Rwanda. I'm conducting research for my master’s thesis with the title: "**Medical Oxygen Alarm System in ICU Hospitalisation Area** ". This questionnaire is to fulfil the requirement of MSc project in Biomedical Engineering, and the data that I will get through this questionnaire will be only used for academic purpose in my thesis project. It will take less than 5 min of your time to answer. This questionnaire will allow me to collect data that will help me to gain an understanding of the current status of Medical Oxygen Alarm System in ICU. For making a credible and trusted lifesaving of ICU patients, the central oxygen supply source may be equipped by such alarm systems that can warn clinical and Biomedical Engineers to know that the low-level supply of oxygen is knocking in ICU and setting quick intervention for this incident to save patient’s life without taking long time suffering with lack of O2 that may cause serious problems to patients. To reach this purpose by this new system, Clinical staff and biomedical Engineers will be communicated by using Phone SMS and calls at the same time everywhere they are for setting quick intervention to this issue in possible shortest time. Microsoft forms is used to allow an automatic return of the questionnaire to me once completed. This questionnaire will expire in 2 weeks' time. Thank you in advance for your help. Philemon MUCYURABUHORO (UR Biomedical Engineering MSc. student).

* Required

1. What is your professional background? *

◯ Doctor
◯ Nurse
◯ Biomedical Technician
◯ Biomedical Engineer

2.What is your primary organization / Institution? *

- ◯ MOH
- ◯ RBC
- ◯ HOSPITAL

3. DO you have Intensive Care Unit in your institution? *

- ◯ Yes
- ◯ No

4.Which way do you use to supply o2 in your ICU? *

- ◯ Internal O2 Cylinders are used
- ◯ Centralized O2 wall supply by manifold

5.Is oxygen pressure level of your used system controlled? *

- ◯ Yes
- ◯ No

6.If yes, which way among the lowest do you use to control it? *

- ○ By visual system
- ○ By sound system

7.If visual system is used, do you watch by electronic screens or by pressure gauges? *

- ○ Electronic screens
- ○ Pressure gauges
- ○ Not applicable

8.WHAT challenges do you face with the current system? *

- ○ When the alarm is generated, it is difficulty to be aware once we are not at the nearest place.
- ○ It requires frequent checkup of centralized manifold pressure gauge.

9. Are there any associated risks derived to these challenges? *

- ○ Yes
- ○ No

10 . Compared to the current used system, do you think this Medical Oxygen Alarm System will be helpful in your daily working system? *

- ○ Yes
- ○ No

11.Do you think this Medical Oxygen Alarm System can improve the healthcare service delivery of your health facility? *

- ○ Yes
- ○ No

12. Is there any other idea or suggestion can you propose, for the Improvement of the Medical Oxygen Alarm System in the ICU Area? *

Appendix 2: Mode of Data analysis table

Table 3.2 Data analysis table

SN	Description Asked Question	Number respondents who replied "Yes"	Number respondents who replied "NO"	The low percentage (%)	The highest percentage (%)"
1	Professional background question?				100 were -Doctor -Nurses -Biomedical engineer -Biomedical technician
2	About respondents' primary organizations				100% works in Hospitals
3	About having intensive care unit in the hospital	18/18	0/18	0	100
4	The way used to supply oxygen in ICU	18/18 (Use Centralized O2 wall supply by manifold)	0/18 (use Internal O2 Cylinders are used)	0	100
5	To Control of oxygen pressure supply system	18/18	0/18	0	100
6	way used to control Oxygen Pressure level	12/18 (Visual system)	6/18 (sound system)	33.3	66.7
7	the method used to receive alarms (o2 Pressure level) for those using visual system	12/18 (those using pressure gauge)	6/18 (not applicable (Sound))	33.3	66.7

8	Challenges faced while using current system the current system	(12/18) frequent checkup of centralized manifold pressure gauge is highly Requested.	(6/18) difficulty awareness of the time of the alarm generation time, while you are far of alarm production place.	33.3	66.7
9	Availability of associated risks derived to these above faced challenges?	18/18 Respond affirmatively	0/18 Respond negatively	0	100
10	Comparison of current used systems to Medical Oxygen Alarm System to be helpful in their daily working system?	18/18 confirmed the effectiveness of new system compared to the current ones	0/18 confirmed the effectiveness of the current systems compared to new system	0	100
11	Suggestion on the Healthcare service delivery improvement possibility using Medical Oxygen Alarm System	18/18 confirmed that with the new system it is possible	0/18 confirmed the opposite suggestion	0	100

	Description Asked Question	Description of answer responded	Number of respondents	Percentage	Total percentage
12	About other suggestions, for the Improvement of the Medical Oxygen Alarm System in the ICU Area?	The process of data storage and review has been advised	6/18	33.3%	33%
		Availability, installation and training on new system is needed to overcome current challenges	12/18	66.7%	67%

Appendix 3: Data analysis Results

After analysis of data from respondent answers different results have been gotten

Q1. What is your professional background?

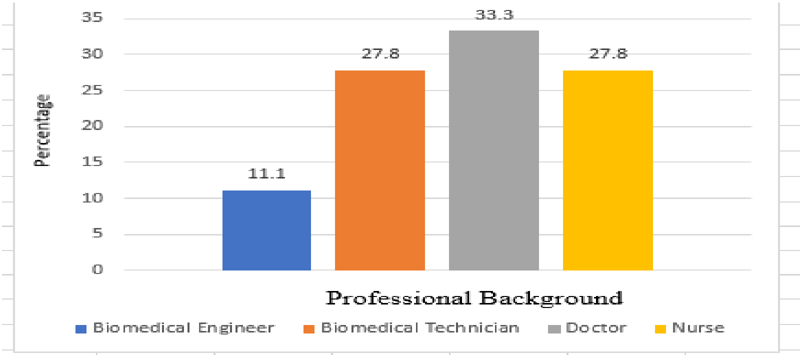


Figure 4.29 Data analysis result to question 1

Q2. What is your primary organization / Institution?

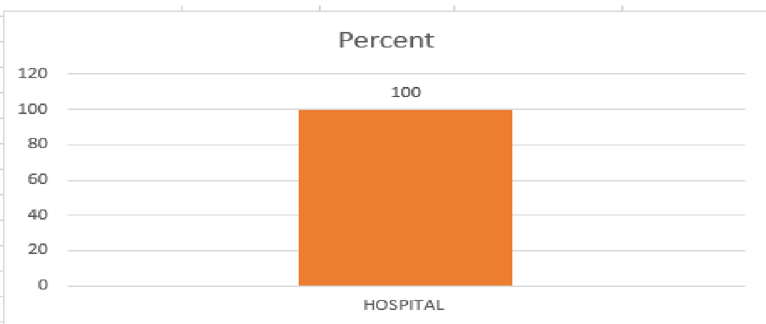


Figure 4.30 Data analysis result to question 2

Q3. Do you have Intensive Care Unit in your institution?

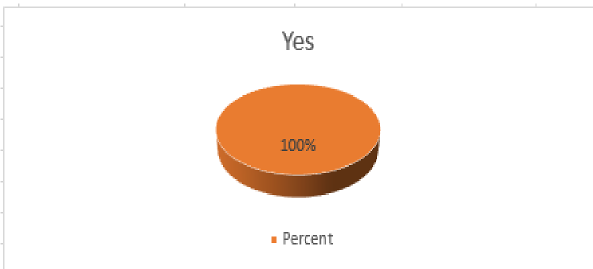


Figure 4.31 Data analysis result to question 3

Q4. Which way do you use to supply o2 in your ICU?

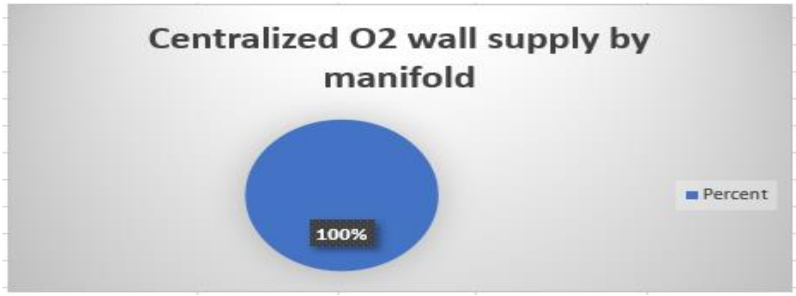


Figure 4.32 Data analysis result to question 4

Q5. Is oxygen pressure level of your used system controlled?

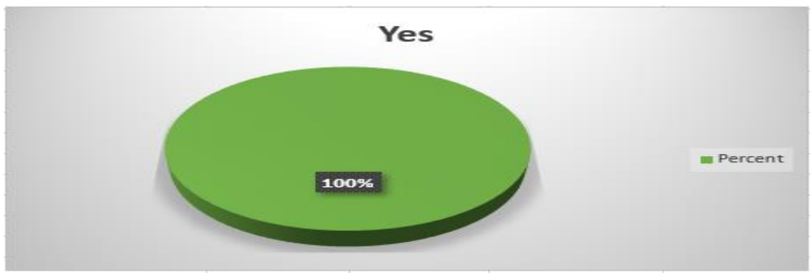


Figure 4.33 Data analysis result to question 5

Q6. If yes, which way among the lowest do you use to control it?

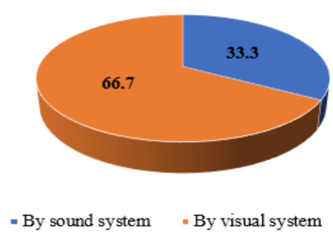


Figure 4.34 Data analysis result to question 6

Q7. If visual system is used, do you watch by electronic screens or by pressure gauges?

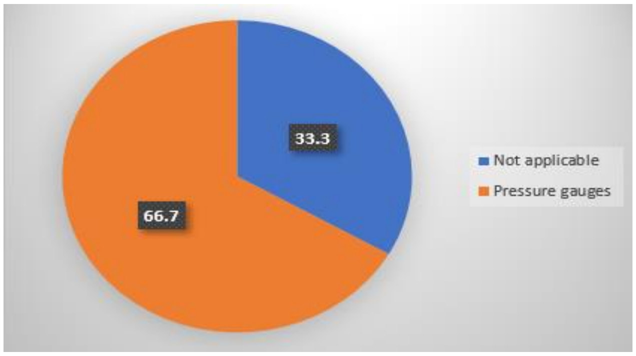


Figure 4.35 Data analysis result to question 7

Q8. What challenges do you face with the current system?

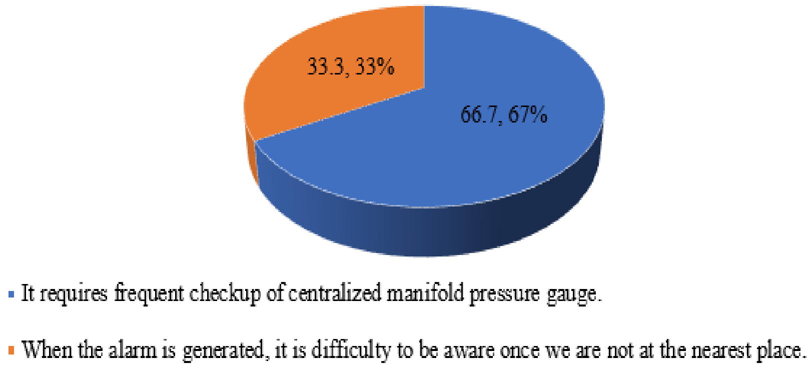


Figure 4.36 Data analysis result to question 8

Q9**.** Are there any associated risks derived to these challenges?

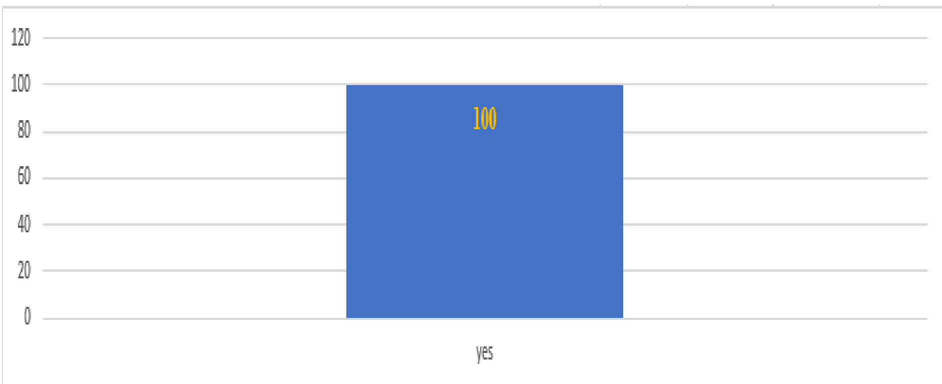


Figure 4.37 Data analysis result to question 9

Q10.Compared to the current used systems, do you think this this developed

System will be helpful in your daily working system?

Figure 4.38 Data analysis result to question 10

Q11.Do you think this medical oxygen alarm system can improve the healthcare service

delivery of your health facility?

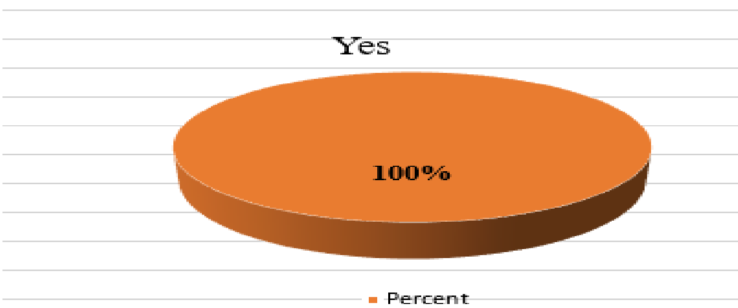


Figure 4.39 Data analysis result to question 11

Q12.Is there any other idea or suggestion can you propose, for the Improvement of the

Medical Oxygen monitoring System in the ICU Area?

Table 3.3 Data analysis result to question 12

	Description Asked Question	Description of answer responded	Number of respondents	Percentage	Total percentage
12	About other suggestions, for the Improvement of the Medical Oxygen monitoring System in the ICU Area?	The process of tata storage and review has been advised	6/18	33.3%	33%
		Availability, installation and training on new system is needed to overcome current challenges	12/18	66.7%	67%

Appendix 4 : The Utilized Codes

```
#include <SPI.h>
#include <SD.h>
File myFile;
#include <RTClib.h>
// TCS230 or TCS3200 pins wiring to Arduino COLOR SENSOR
#define S0 9
#define S1 10
#define S2 7
#define S3 6
#define sensorOut 8
#include <SoftwareSerial.h>
//Create software serial object to communicate with A6
SoftwareSerial mySerial(3, 4); //A6 Tx & Rx is connected to Arduino #3 & #4

// Stores frequency read by the photodiodes DECLARATION
int redFrequency = 0;
int greenFrequency = 0;
int blueFrequency = 0;

// Stores the red. green and blue colors
int redColor = 0;
int greenColor = 0;
int blueColor = 0;



RTC_DS3231 rtc; //REAL TIME CLOCK

char daysOfTheWeek[7][12] = {
  "Sunday",
  "Monday",
  "Tuesday",
  "Wednesday",
  "Thursday",
  "Friday",
  "Saturday"
};
void setup(void) {

   // Setting the outputs
  pinMode(S0, OUTPUT);
  pinMode(S1, OUTPUT);
  pinMode(S2, OUTPUT);
  pinMode(S3, OUTPUT);

  // Setting the sensorOut as an input
  pinMode(sensorOut, INPUT);
```

```
  // Setting frequency scaling to 20%
  digitalWrite(S0,HIGH);
  digitalWrite(S1,LOW);
// Open serial communications and wait for port to open:
  Serial.begin(9600);
while (!Serial) {
; // wait for serial port to connect. Needed for native USB port only
}
Serial.print("Initializing SD card...");
if (!SD.begin(5)) {
Serial.println("initialization failed!");
while (1);
}
Serial.println("initialization done.");
// open the file. note that only one file can be open at a time,
// so you have to close this one before opening another.
myFile = SD.open("test.txt", FILE_WRITE);
Serial.println("initialization done.");
// if the file opened okay, write to it:
// SETUP RTC MODULE
  if (! rtc.begin()) {
    Serial.println("Couldn't find RTC");
    Serial.flush();
    while (1);
  }

  // automatically sets the RTC to the date & time on PC this sketch was compiled
  rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));

  // manually sets the RTC with an explicit date & time, for example to set
  // January 21, 2021 at 3am you would call:
// rtc.adjust(DateTime(2023, 1, 19, 6, 46, 0));

}


void loop(void) {

  // Setting RED (R) filtered photodiodes to be read
  digitalWrite(S2,LOW);
  digitalWrite(S3,LOW);

  // Reading the output frequency
  redFrequency = pulseIn(sensorOut, LOW);
  // Remaping the value of the RED (R) frequency from 0 to 255
  // You must replace with your own values. Here's an example:
 redColor = map(redFrequency, 70, 120, 255,0);
//  redColor = map(redFrequency, XX, XX, 255,0);

  // Printing the RED (R) value
```

```
  Serial.print("R = ");
  Serial.print(redColor);
  delay(100);

  // Setting GREEN (G) filtered photodiodes to be read
  digitalWrite(S2,HIGH);
  digitalWrite(S3,HIGH);

  // Reading the output frequency
  greenFrequency = pulseIn(sensorOut, LOW);
  // Remaping the value of the GREEN (G) frequency from 0 to 255
  // You must replace with your own values. Here's an example:
   greenColor = map(greenFrequency, 100, 199, 255, 0);
//  greenColor = map(greenFrequency, XX, XX, 255, 0);

  // Printing the GREEN (G) value
  Serial.print(" G = ");
  Serial.print(greenColor);
  delay(100);

  // Setting BLUE (B) filtered photodiodes to be read
  digitalWrite(S2,LOW);
  digitalWrite(S3,HIGH);

  // Reading the output frequency
  blueFrequency = pulseIn(sensorOut, LOW);
  // Remaping the value of the BLUE (B) frequency from 0 to 255
  // You must replace with your own values. Here's an example:
   blueColor = map(blueFrequency, 38, 84, 255, 0);
  //blueColor = map(blueFrequency, XX, XX, 255, 0);

  // Printing the BLUE (B) value
  Serial.print(" B = ");
  Serial.print(blueColor);
  delay(100);
 DateTime now = rtc.now();
   Serial.print("Date & Time: ");
   Serial.print(now.year(), DEC);
      Serial.print('/');
    Serial.print(now.month(), DEC);
     Serial.print('/');
  Serial.print(now.day(), DEC);
    Serial.print(" (");
     Serial.print(daysOfTheWeek[now.dayOfTheWeek()]);
     Serial.print(") ");
    Serial.print(now.hour(), DEC);
   Serial.print(':');
     Serial.print(now.minute(), DEC);
      Serial.print(':');
   Serial.println(now.second(), DEC);
```

```
  // Checks the current detected color and prints
  // a message in the serial monitor


  if(redColor > greenColor && redColor > blueColor){

// SAVE TO SD CARD

  DateTime now = rtc.now();
   myFile.println("Date & Time: ");
 myFile.print(now.year(), DEC);
   myFile.print('/');
  myFile.print(now.month(), DEC);
  myFile.print('/');
  myFile.print(now.day(), DEC);
  myFile.print(" (");
  myFile.print(daysOfTheWeek[now.dayOfTheWeek()]);
  myFile.print(") ");
  myFile.print(now.hour(), DEC);
 myFile.print(':');
   myFile.print(now.minute(), DEC);
   myFile.print(':');
 myFile.print(now.second(), DEC);
  myFile.print("the oxygen pressure level is low");
// close the file:
myFile.close();
Serial.println("done.");

sendbme();
delay(5000);
sendclinical();
delay(5000);
callbme();
delay(5000);
callclinical();
delay(5000);
callbme();
delay(5000);



  }

}

  void updateSerial()
{
delay(500);
while (Serial.available())
{
```

```
mySerial.write(Serial.read());//Forward what Serial received to Software Serial Port
}
while(mySerial.available())
{
Serial.write(mySerial.read());//Forward what Software Serial received to Serial Port
}
}



void sendbme(){
//Begin serial communication with Arduino and A6,send message to BME
mySerial.begin(9600);

Serial.println("Initializing…");
delay(1000);

mySerial.println("AT"); //Once the handshake test is successful, it will back to OK
updateSerial();

mySerial.println("AT+CMGF=1"); // Configuring TEXT mode
updateSerial();
mySerial.println("AT+CMGS=\"+250788476756\"");//change ZZ with country code and
xxxxxxxxxxx with phone number to sms
updateSerial();
mySerial.print("The oxygen pressure level is low , please you have to come and fill the oxygen
pressure at maximum for avoiding ICU patients risks"); //text content
updateSerial();
mySerial.write(26);// send
}


void sendclinical(){
//Begin serial communication with Arduino and A6/Send messages to clinicall staff
mySerial.begin(9600);

Serial.println("Initializing…");
delay(1000);

mySerial.println("AT"); //Once the handshake test is successful, it will back to OK
updateSerial();

mySerial.println("AT+CMGF=1"); // Configuring TEXT mode
updateSerial();
mySerial.println("AT+CMGS=\"+250787394447\"");//change ZZ with country code and
xxxxxxxxxxx with phone number to sms
updateSerial();
mySerial.print("The oxygen pressure level is low , please you have to come and fill the oxygen
pressure at maximum for avoiding ICU patients risks"); //text content
updateSerial();
```

```
mySerial.write(26);// send
}

void callbme(){


//Begin serial communication with Arduino and A6 call biomedical
mySerial.begin(9600);

Serial.println("Initializing…");
delay(1000);

mySerial.println("AT"); //Once the handshake test is successful, i t will back to OK
updateSerial();

mySerial.println("ATD+250788476756"); // change ZZ with country code and xxxxxxxxxxx
with phone number to dial
updateSerial();
delay(20000); // wait for 20 seconds…
mySerial.println("ATH"); //hang up
updateSerial();
}
void callclinical(){


//Begin serial communication with Arduino and A6 call clinical staff
mySerial.begin(9600);

Serial.println("Initializing…");
delay(1000);

mySerial.println("AT"); //Once the handshake test is successful, i t will back to OK
updateSerial();

mySerial.println("ATD+250787394447"); // change ZZ with country code and xxxxxxxxxxx
with phone number to dial
updateSerial();
delay(20000); // wait for 20 seconds…
mySerial.println("ATH"); //hang up
updateSerial();
}
```