LOW COST MINI VENTILATOR

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Certification

This is to certify that [**Noor ul ain]**, **[20BME027]** , **[Sapna Dahar]**, **[20BME030],[Areej Abbas],[20BME010]** and **[Dua Hanif], [20BME013]** have successfully completed the final project **[Low cost mini ventilator],** at the **[Liaquat university of medical halth and science]**, to fulfill the partial requirement of the degree **[Biomedical Engineering and Technology].**

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Low cost mini ventilator

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3 ✸	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4 ✸	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
4	Familiarity of issues	Involve infrequently encountered issues	
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	

Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

A lack of access to medical equipment such as a ventilator during the pandemic has been indicated by the catastrophic losses caused by the global spread of COVID-19. As an illustration, Bangladesh, a country with a large population, is unable to provide for the needs of its COVID-19 affected residents, who require ventilators. Because of the increased cost. Due to lack of availability and manufacturing flaws, the majority of medical professionals cannot afford to buy this ventilator, which results inhorrible passing due to a respiratory issue. In each of these situations, a mechanical ventilator that will aid in anticipating COVID-19 affected individuals andincreased ventilator costs. With the use of electromechanical tools, a lightweight prototype was readilytransportable and equipped with an automated digital feedback system ventilator that provides oxygen when needed.Delivering breaths via the ventilator Having a pivoting cam arm, compressing a traditional bag-valve mask (BVM), removing the for the BVM to require a human operator. The first prototype, made of acrylic and measuring9 lbs (4.1 kg) and measuring 11.25 x 6.7 x 8 inches (285 x 170 x 200 mm). It's powered by an electric motor with an adjustable tidal capacity up to 750 cc, driven by a 14.8 VDC battery. Tidal volume and breaths per minute are controlled by simple input controls. Additionally, the prototype has an alarm to signal overpressurization of the system and an assist-control mode. In further generations, the apparatus will incorporate a controlled an LCD screen, a pressure release valve, PEEP capability, and an inspiration to expiration time ratio. At a mere $420 for prototyping, the ventilator's bulk manufacturing cost is thought to be lower.

Keywords: method; thesis; computer

Undertaking

I certify that the project **[Low cost mini ventilator]** is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

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We are also thankful to our friends and families whose silent support led us to complete our project.

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List of Acronyms

SARS	Severe acute respiratory syndrome
PIP	Peak inspiratory pressure
PIFR	Peak inspiratory flow rate
SPO2	Saturation power of oxygen
EtCO2	End tidal carbon dioxide
COPD	Chronic obstructive pulmonary disease
DC	Direct current
ICU	Intensive care unit
BVM	Bag valve mask
BMV	Bag mask ventilation
VT	Tidal volume
RR	Respiratory rate
PPV	Positive pressure ventilation
IPPV	Invasive positive pressure ventilation
ARDS	Acute Respiratory Distress Syndrome
PEEP	Peak Expiratory End Pressure
CPAP	Continuous Positive Airway Pressure
LCD	Liquid crystal display
NIPPV	Non invasive positive pressure ventilation
IPPV	Invasive positive pressure ventilation

PL	Plateau pressure
MCU	Microcontroller unit
IC	Integrated circuit
USB	Universal serial bus
I:E	Inhalation to exhalation ratio
CF	Critical flow

Chapter 1 INTRODUCTION AND BACKGROUND

1. Introduction

Nowadays, preoperative care, critical care delivery, and drug movement are essential components of the mechanical breathing system. Ventilators are readily available and necessary in both pre-hospital and hospital settings. Despite being trustworthy and safe, modern devices have several drawbacks. These include their high cost, the necessity for large consumables like compressed gas supplies, and practical inefficiencies like size and complexity. Concerns around price, portability, and size are particularly pertinent when it comes to emergency or transport ventilators. include instruments to track patient safety, Modern microprocessor-controlled electrical devices are expensive to produce and maintain, and their pneumatically driven counterparts are less durable and long-lasting due to the intricacy of their component parts and need on a compressed gas supply. Short-term ventilation is frequently provided using hand-delivered positive-pressure breathing devices, such as bag-valve masks, but doing so interferes with the operator's ability to carry out other critical therapeutic procedures promptly. Additionally, because these methods are imprecise, the patient may be more vulnerable to hyperventilation, volutrauma, and barotrauma. Many technologies have significant costs and mechanical or electrical liability due to the use of complex, high-tolerance digital pressure sensors, pneumatic components, and multilayered software. Operating in harsh, isolated, or arid settings with little space, manpower, and resources is not the best use for such heavy, fragile equipment. The deployment of enough ventilators in the case of a mass casualty scenario is further complicated by the high cost and complexity of current systems. A low-cost alternative technology might offer a scalable solution to this problem, however current options need the triaging of ventilator utilization. Patients who most need portable ventilation must be served by a novel strategy that can deliver safe, dependable ventilation.

One of the biggest issues facing public health in both industrialized and developing nations is respiratory infections and injury-induced respiratory failure. Numerous people suffer from chronic respiratory diseases such as asthma, chronic obstructive pulmonary disease, and others. Burning biomass for fuel, smoking, and air pollution all worsen these disorders. which, in emerging nations, are increasing1, 2, Mechanical ventilation may be necessary to support patients with underlying lung disease who experience respiratory failure due to various problems. Artificial respiration is the process of exhaling and inhaling oxygen and carbon dioxide into the lungs with the use of these machines.

Though operationally and technologically quite complex, the ventilators utilized in modern American hospitals come with hefty purchasing costs (up to $30k). Too expensive to utilize in nations with limited resources, such high-tech mechanical systems are prohibitively expensive. These ventilators also need expensive service contracts from the manufacturer because they are frequently brittle and subject to damage when used continuously. Due of this, hospitals in developing nations are now forced to share ventilators and buy refurbished equipment that is less dependable. Mechanical ventilators are sometimes completely inaccessible to rural and outlying areas due to the concentration of medical resources in these countries' large urban centers. It is consequently imperative that a low-cost transport ventilator be used.

In industrialized nations, where access to well-stocked medical facilities is common, the issue is distinct. Although there are adequate ventilators for routine use, there is insufficient planning for mass casualty scenarios like influenza pandemics, natural disasters, and large-scale toxic chemical spills. In affluent countries, it is prohibitively expensive to stockpile and deploy state-of-the-art mechanical ventilators for mass casualty scenarios. In a worst-case pandemic, the United States may require up to 742,500 ventilators, according to President Bush's national preparedness plan, which was released in November 2005.

The system clearly has flaws when compared to the 100,000 currently in use4. During Hurricane Katrina, as an illustration of this shortage, staff were compelled to use manual BVM ventilation due to a lack of ventilators.6. More recently, the Centers for Disease Control and Prevention (CDC) acquired 4,500 portable emergency ventilators for the strategic national stockpile 7, which is one example of the steps taken to increase preparation. Unfortunately, there is a need for an affordable portable ventilator whose production may be increased in response to demand, given the dearth of ventilators on hand and their current high cost.

1.2 Statement of the problem

Pneumonia and chronic obstructive pulmonary disease (COPD) are two of the top 10 causes of death in Pakistan, according to a study on the global burden of illness. Patients needing quick access to ventilation due to severe pneumonia, COPD, or COVID-19 need adequate ventilation. We introduce AmbuBox, a low-cost, clinically viable ventilator design that uses a standard, readily available manual resuscitators (AmbuBag) and a controllable pneumatic enclosure. AmbuBox can be quickly deployed during pandemics and mass-casualty events and requires a minimal set of components to assemble. With a long lifespan and high-precision flow control, the AmbuBox is made to solve the problems with current low-cost ventilator designs. It is an equipment that is straightforward to install and run.

1.3 Goals/Aims & Objectives

- It will be dependable equipment that will be employed in an emergency.
- It will be transported in an ambulance with patients to treat any fluctuations in the patients respiratory status.
- It is less expensive alternative to standard icu ventilator
- Continuous monitoring would be placed in charge of physicians, paramedics, and doctors, among others who travel with the patient.
- It will be used to treat patients with influenza and corona viruses.

1.4 Motivation

COVID-19 can lead to Acute Respiratory Distress Syndrome (ARDS):

Rapid invasion of lung cells.

Attack of epithelial cells lining airways.

Airways flooding with debris and fluids.

Pneumonia.

Respiratory failure.

Report Overview

Low-cost mechanical ventilators have been developed in order to deal with the shortage of traditional ventilators whose quantity is not sufficient in an emergency context in Perú. Protofy, a company from Spain, designed one of the first low-cost mechanical ventilation systems OxyGEN which was approved by a medicine agency in its country in special context of COVID 19. Therefore, as main of this article, a redesign of this system named OxygenIP.PE was carried out according to local requirements and available technology, but maintaining its working concept based on compression mechanism by cams. Sensors were added and a control algorithm of the respiratory rate was developed. Ventilation curves monitoring over time was implemented; in this sense, a mathematical model of the whole system was developed. OxygenIP.PE was redesigned, fabricated, and tested measuring its ventilation curves over time. Results indicate that this redesign provides a sturdy equipment able to work during a longer lifetime than the original. The replicability of the ventilation curves behavior is ensured, while the mechanism dimensions are adapted for a particular airbag resuscitator. The mathematical model of the whole system can satisfactorily determine the ventilation curves over time and is used to show the air pressure, volume, and flow as a function of the compression arm's angular position and differential pressure through the breathing circuit measurement, furthermore the algorithms designed as a consequence of the mathematical model were implemented for Raspberry and ARDUINO microcontrollers.

2. Chapter 2 METHODOLOGY AND EXPERIMENTAL WORK

2.1 PROPOSED METHOD

This project makes use of a silicon ventilator bag that is pushed by a single-side push mechanism using a stepper motor. Deflation and inflation are accomplished by the use of the cam shaft mechanism. Here, a cam is used to translate rotary motion into linear motion via the stepper motor shaft. The oval-shaped cam is intended to elevate the pressing arm's upper end. The joint mechanism is linked to the pressing arm. & put in place atop the ventilator. It results in a process akin to a seesaw. The stepper motor presses against the bag on one end when it turns and raises the arm on one side. The motor's revolutions per minute determine the rate of inflation and deflation. According to the setup's parameters, the motor RPM is

changed to get the appropriate heart rate. In this experiment, switching is accomplished using a toggle switch and variable pot when the patient employed this technique, to modify the duration of the breath and the BPM. Using this system, a An oxygen sensor and a sensitive pressure sensor are utilized to track the patient's vital signs. show the same thing on a tiny screen. This system also has an emergency buzzer alarm installed to emit an.

2.2 Mechanical design

The mechanical design supports the most important aspect of building a concept into a visual image; the structure and material requirements enable the proposed gadget to serve its intended purpose. Within a respirator two different kinds of materials for the suggested design of ventilator.

2.2.1 Formation design

Numerous mechanical features were employed in the proposed ventilator, which led to its design as a mechanical ventilator. Six key components make up the entire design, as seen in the illustration below.

2.2.2 Stander

Well, an aluminum extrusion stand wasselected for this ventilator. It can hold a whole breathing chamber, and pressure of spiral spring and slidercrank. Vertically two stand 12 1.5 inches and horizontally one 10.5 1.5-inch aluminum extrusion stand has been chosen to make a Stander frame. Two sliders moving rail appointed with the vertical stand, to help slider moved through up and down. This Stander frame also adjusted with those slider-moving rails and ground wooden box by angle clamp pointed this in components 1 and 2 in Figure 1. Below space one, Ambu Bag will appear and a positive force will occur into the Ambu Bag to make a breathing chamber.

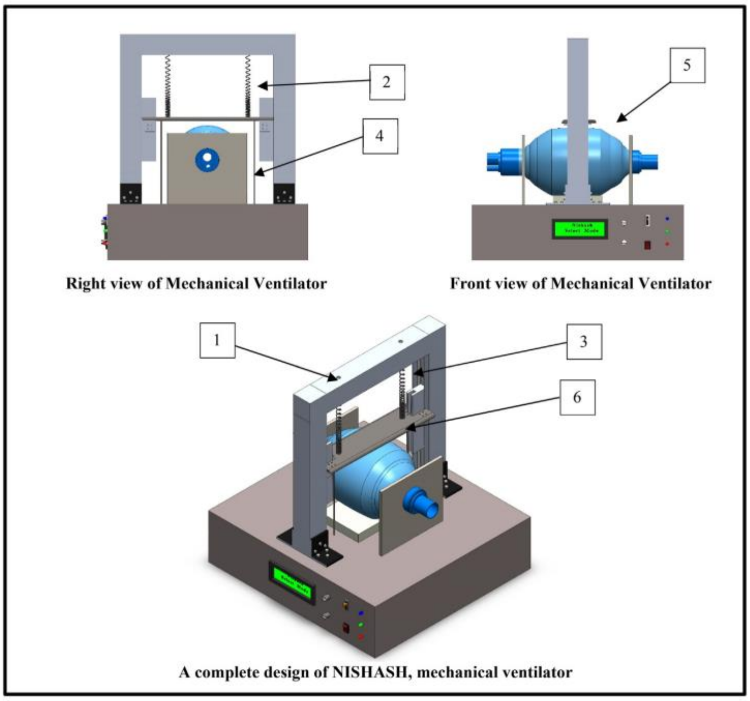


Figure 1Design of the mechanical ventilator of NISHASH. 1. Stander. 2. Slider. 3. Mechanical Spiral Spring. 4. Nylon wire. 5. AMBU Bag. 6. Pressure plate

2.2.3. Slider

Slider is one of the most common useful and fundamental components in the mechanical ventilator. In this work, two sliders 6 X 1 inch are used. on two opposite sides, which will move on top of the moving rail illustrates components 2 in Figure 1. An aluminum 9.5-inch plate is connected by a joint clamp with a slider, which will change directions altogether.

2.3 Power electronics system design

In this given system, a power on/off switch is placed to run or turn off the device and set up a charge controller to transfer AC 220 v to DC 12 V. This charge controller has a dual function where one is connected with the 12 v battery cell to charge it, another portion is fixed with a step-down buck converter. This converter is responsible to regulate DC to DC voltage e.g. 12v to 5v. In this work, have chosen a 7v Dc input voltage to run the servo motor and microcontroller. A slide switch is an import to control the whole process of the work, it regulates in three different modes. When Child mode (C) is placed, a signal is sent to the microcontroller to operate the motor and same time Blue LED will appear same time as an output. Similarly, switching the slide switch of Adult mode (A) and Manual mode (M) different signals will act as an input to the microcontroller and different types of rotation will happen towards the motor with Green and Red LED respectably. In a Manual mode, it is possible to associate different levels of airflow by the motor operation, where two variable resistors will assist the motor speed rate and air volume. A buzzer is set for safety purposes, when motor speed will be high from the given parameter setting in any mode for any kind of internal fault or manually selection then this buzzer will make an alarm for 1 min, it will turn off the whole system. Meanwhile, if electricity will go in any time then this device can run with the external power source of 12v battery cell for two hours, tagged for emergency purpose of electricity, which is the solution of any emergency either inside of the hospital or ambulance. Finally, a display is connected with the microcontroller to visualize the full process of operation to understand the operator in every section. Figure 2 showed the whole circuit diagram of the system.

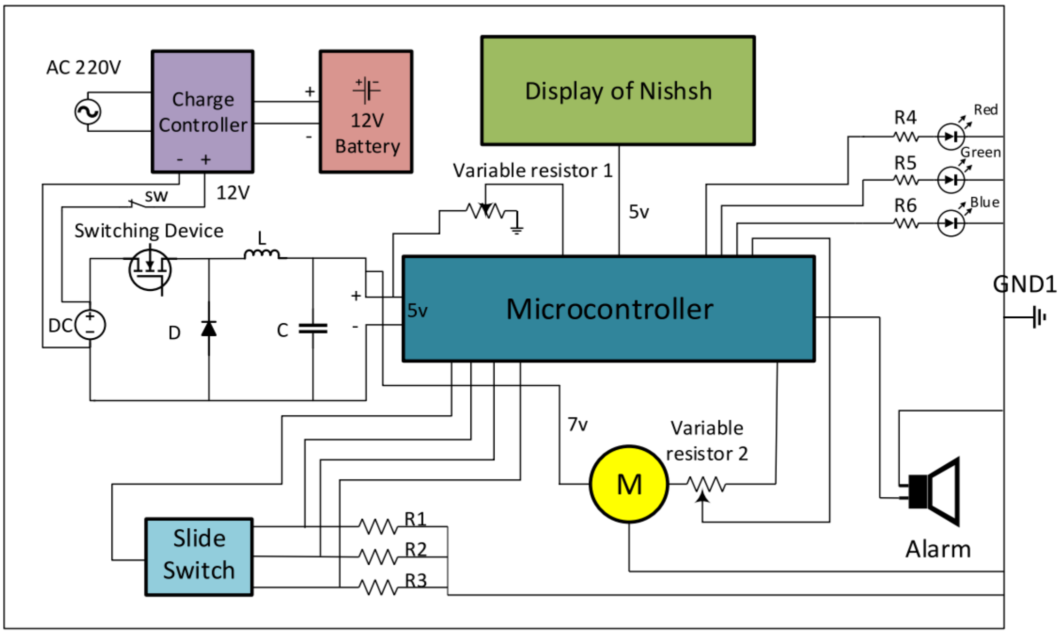


Figure 2Circuit Design of the whole Device

2.4Methodology

2.4,1 Control design:

This ventilator provides assured tidal volumes using an assist-control (AC) mode. The operator selects the tidal volume appropriate to the patient, usually 6-8 mL/kg of ideal body weight and a minimum respiratory rate. This provides a minimum assured minute ventilation (Ve). If the patient is breathing above the set rate, negative inspiratory pressure that exceeds 2 cmH20 vacuum triggers the ventilator to deliver the set tidal volume. The advantage of AC mode is that the patient has an assured minute ventilation to meet physiologic needs for adequate gas exchange. A disadvantage is that if the patient is tachypneic or breathing too fast, respiratory alkalosis may develop or, for those with obstructive lung disease, air trapping may occur, raising intrathoracic pressure with adverse hemodynamic and gas exchange consequences. However, these issues are commonly handled with reductions in respiratory rate and sedation as needed. AC mode, one of the most widely utilized mechanical ventilator modes, is adequate for the management of the majority of most clinical respiratory failure scenarios. This ventilator can be used for patients who are intubated with an endotracheal tube or who would receive noninvasive mechanical ventilation through a mask that is commonly used for provision of continous positive airway pressure (CPAP).

2.4.2 Parameters

The operator adjusts tidal volume, breath rate, and inspiratory to expiratory time ratio using three continuous analog knobs mounted to the outside of the ventilator. The prototype has a range of 200-750 mL tidal volume and 5-30 breaths per minute (bpm). This yields a maximum minute ventilation (Ve) of 21L and a minimum Ve of 1.5L. However, these values do not reflect the limits of the final design only the settings of the prototype. Theoretically, the ventilator is able to deliver anywhere from 0L minute volume to 60L minute volume. However, this has not been fully tested. I:E ratio was not implemented on the prototype but theoretically could have any desired range within the limits determined by the other parameters. The ranges on the final design will be determined in consultation with respiration specialists to allow for the broadest range of safe settings.

2.4.3 Controller:

An off-the-shelf Arduino Duemilanove microcontroller board was selected to control our device. The microcontroller runs a simple control loop to achieve user-prescribed performance. The control loop is triggered by the internal timer set by user inputs, with the inspiratory stroke initiated at the beginning of the loop. Once the prescribed tidal volume is reached, the actuator returns the cam back to its initial position and holds until the next breath. The loop then repeats to deliver intermittent breaths. If the loop is interrupted by a breath attempt by the patient (sensed through the pressure sensor), the ventilator immediately delivers a breath, interrupting the loop and resetting the timer. A diagram showing this loop is found.

2.4.4 Motor

According to initial experiments, a maximum torque of 1.5 Nm was required for maximum volume delivery. A PK51 DC gearmotor with a stall torque of 2.8 Nm was selected for the prototype. Despite the lower torque value measured in our experiment, we found that this motor did not provide quite enough torque to effectively drive the cam at the slower inhalation cycle rates prescribed to some patients. While a larger motor will be necessary to achieve better speed control, this motor functioned acceptably

at the proof-of-concept phase. It was desirable for its gear reduction ratio of 51:1, and an operating speed in the required range of 50-70 rpm.

2.4.5 Motor Driver :

The motor driver comprises of two H-Bridge circuits. These circuits direct current through the motor in opposite directions, depending on which set of switches on the circuits are energized. Speed of the motor is signaled with a pwm pin. The power is supplied directly from the battery, so the only limit is the current capability of the chip and battery. We opted to use the Solarbotics® motor driver, which is capable of supplying 5 amps of current to the two circuits. The PK51 motor's stall current is rated at 5.2 amps which means the motor driver will be able to handle the requirements for the system. 4.6. User Interface The three user inputs (tidal volume, bpm and I:E ratio) are set via three potentiometer knobs. Future iterations of the device will include the addition of an LCD display to show the input settings as well as airway pressure level and battery power status.

2.4.6 Safety Features

To ensure that the patient is not injured, the airway pressure is monitored with a pressure sensor connected to a sensor output on the BVM. The same pressure sensor used for initiation of assist control also triggers an alarm if the pressure rises too high, alerting the physician to attend to the patient. As a further safety measure to prevent over-inflation, future iterations of the device will include a mechanical pressure relief valve.

2.4.7 Power Delivery

An AC/DC converter can be used to power the ventilator directly from a wall outlet or a vehicle inverter. When external power is unavailable, the ventilator can run off of any battery capable of delivering 12-15 volt at least 3.5 Amps. For the prototype, we used a 14.8 volt, four-cell LiIon battery pack capable of 4.2 Amps (limited by protective circuitry), with a capacity of 2200 mA-hr.

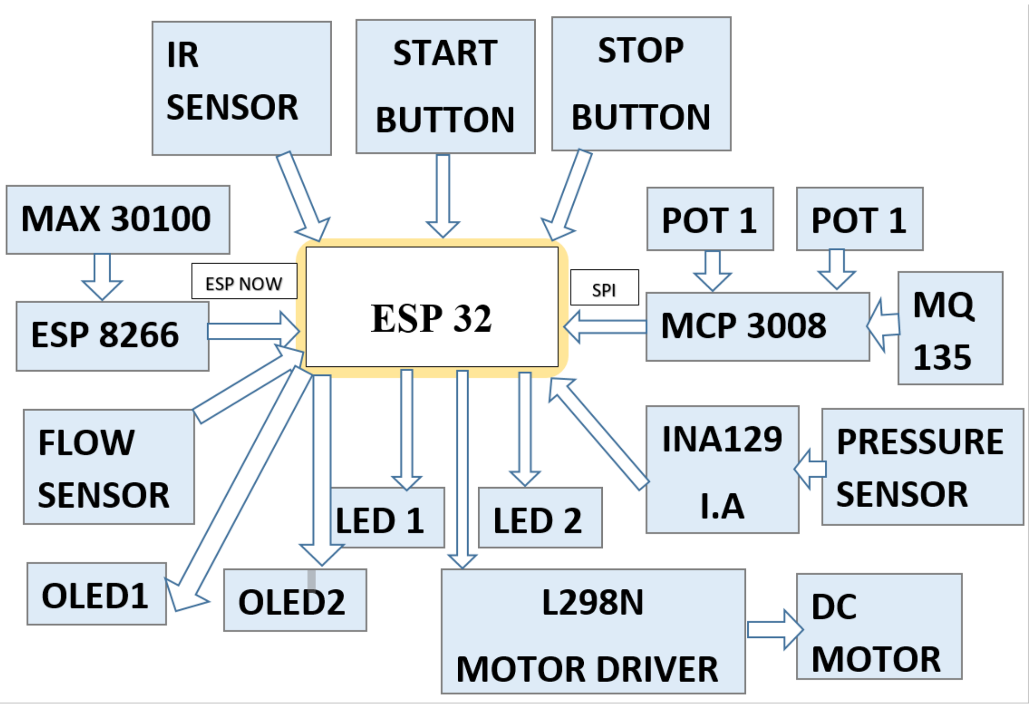


Figure 3 block diagram

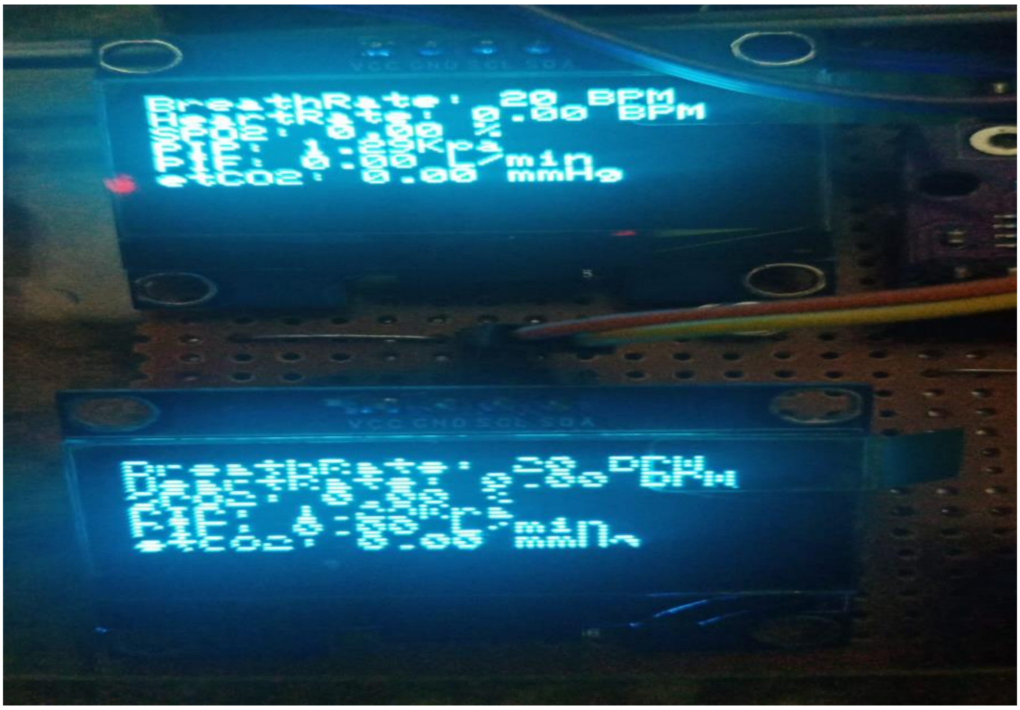
Chapter RESULTS AND DISCUSSION

3.1. Results

The results of this prototype were obtained by testing it on a group of subjects. The proposed system is intended to monitor multiple parameters related to the respiratory and ventilation functions of the human body. This will aid in the identification and diagnosis of various risky diseases such as asthma, chronic obstructive pulmonary disease (COPD), and sleep apnea. By collecting real-time data on breathing rate, oxygen saturation levels, and lung capacity, the system can provide valuable insights to healthcare professionals for timely intervention and personalized treatment plans. The parameters includes breath rate (breaths per minute , BPM this is frequently the ideal pace for breathing in. Its range is 10 to 30 breath) , heart rate (beats per minute (BPM), which indicates the number of times the heart beats in a minute. The normal range for heart rate is typically between 60 to 100 BPM), SpO2 (oxygen saturation levels, which measure the percentage of oxygen in the blood. The normal range for SpO2 levels is usually between 95% to 100%), peak inspiratory pressure (PIP which measures the maximum pressure applied to the airways during inhalation. This parameter is crucial in assessing lung function and can help detect any abnormalities or respiratory disorders. The normal range for PIP is typically between 20 to 30 cmH2O), peak inspiratory flow (PIF which measures the maximum flow rate of air during inhalation. This parameter is important in evaluating the efficiency of lung function and can aid in diagnosing respiratory conditions. The normal range for PIF is typically between 60 to 90 liters per minute). Additionally, the proposed system also monitors end-tidal carbon dioxide (EtCO2) levels, (which indicate the amount of carbon dioxide exhaled at the end of each breath. Normal EtCO2 levels range from 35 to 45 mm) using the above described sensors and circuitry. The two OLEDs used in the display of these parameters are intended to provide output readings that are easy to read and clear , ensuring that users can quickly and accurately interpret their lung function and carbon dioxide levels. Half of the parameters mentioned above are displayed on one of the OLEDs, while the other OLED is programmed to display the remaining half of the parameters. This user-friendly display is crucial for individuals with respiratory conditions who may need to regularly monitor their lung health at home or on the go. This system ensures comprehensive monitoring by utilizing the sensors and circuitry to measure and analyze multiple vital parameters accurately.

3.2. Discussion

The proposed system is designed to monitor various ventilation related parameters such as breath rate, heart rate, and peak inspiratory pressure and so on. By continuously monitoring these parameters, individuals can gain valuable insights into their lung function and overall respiratory health. This comprehensive approach allows for early detection of any abnormalities or changes in lung function, enabling timely intervention and management of respiratory conditions. Additionally, the system's ability to accurately measure carbon dioxide levels provides important information about gas exchange in the lungs, further enhancing its usefulness in monitoring respiratory health. Because it is an inexpensive alternative to a standard ventilator, it helps those who cannot afford more expensive ventilators and is easily available to those in need. The device is user-friendly and accessible to patients' relatives as well , allowing them to assist in monitoring and managing the respiratory health of their loved ones. This not only empowers patients and their families but also reduces the burden on healthcare professionals, as they can rely on the support and involvement of caregivers in the monitoring process. Additionally, the device's portability makes it convenient for patients to use at home or while traveling, ensuring continuous monitoring and timely intervention even outside of medical facilities. There are a few limitations on this project, but they could be improved later through further research and development. For instance, the device could be enhanced to provide real-time data analysis and alerts to both patients and healthcare professionals, enabling proactive intervention and preventing potential respiratory complications. Furthermore, incorporating features such as remote monitoring capabilities and data sharing options could facilitate seamless communication between patients, caregivers, and healthcare providers, promoting collaborative care and improved patient outcomes. This could lead to more efficient and effective care delivery. Additionally, these features could enhance patient engagement and empowerment, leading to better health outcomes.



```
BreathRate: 20 BPM
HeartRate: 0.00 BPM
SPO2: 0.00 %
PIP: 1.09Kpa
PIF: 0.00 L/min
etCO2: 0.00 mmHg
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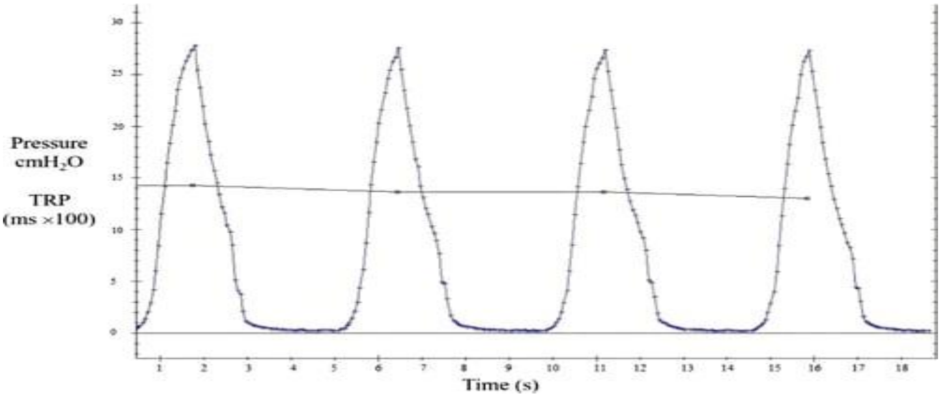
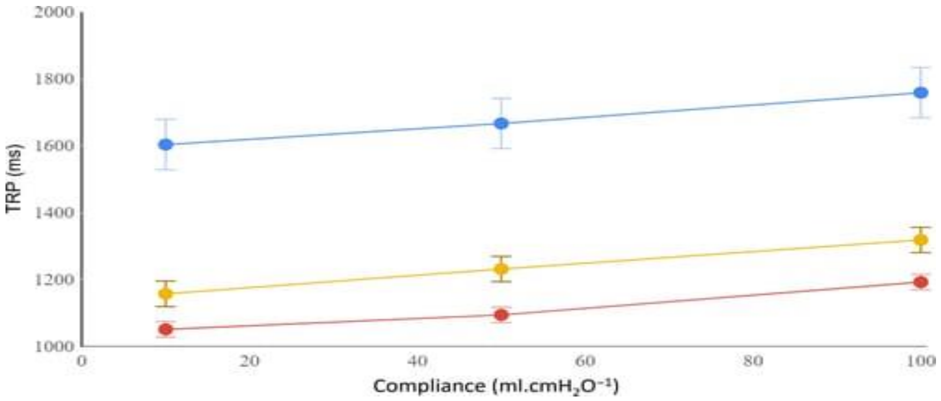
Chapter 4

The Performance results of the ISO 80601-2-80-2018 pressure controlled ventilator standard tests with an intended delivered tidal volume of 500 mL. For each configuration the following parameters are listed: the test number (from table 201.105 in the ISO standard), the compliance (C, mL/cm H2O), linear resistance (R, cm H2O/L/s), respiratory frequency (f, breaths/min), peak inspiratory pressure (PIP, cm H2O), positive end-expiratory pressure (PEEP, cm H2O), and flow adjustment setting. PIP is reached in every test condition except for case 2, which is approximately 2.4cm H2O below the set point



The experiments showed how the TRP value of each breath varies with changing test-lung characteristics. In other words, how the time taken between the motor starting and the pressure-sensitive switch ‘tripping’ on each delivered breath varies when circuit parameters are changed test-lung compliance was increased, the measured TRP value increased, a trend observed across each pressure group (Fig. 6). For example, in the highest ventilation pressure group, the measured mean (SD) TRP value was 1605 (74) ms at a test-lung compliance of 10 ml.cmH2O−1. This means it took on average 1605 ms for the pressure to reach the threshold pressure on the pressure-sensitive switch.


2000
1800
1600
1400
1200
1000
TRP (ms)
0
20
40
60
80
100
Compliance (ml.cmH$_2$O^{-1})