DESIGN AND FABRICATION OF LOW COST PORTABLE MECHANICAL VENTILATOR

A Project report Submitted to

P.E.S. COLLEGE OF ENGINEERING, MANDYA

(AN AUTONOMOUS INSTITUTE AFFILIATED TO VTU, BELAGAVI)

In partial fulfillment of the requirement for the award of the degree

BACHELOR OF ENGINEERING

in

MECHANICAL ENGINEERING

Submitted by

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DEPARTMENT OF MECHANICAL ENGINEERING

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DEPARTMENT OF MECHANICAL ENGINEERING
P.E.S. COLLEGE OF ENGINEERING, MANDYA
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CERTIFICATE

This is to certify that the project work entitled **"DESIGN AND FABRICATION OF LOW COST PORTABLE MECHANICAL VENTILATOR"**,carried out by **RAJENDRA K M (4PS17ME073), RAKESH U (4PS17ME074), RAKESHA A S (4PS17ME075), RAKSHITH B S (4PS17ME076),** bonafide students of **P.E.S. College of Engineering, Mandya** in partial fulfillment for the award of **Bachelor of Engineering in Mechanical Engineering** under **Visvesvaraya Technological University, Belagavi** during the year 2020-2021. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the Report deposited in the departmental library. The project report has been approved as it satisfies the academic requirements in respect of Project work Phase II prescribed for the said Degree.

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DECLARATION

We **RAJENDRA K M(4PS17ME073), RAKESH U(4PS17ME074), RAKESHA A S(4PS17ME075), RAKSHITH B S(4PS17ME076)** students of 8th semester Bachelor of Engineering in Mechanical , PESCE, Mandya , hereby declare that the project work being presented in the dissertation entitled **"DESIGN AND FABRICATION OF LOW-COST PORTABLE MECHANICAL VENTILATOR"** is an authentic record of the work that has been independently carried out by us and submitted in partial fulfilment of the requirements for the award of degree in **Bachelors of Engineering in Mechanical**, affiliated to **Visvesvaraya Technological University (VTU), Belagavi** during the year 2020-2021.

Place: Mandya

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ABSTRACT

The coronavirus Covid-19 pandemic is defining global health crisis of our time and greatest challenge we have faced since world war. It threatens to overwhelm our medical infrastructure at the regional level causing spikes in mortality rates because of shortage of critical equipment’s like ventilators. Fortunately, with the recent development and widespread deployment of small-scale manufacturing technologies like open-source ventilators mass distribution, manufacturing of ventilators has the potential to overcome medical supply shortages. So, we have designed a low-cost portable mechanical ventilator. This ventilator uses rack and pinion mechanism to squeeze the Ambu bag with the help of servomotor motor. It is also connected with Arduino and sensors in order to provide adjustable setting like respiratory rate, tidal volume I/E ratio. The ventilator is fabricated mostly using readily available equipment’s so that it can be built by needed people at low cost and with minimum knowledge of Engineering.

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LIST OF ABBREVIATIONS

Sl. NO	ABBREVIATION	ACRONYM
1	Bag valve mask	BVM
2	Intensive care unit	ICU
3	Continuous positive air pressure	CPAP
4	Association for the advancement of medical instrumentation	AAMI
5	World health organization	WHO
6	Breaths per minute	BPM
7	Intermittent mandatory ventilation	IMV
8	Tidal volume	TV
9	Polyvinyl chloride	PVC
10	Analog-to-digital converter	ADC

CHAPTER 1

INTRODUCTION

Mechanical ventilation or assisted ventilation sometimes abbreviated as Intermittent Mandatory Ventilation (IMV), is the medical term for artificial ventilation where mechanical means are used to assist or replace spontaneous breathing. This may involve a machine called a ventilator, or the breathing may be assisted manually by a suitably qualified professional, such as an anesthesiologist, Registered Nurse (RN), paramedic or other first responder, or in some parts of the World, by a Respiratory Therapist (RT), by compressing a bag valve mask device.

Mechanical ventilation is termed "invasive" if it involves any instrument inside the trachea through the mouth, such as an endotracheal tube or the skin, such as a tracheostomy tube. Face or nasal masks are used for non-invasive ventilation in appropriately selected conscious patients.

The two main types of mechanical ventilation include positive pressure ventilation where air (or another gas mix) is pushed into the lungs through the airways, and negative pressure ventilation where air is usually, in essence, sucked into the lungs by stimulating movement of the chest. Apart from these two main types, there are many specific modes of mechanical ventilation, and their nomenclature has been revised over the decades as the technology has continually developed.

1.1 MODES OF MECHANICAL VENTILATION

Mechanical ventilation utilizes several separate systems for ventilation referred to as the mode. Modes come in many different delivery concepts but all modes fall into one of three categories; positive, negative, intermediate. In general, the selection of which mode of mechanical ventilation to use for a given patient is based on the familiarity of clinicians with modes and the equipment availability at a particular institution.

1. **Positive pressure ventilation**: The design of the modern positive-pressure ventilators was based mainly on technical developments by the military during World War II to supply oxygen to fighter pilots in high altitude. Such ventilators replaced the iron lungs as endotracheal tubes with high-volume/low-pressure cuffs were developed. The

popularity of positive-pressure ventilators rose during the polio epidemic in the 1950s in Scandinavia and the United States and was the beginning of modern ventilation therapy. Positive pressure through manual supply of 50% oxygen through a tracheostomy tube led to a reduced mortality rate among patients with polio and respiratory paralysis. However, because of the sheer amount of man-power required for such manual intervention, mechanical positive-pressure ventilators became increasingly popular.

2. **Negative pressure ventilation**: A Negative Pressure Ventilator (NPV) is a type of mechanical ventilator that stimulates an ill person's breathing by periodically applying negative air pressure to their body to expand and contract the chest cavity. Negative pressure mechanical ventilators are produced in small, field-type and larger formats. The prominent design of the smaller devices is known as the cuirass, a shell-like unit used to create negative pressure only to the chest using a combination of a fitting shell and a soft bladder. In recent years this device has been manufactured using various- sized polycarbonate shells with multiple seals, and a high-pressure oscillation pump in order to carry out biphasic cuirass ventilation. Its main use has been in patients with neuromuscular disorders that have some residual muscular function.

1.2 TYPES OF VENTILATORS

Ventilators come in many different styles and method of giving a breath to sustain life. There are manual ventilators such as bag valve masks and anesthesia bags that require the users to hold the ventilator to the face or to an artificial airway and maintain breaths with their hands. Mechanical ventilators typically require power by a battery or a wall outlet (DC or AC) though some ventilators work on a pneumatic system not requiring power. There are a variety of technologies available for ventilation.

1. **Transport ventilators:** These ventilators are small and more rugged, and can be powered pneumatically or via AC or DC power sources.
2. **Intensive-care ventilators:** These ventilators are larger and usually run-on AC power (though virtually all contain a battery to facilitate intra-facility transport and as a back-up in the event of a power failure). This style of ventilator often provides greater control of a wide variety of ventilation parameters (such as inspiratory rise time). Many

Intensive Care Unit (ICU)ventilators also incorporate graphics to provide visual feedback of each breath.

3. **Neonatal ventilators (Bubble CPAP):**Designed with the preterm neonate in mind, these are a specialized subset of ICU ventilators that are designed to deliver the smaller, more precise volumes and pressures required to ventilate these patients.
4. **Positive airway pressure ventilators (PAP) :** These ventilators are specifically designed for non-invasive ventilation. This includes ventilators for use at home for treatment of chronic conditions such as sleep apnea or COPD.

1.3 PROBLEM DEFINITION

Ventilator is a medical equipment machine which is employed to provide respiratory support to the patients whose lungs are significantly compromised due to infection (pneumonia) etc. leading to severe respiratory problems. The ventilator uses a positive pressure to supply oxygen into the lungs through the inner ways and fully regulate the breathing process of the patients. Mechanical ventilators are most necessarily used in the situations where patients suffer from Acute Respiratory Distress Syndrome (ARDS) such as in COVID-19. This helps in normalizing the levels of oxygen in the body. They are primarily used in home care, emergency care, intensive care settings and as one of the parts of general anaesthesia machines. More importantly the average cost of high-end ventilators is around 8 to 10 lakhs which is very difficult to afford for rural and poor people. So, there is a need to develop a cost-effective ventilator.

1.3.1 PRESENT SCENARIO

The coronavirus Covid-19 pandemic is defining global health crisis of our time and greatest challenge we have faced since World War II. COVID-19 is an infectious disease which is caused by novel coronavirus. It is a highly contagious disease which begun in Wuhan in China at the end of December 2019 and now has spread across the globe to around 200 countries, in a short period of three months and has affected more than 2.1 million individuals and has caused death in more than 145 thousand patients. It can present as a mild infection (such as common cold) to a serious respiratory illness (such as pneumonia). The seriously ill patients suffering from COVID-19 need respiratory support, as their lungs get damaged by the coronavirus leading to breathing difficulties. Ventilators are needed in such cases for supplying adequate oxygen (O_2) into their lungs and also removing the carbon dioxide (CO_2), as a lifesaving supportive measure. The ventilators are one of the most vital medical devices needed to keep these critically ill COVID-19 patients alive. There has been a drastic increase in the number of patients struck by COVID-19 pandemic in the

hospitals and ICUs worldwide. However, sufficient ventilators are not available in the hospitals at present. An influential report from Imperial College London estimates that 30% of patients admitted in hospitals due to COVID-19 are expected to need the mechanical ventilation. Health care systems worldwide are facing the extreme shortfall of ventilators particularly mechanical ventilators and their components. The shortage of ventilators has already been experienced by most of the countries who are extremely hit by this pandemic.

1.3.2 NEED FOR VENTILATOR

COVID-19 pandemic has caught every one of us unaware of the need for emergency tools like lifesaving ventilators. There is an urgent need to escalate the production of ventilators by the existing and potentially new manufacturers. Alternative manufacturing of the ventilators like open-source ventilators must be explored to maximum, to overcome this acute and huge medical crisis. Companies including Apollo, Mahindra are stepping up to meet the demand for ventilators, alongside other innovations. There is also an acute shortage of trained healthcare workers.

One of the main reasons for the shortage of ventilators is the issues related to their global supply chain. Due to the worldwide spread of infection, the exports of the medical equipment's including ventilators have come to a halt. The situation has been become so alarming that as many as fifty-four countries have stopped exporting the Goods related to medical field including ventilators. The production of medical machines such as ventilators demands more intensive capital and expertise.

TABLE 1.3.2.1 The following table shows the complete picture ventilator shortage.[1]

Table no	Parameters	Role of Ventilators and Challenges
1.	Ventilator and its importance in COVID-19 pandemic	• Around 1 in every 5 people who are infected with COVID-19 develop difficulty in breathing and require hospital care. • People who are aged over 60 years, and people who have underlying medical conditions such as diabetes, heart disease, respiratory disease or hypertension are among those who are at greater risk.
2.	Challenge of shortage and the cost of ventilators	• There is an acute shortage of ventilators for COVID-19 patients • Their high cost and availability are a challenge
3.	Effects of shortages of ventilators	• Severely sick people are getting affected from getting the optimal treatment • Innovative means of manufacturing and optimizing their use is being tried out

CHAPTER 2

LITERATURE SURVEY

Due to the shortage of high-end ventilator many companies and students have developed innovative ideas for ventilator (automated resuscitator). These methods use of Ambu bag squeezing. A brief view of some of major works are discussed below.

- **Badre El Majid, Saad Motahhir [2]:** Preliminary design of an innovative, simple, and easy-to-build: This design involves a circular wooden tank which has dc motor on top. Top and bottom circle are connected by wires. when motor runs it causes the upper circle to rotate in one direction. The movement of the motor causes the wire to bend. This pulls the bottom circle upwards, which pressurizes the air inside the tank. And this pressurized air is connected to a pipe which is utilizes to ventilate the patient.
- **Harminder singh Johar, Kuldeep Yadav [3]:** DRDO's Portable Low-Cost Ventilator "DEVEN": This was proposed by scientists of DRDO. This ventilator has 2 working modes, Hospital mode and stand-alone mode. Hospital mode works with pressurized air which is readily available in the hospitals & Stand-alone mode works with tyre inflator. This stand-alone mode is used when there is shortage of oxygen in hospitals.
- **Aditya Vasan, Reiley Weekes William Connacher[4]:** MAD Vent: A low-cost ventilator for patients with COVID-19:The MAD Vent ventilator has a novel torque conversion mechanism via a simple pulley and lanyard system to convert the relatively low-torque, high speed rotation of the motor to a high-torque.It also uses Lever and pulley mechanism for reliable and quiet actuation.
- **Alexander Slocum, Daniela Rus, Albert Kwon [5] :** MIT Emergency Ventilator Project: Students and faculty from MIT have proposed this. This mechanism uses motor driven cam mechanism where the ambu bag is squeezed with the help of motor.
- **San Reilly, Sadie, Tom Breddal [6]:** Open Vent-Bristol V2.0 COVID-19 Rapid Manufacture Ventilator BVM Ambu bag. This mechanism uses high torque DC motor placed above the Ambu bag. It uses acrylic housing and controllable LCD display. The approximate cost of this ventilator is 400 EUR(40,000 INR)
- **MPS open-source ventilator[7]:** MPS university students and professors developed this ventilator. This uses three gears mechanism connected to each other i.e., all the three gears are driven by the same motor. This has got maximum 800 ml of tidal volume

and 40 BPM. This system has got extra battery back up to operate in power loss situation.

- **Association for the Advancement of Medical Instrumentation (AAMI) and WHO design guidance for ventilator [8]:** AAMI has given some of the guidance for design of mechanical ventilator. Which include,

1. For mandatory modes, respiratory rate from (10 to 30) inflations/min preferably adjustable in steps of no more than 2 inflations/min.
2. Tidal volume (350 to 450) ml ±10 % in no more than steps of 50 ml, preferably a lower range of 250 ml and an upper range of 600 ml or 800 ml
3. Ventilator should contain PEEP (Positive End Expiratory Pressure) valve which is used to maintain pressure on the lower airways at the end of the breathing cycle which prevents the alveoli from collapsing during expiration.it prevents ventilator induced lung injury and also improves oxygenation.
4. In case of emergency the ventilator should have an option of manual squeezing.
5. It should contain volume control and BPM (breaths per minute) control
6. It should deliver air or a mixture of air and oxygen at high flow rates and a single set pressure, typically between 3 and 20 cmH2O,
7. It should be easily potable and preferable cost.

2.1 SUMMARY OF LITERATURE SURVEY

- The literature on the present context reveals that there have been number of attempts to design low-cost mechanical ventilator by giving automated touch to manual resuscitator.
- However, many of these devices cannot be used in ICU and serious conditions of the patients. Majority of these devices use complex circuit’s which increases the risk of being failed.

CHAPTER 3

OBJECTIVES AND METHODOLOGY

3.1OBJECTIVES

- To design a very simple low-cost mechanical ventilator.
- To fabricate the mechanical ventilator using readily available components. So that people in rural area can make this mechanism with minimum knowledge of engineering.
- Industries can manufacture it quickly and easily with low cost of investment.
- Ventilator can operate from 10 BPM to 30 BPM, tidal volume of 10% to 100%.
- To incorporate modern technology to increase ventilators efficiency

3.2 METHODOLOGY

This ventilator has an automated touch to a manual resuscitator. Manual resuscitator ventilation is carried out by professional nurses and experts. it is not possible to do it for a long time by nurse because they nurse gets tired and also not feasible to do it with a constant rate. So, we have used a servomotor motor with Arduino in order to squeeze the Ambu bag.

The procedure mentioned in flow chart will be followed during design and fabrication of the product

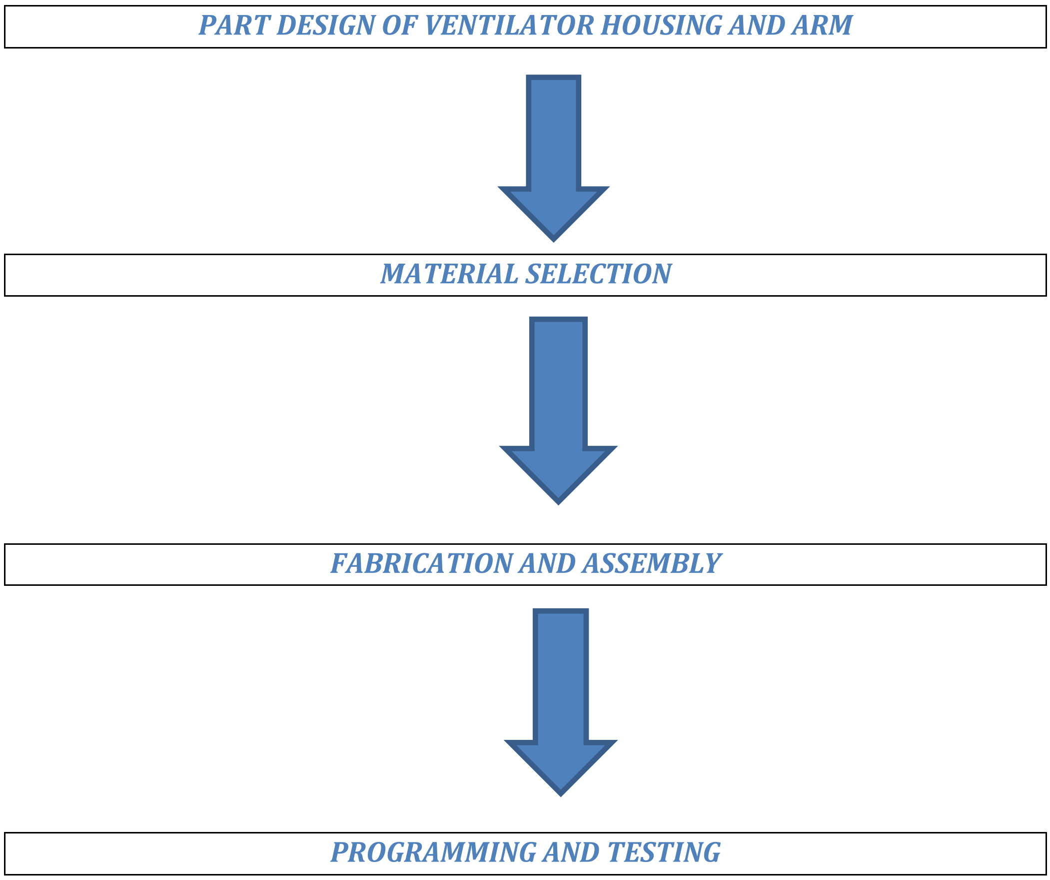

Fig 3.2 Flow chart of methodology

CHAPTER 4

VENTILATOR SPECIFICATION, DESIGN & SELECTION OF COMPONENTS

4.1Specifications of portable mechanical ventilator:

- Respiratory rate (breaths per minute): 10 to 30 bpm.
- Tidal Volume (TV) (air volume pushed into lung): between 200 – 800 mL based on patient weight.
- I/E ratio (inspiration/expiration time ratio): recommended to star around 1:2; best if adjustable between range of 1:1- 1:4.
- FiO_2 (The fraction of inspired oxygen is the concentration of oxygen in the gas mixture): 21 to 100 %.
- Volume and pressure control modes.
- Noise level to be less than 35 dBA at mid pressure range.
- Expiratory relief features that reduce the pressure slightly at the end of each breath to make it easier for the patient to exhale.
- Portable equipment with mechanical strength to withstand rough handling.
- Inlet and expiratory bacterial filters.
- Safety alarms.

4.2 CAD MODEL:

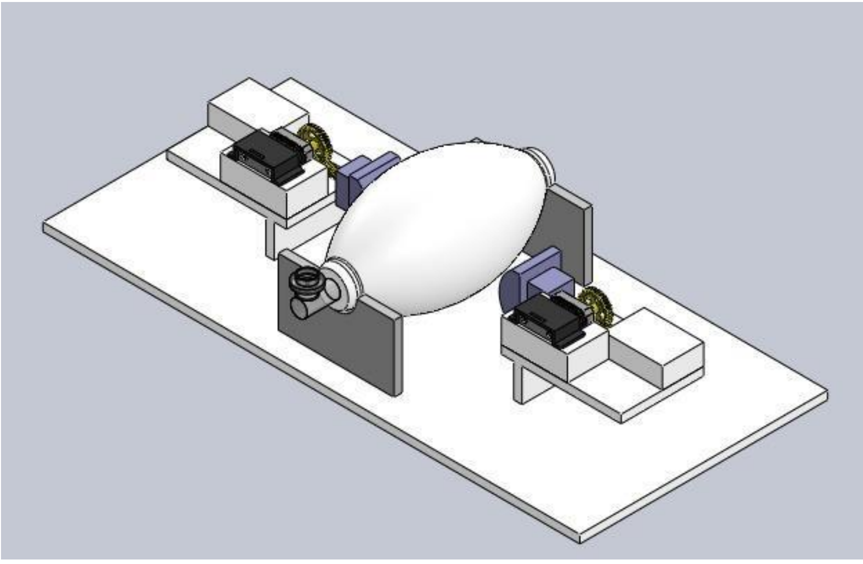

Fig 4.2 a. An Isometric view of ventilator

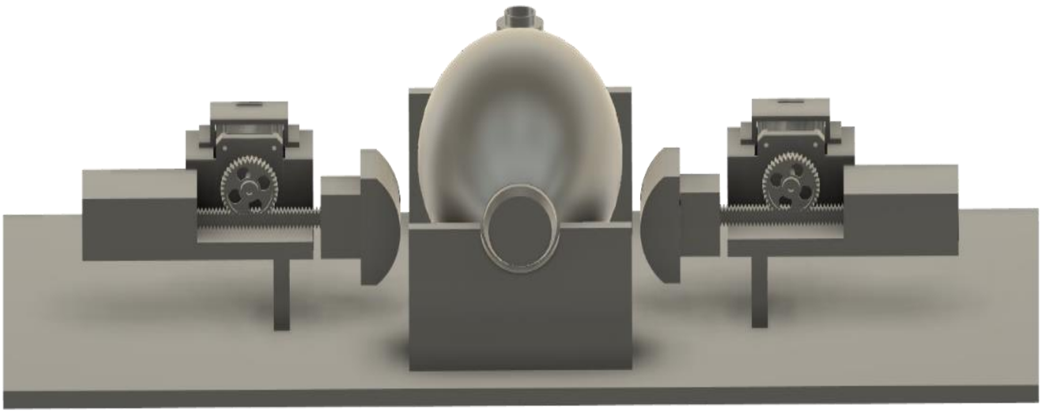

Fig 4.2 b. Handler side view

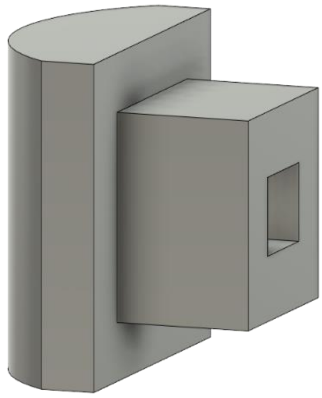

Fig 4.2 c. Pressing Arm

4.2.1 2D DRAWING OF VENTILATOR ASSEMBLY

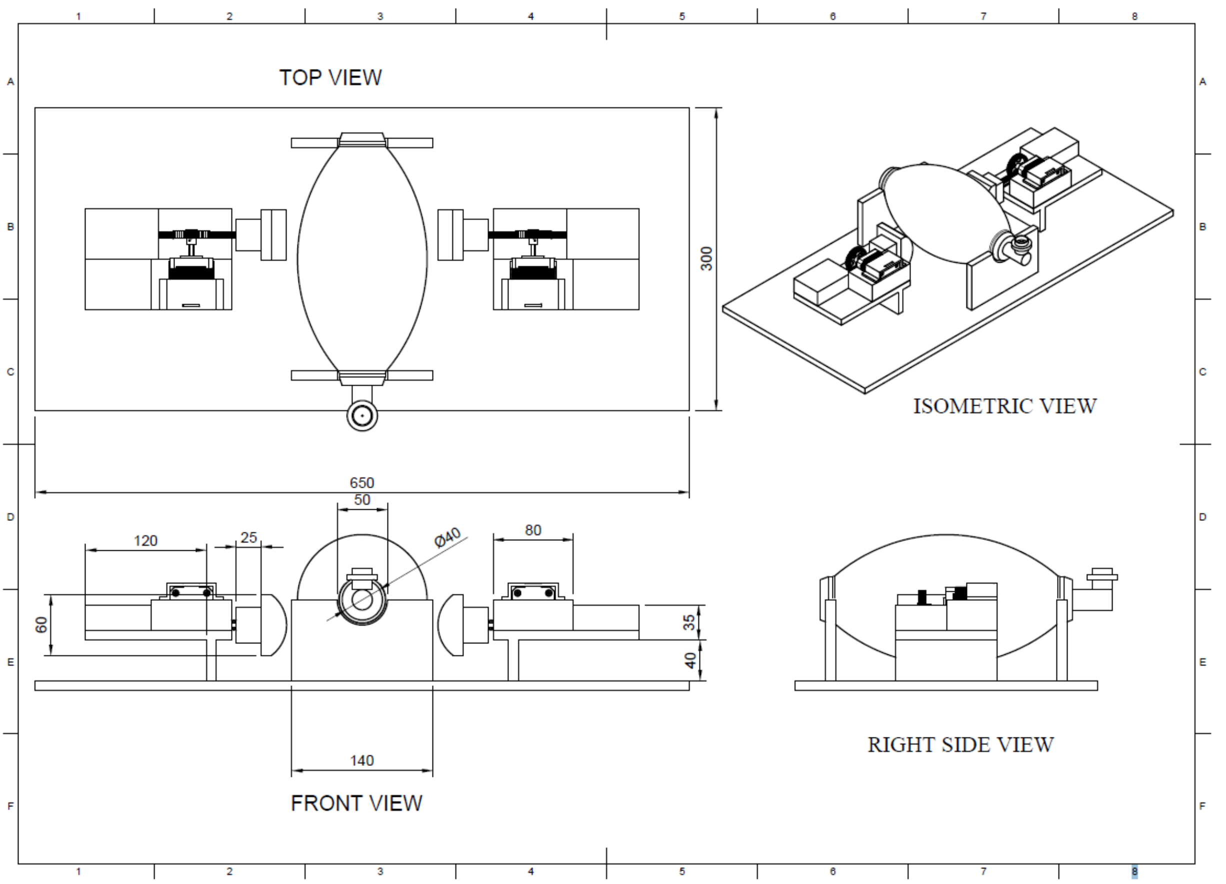

Fig 4.2.1 2D drawing of ventilator assembly

4.3 Main components:

- Bag valve mask setup
- Waterproof 35kg 180 Degree Large Torque Digital Coreless Servomotor
- 2004 LCD Display Module with Blue Backlight
- 24-bit Analog-to-digital converter (ADC) with built-in temperature sensor (HX710A) and voltage difference detection (HX710B)
- Arduino UNO R3 Development Board
- Rotary Encoder for Arduino
- Pressure sensor
- Pulse Oximeter Heart Rate Sensor Module.
- Power adapter.
- Sun board sheet or PVC Foam Boards.

4.4 Detailed description of components:

4.4.1 Bag valve mask:

- The important component of this portable mechanical ventilator is bag valve mask (BVM), the BVM has several different names: like Ambu(Artificial Manual Breathing Unit) ,manual resuscitator, self- inflating bag.
- It is a hand-held device commonly used to provide positive pressure ventilation to patients who are not breathing or not breathing adequately.
- Depending on bag size it comes in three different varieties like for infant, children and adult.
- According to people affected by respiratory problems adult Ambu bag is chosen.
- This can be used for people weighing more than 40 kg. This fixture is equipped with a mask, equipped with a mask, a tank of oxygen with a volume of 1800 ml, bag of 1500 ml., the air mixture comes out in a volume of 800-1350ml.
- The components of bag valve mask are:
- **Self-inflating bag:** It is designed in such a way that when it is manually compressed, it will automatically re-expand on its own there by drawing in air for the next breathes.

Specifications:

- Operating temperature -18 °C to 50 °C (-4 °F to 122 °F) at humidity between 15% and 95%
- Storage temperature -40 °C to 60 °C (-40 °F to 140 °F) at humidity between 40% and 95%
- Bag material: silicone rubber.
- Total bag volume: 1475 ml

Non rebreathing valve:

- It is an internal valve which is used to control the direction of air flow during inspiration and expiration.
- Most non rebreathing valves are T shaped. It is most preferred that the housing be transparent so that internal mechanism can be observed.

Patient connector:

- It is the part that connects to the tracheal tube or face mask or supra glottic device (Supraglottic devices or airways (SGAs) are a group of airway devices that can be inserted into the pharynx to allow ventilation, oxygenation). It has a 15mm female and 22 mm male coaxial fitting.

Oxygen reservoir:

- High concentrations of oxygen can be achieved with a self-inflating bag through the use of an oxygen reservoir. It provides a chamber filled with a high concentration of oxygen. During re-inflation, instead of room air being drawn in, the bag draws the highly oxygen enriched air in the reservoir.

Specification: Oxygen reservoir volume: 2600 ml

Bacterial viral filter:

- These are medical devices used in respiratory ventilators or breathing circuits to protect patients, equipment, and/or the environment from viruses and bacteria.
- They are of two types, electrostatic or mechanical, based on their working principle: electrostatic filters use an induced electrostatic charge to capture particles, while mechanical filters use a pleated porous membrane. Mechanical filters can reach higher filtration efficiency than electrostatic filters.

Fig 4.4.1 e Bacterial viral filter

- **Pop off valve**

The purpose of this is to prevent accidental over- pressurization of the lungs. These pressure release valves are set to release at 30-40 cm of water. Therefore, if pressures in excess of this limit are generated, the valve opens, preventing the excess pressure from being transmitted to the patient.

4.4.2 Digital Servomotor motor:

- In order to have automated resuscitation digital coreless servomotor is used. The main function of any motor is to convert electrical power to mechanical power.
- The options we had was AC motor, DC motor, stepper motor. where Ac motor operates at low speeds and DC motor has high initial investment and maintenance. The motors available for precise motion control are stepper and servomotor. where Stepper motors make some noises, which cannot be used in hospitals.
- Servomotors can be defined as a rotary actuator or linear actuator. or that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback
- The advantages of servomotors are high efficiency, high output power relative to their size, quite operation, more reliable, torque control and high accuracy.
- Some of the application include robotic application, machine tools where high accuracy is required, printing press, defense application.

4.4.3 Theoretical Power Requirement: The required power output can be computed from the worst-case values of the following variables:

- Maximum pressure at airway: $P_{airway,max}$ = 40 cm H_2O (pop off cracking pressure)= (3922.66 Pa)
- Maximum respiration rate: RR_{max} = 30 bpm
- Minimum inhale/exhale ratio of 1:4: IEratio, min = 4
- Maximum volume output: Vmax = 700 cm^3

That is, in the worst case the device needs to squeeze of air at a pressure of 40 cm H_2O, in a 0.3 second (t_{inhale} = 60 sec / RR_{max}) / (1 + IEratio, min)).

(60/30) / (1 + 4) = 0.4

The volumetric flow rate needed in the worst-case (peak) scenario is, then:

$Q_{airway} = V_{max} / t_{inhale}$

(0.0007/0.4) = 0.00175 m3/s

The power output (in the form of pressurized volume flow in the airway) is:

$Power_{airway} = P_{airway,max} \times Q_{airway}$

3922.66 x 0.0027 = 6.865 W

However, some of the power used for squeezing the bag is lost (Bag deformation, friction etc.) and estimating it as 50% is converted to pressurized volume flow. Taking this efficiency into account power required is

Power= 2Powerairway

= 2 x 6.865

= 13.73 W

Now power= torque x rotational speed

By taking no load speed 50 rpm (5.236 rad/sec) Torque = 13.73 / 5.236

= 2.622 n-m ≈ 27 kg-cm

Depending on the value of torque 35 kg-cm Servo motor is chosen.

Fig 4.2.3: Servomotor

Specifications:

- Size: 40.0*20.5*40.5mm
- Weight: 56g±2g
- Limit angle: 360°
- Horn gear spline: 25T Diameter :5.9mm
- Motor: Carbon brush moto
- Operating voltage: 4.8V - 7.2V
- Running current: 140mA - 200mA
- Peak stall torque: 32.7kg.cm - 35.2kg.cm
- Stall current: 2600mA±10% - 3400mA±10%
- Working voltage range: 4.8 - 7.2V

4.4.4 LCD Display Module:

Fig:4.4.4: 2004 LCD display module

This LCD 2004 Parallel Display Module is very commonly used in various devices and circuits and also easy to interface with Arduino or Other Microcontrollers. A 2004 LCD means it can display 20 characters per line and there are 4 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. This is standard HD44780 controller LCD.

The values shown on the display can be either a simple text or numerical values read by the sensors, such as temperature or pressure, or even the number of cycles that the Arduino is performing.

Specification:

- Model: LCD2004
- Input Voltage (V): 5
- Characters: 20
- Lines: 4
- Backlight: Blue
- Character color: white

4.4.5 24-bit ADC with built in temperature sensor (HX710A) and voltage difference detection (HX710B):

Based on Avia Semiconductor's patented technology, HX710(A/B) is a precision 24-bit analog-to-digital converter (ADC) with built-in temperature sensor (HX710A) or DVDD, AVDD voltage difference detection (HX710B). It's designed for weigh scales and industrial control applications to interface directly with a bridge sensor. The input low-noise amplifier (PGA) has a fixed gain of 128, corresponding to a full-scale differential input voltage of ±20mV, when a 5V reference voltage is connected to the VREF pin. On chip oscillator provides the system clock without any external component. On-chip power on- reset circuitry simplifies digital interface initialization. There is no programming needed for the internal registers. All controls to the HX710 are through the pins.

4.4.6 Arduino NANO R3 Development Board

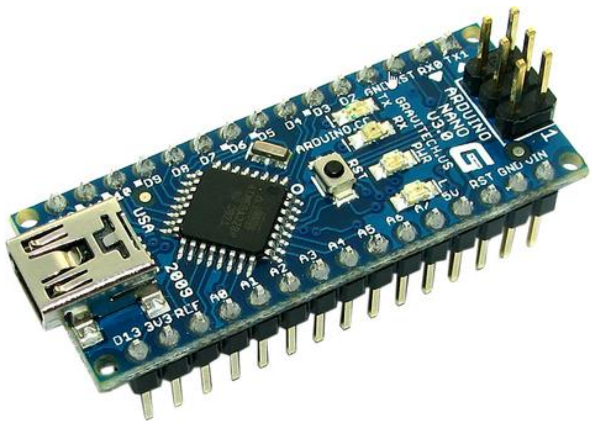

Fig 4.4.6 Arduino NANO board

The Arduino Nano is a compact board similar to the UNO. The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x). The Arduino Nano can be powered via the Mini-B USB connection, 6-20V unregulated external power supply, or 5V regulated external power supply. The power source is automatically selected to the highest voltage source. Each of the 14 digital pins on the Nano can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA The Arduino Nano can be programmed with the Arduino software

Specification:

- Microcontroller: ATmega328
- Architecture: AVR
- Operating Voltage: 5 V
- Flash Memory:32 KB of which 2 KB used by bootloader
- SRAM:2 KB
- Clock Speed: 16 MHz
- Analog I/O Pins: 8
- EEPROM:1 KB
- DC Current per I/O Pins:40 mA (I/O Pins)
- Input Voltage: 7-12 V

- Digital I/O Pins: 22
- PWM Output: 6
- Power Consumption 19 mA

4.4.7 Pinout Diagram:

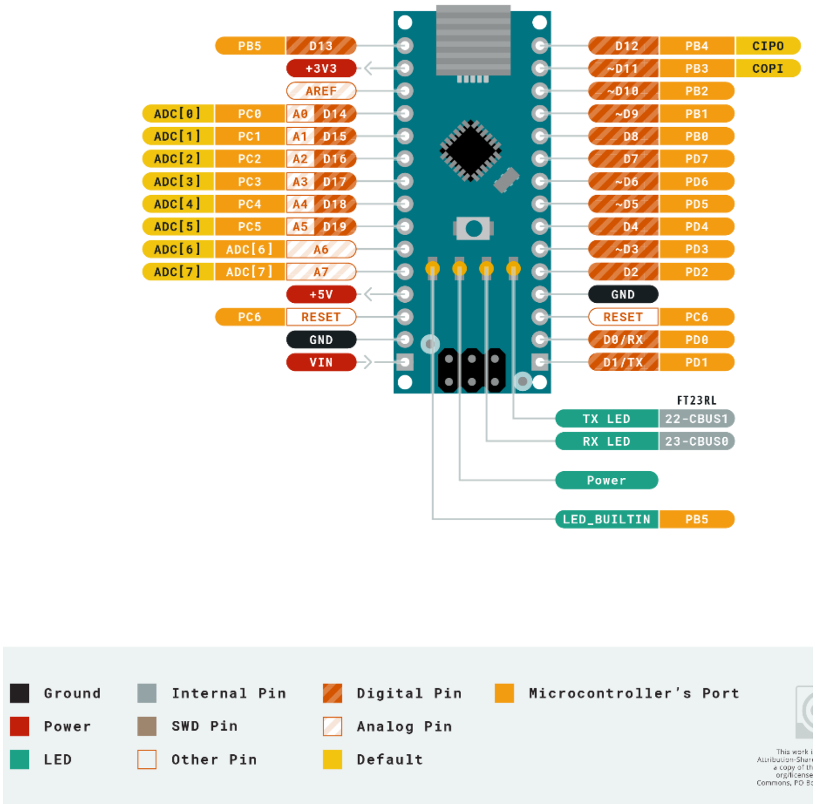

Fig:4.4.7 a Pinout diagram of Arduino uno

4.4.8 Potentiometer for Arduino:

A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat. Potentiometers are used to control volume and tone.10k shaft potentiometer is used in this ventilator.

Pin Assignment: The pin outs for this potentiometer are identified in the illustration below.

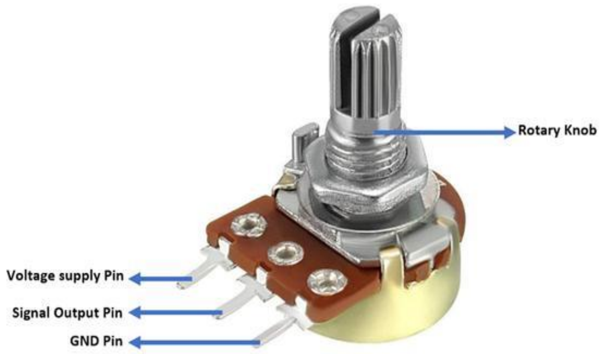

Fig: 4.4.8 Pin Assignment

The diagram shows the parts present inside a potentiometer. It has 3 pins. Two terminals are connected to a resistive element and the third terminal is connected to an adjustable wiper. The potentiometer can work as a rheostat (variable resistor) or as a voltage divider. So, a 10k potentiometer is 10k ohms across, and the wiper goes from one end (0 ohms) to the other (10k ohms).

Specification:

- Operating voltage: 5V.
- Output signal: Analog signal.
- Resistance Value: 10K ohm;
- Adjustment Type: Top Adjustment.
- Compatible with Arduino/Raspberry Pi controller board.

4.4.9 Pressure Sensor:

Pressure is defined as an evenly distributed force acting over a surface with a given area. The accurate measurement of pressure is essential for applications ranging from material testing to weighing scales, aircraft altitude prediction, and evaluating biological functions in humans relating to respiration and blood flow. Pressure sensors function under a variety of different physical principles that include: fluid density and gravity, piezoelectricity, piezo resistivity, electrical capacitance, and electrical resistivity.

Fig:4.4.9 Pressure sensor

Specification:

- Range: 40kpa (differential pressure)
- Electricity supply: 5VDC or constant current 1Ma
- Measure the pressure range of 580 PSIG, 40KPaG
- Input impedance of 4 - 6 KΩ
- The output impedance of 4 - 6 KΩ
- Operating temperature -40 - 85 ° C -40 ° F - +185 ° F
- Bias voltage ± 25 mV
- Full-scale output voltage 50 - 100 mV

4.4.10 MAX30100 Pulse Oximeter Heart Rate Sensor Module:

Fig:4.4.10 Heart Rate Sensor Module

It is an optical sensor that derives its readings from emitting two wavelengths of light from two LEDs – a red and an infrared one – then measuring the absorbance of pulsing blood through a photodetector. This particular LED color combination is optimized for reading the data through the tip of one's finger. It is fully configurable through software registers and the digital output data is stored in a 16-deep FIFO within the device. It has an I2C digital interface to communicate with a host microcontroller. The pulse oximetry subsystem in MAX30100 consists of ambient light cancellation (ALC), 16-bit sigma delta ADC, and proprietary discrete time filter.MAX30100 operates on a supply in the range of 1.8 to 3.3V.

4.4.11 PVC Foam Boards

PVC Foam Boards are nothing but Rigid PVC Sheets manufactured using foaming agent to foam the PVC Sheets. "Sun board" is the company name that manufactures the boards. And hence brand's popularity has made people remember the product has Sun Board Sheets. These sheets are extruded from Virgin grade PVC granules’ foam board is moisture and corrosion resistant. It is absolutely lightweight. It is also resistant to chemicals. Other feature includes **High Strength & Durability, fire resistant, water resistant.** It is feasible to engrave, emboss, paint, print, laminate and mill the surface of the foam board according to your requirements.

CHAPTER 5

FABRICATION AND ASSEMBLY OF MECHANICAL VENTILATOR

5.1 Fabrication of Ventilator

Fabrication is the process of constructing products by combining typically standardized parts using one or more individual processes. In this ventilator we have used sun board or PVC foam board. This Sun board is cut according to the Cad model created. Also, acrylic sheet is used on the top of the ventilator, to enclose the moving part inside the ventilator which is a safety method.

Some of the fabrication techniques involved in Portable mechanical ventilator are

1. CNC routing
2. 3D printing
3. Drilling

1. **CNC ROUTING:** A computer numerical control (CNC) router is a computer-controlled cutting machine which typically mounts a hand-held router as a spindle which is used for cutting various materials, such as wood, composites, aluminum, steel, plastics, glass, and foams. CNC routers can perform the tasks of many carpentry shop machines such as the panel saw, the spindle molder, and the boring machine. A CNC router is very similar in concept to a CNC milling machine. Instead of routing by hand, tool paths are controlled via computer numerical control. CNC router is used with two software applications—one to make designs (CAD) and another to translate those designs into a G-code program of instructions for the machine (CAM). Acrylic sheet used to cover the ventilator is also cut using CNC routing.
2. **3D PRINTING:** 3D printing or additive manufacturing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by laying down successive layers of material until the object is created. Each of these layers can be seen as a thinly sliced cross-section of the object.3D printing enables us to produce complex shapes using less material than traditional manufacturing methods.

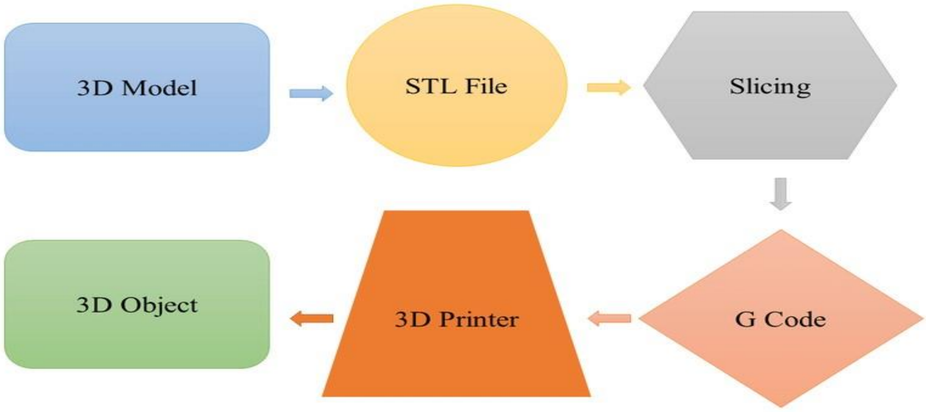

Fig 5.1 3D printing block diagram

The arm fixed to the rack and pinion is manufactured using 3D printer. The CAD model created is extracted in .STL (Standard Tessellation Language) file format and imported into slicing software. In this software all the parameters like temperature, colour, time etc is edited and G codes are created and fed into the 3D printer.

3. DRILLING: Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials. Small holes are drilled into sun board and acrylic sheet in order to Assemble and disassemble the parts easily. Threaded screws are used to fit assemble parts.

5.2 ASSEMBLY

Once all the components are made ready, they have to be assembled to get a final product. In this portable mechanical ventilator, we have two kinds of assembly

1. Mechanical assembly
2. Electronics assembly

5.2.1 MECHANICAL ASSEMBLY: Mechanical assembly is nothing but assembling of mechanical parts in the ventilator i.e., connecting the 3D printed arm to rack and pinion mechanism in turn connecting it to a servomotor. servo horn is used to connect servo to to the rack and pinion mechanism.

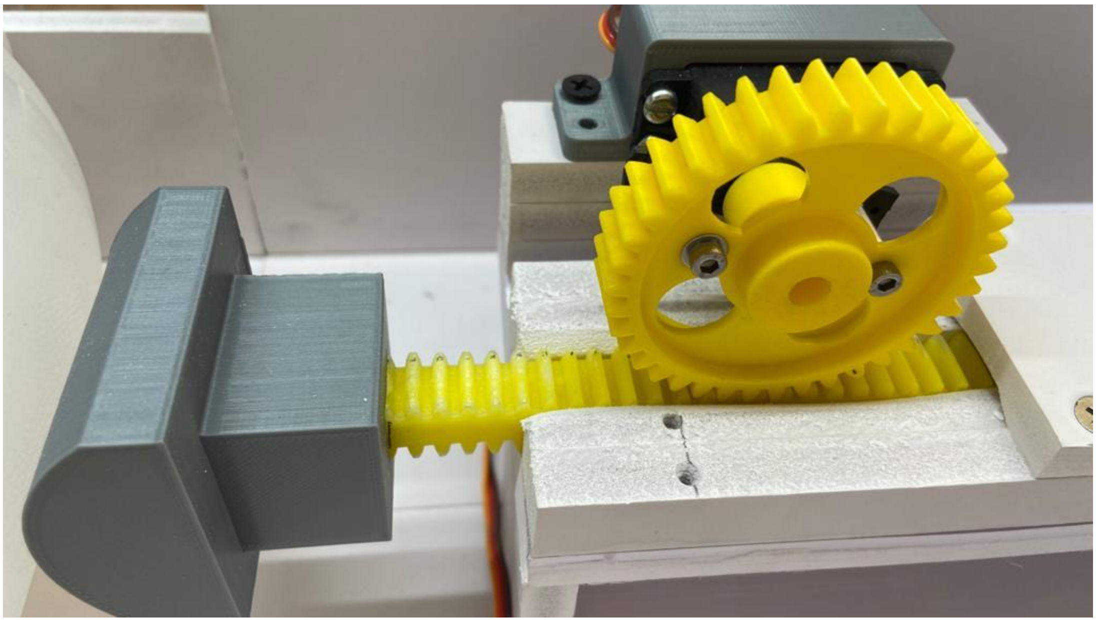

Fig:5.2.1 Mechanical Assembly

5.2.2 ELECTRONICS ASSEMBLY: electronics assembly is the assembly of all the circuits according to the circuit diagram created.

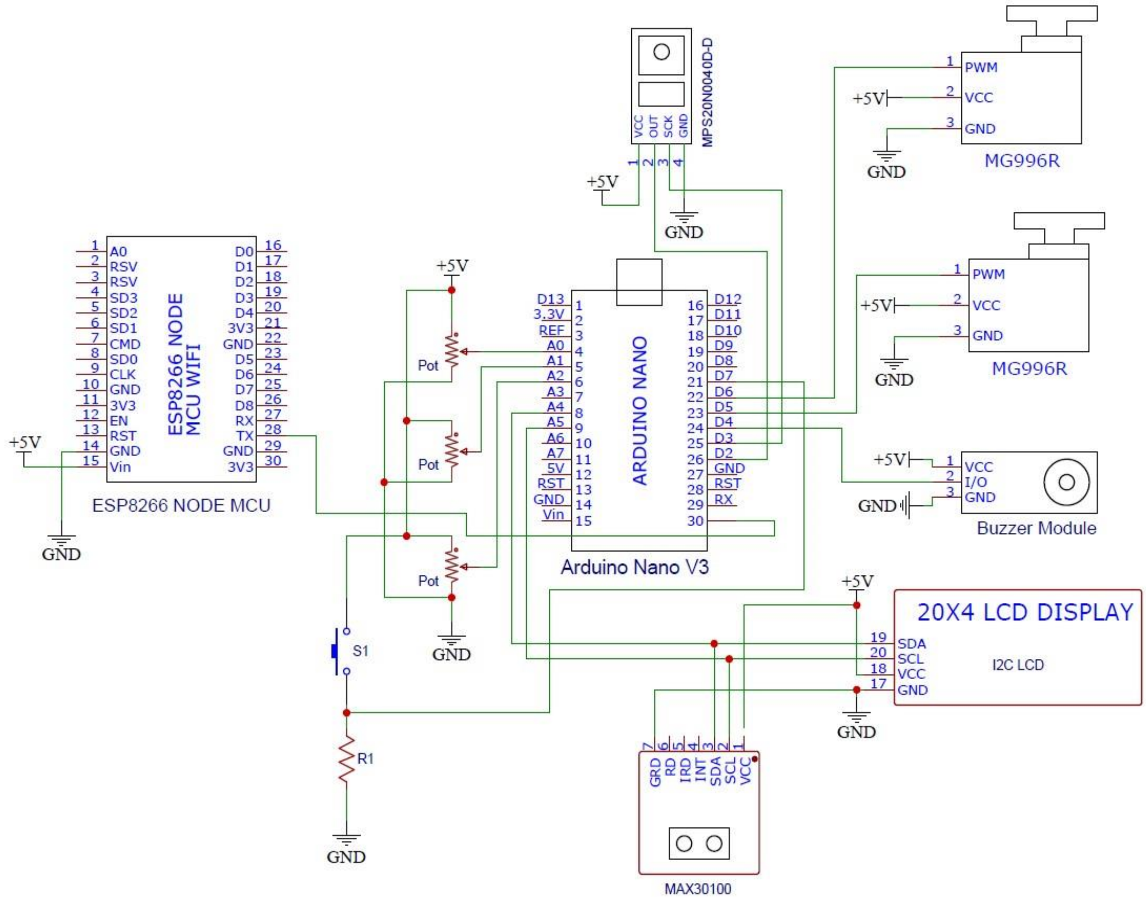

Fig5.2.2 circuit diagram of electronics assembly

The circuit diagram of electronics assembly is shown above. Jumper wires are used to connected between the circuits. Arduino nano V3 is the main circuit to which all the other circuits are connected. Also, this Arduino Nano is connected to node MCU in order to obtain wireless connection. Three potentiometers are connected to Arduino for adjustable respiratory rate, tidal volume and I/E ratio. A buzzer module is also connected to the Arduino. All the circuit connection are made and placed inside ventilator housing

Fig 5.2.2(a) Assembly image 1

Fig 5.2.2(b) Assembly image 2

Fig 5.2.2 (c) Electronics Assembly

CHAPTER 6

PROGRAMMING OF ARDUINO

6.1 SOFTWARE REQUIREMENTS

Arduino is an open-source hardware and software company, project and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices. Arduino board designs use a variety of microprocessors and controllers. The boards are equipped with sets of digital and Analog input/output (I/O) pins that may be interfaced to various expansion boards or breadboards and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs. The microcontrollers can be programmed using the C and C++ programming languages, using a standard API which is also known as the "Arduino language". In addition to using traditional compiler toolchains, the Arduino project provides an integrated development environment (IDE) and a command line tool developed in Go.

6.1.1 ARDUINO INTEGRATED DEVELOPMENT ENVIRONMENT (IDE)

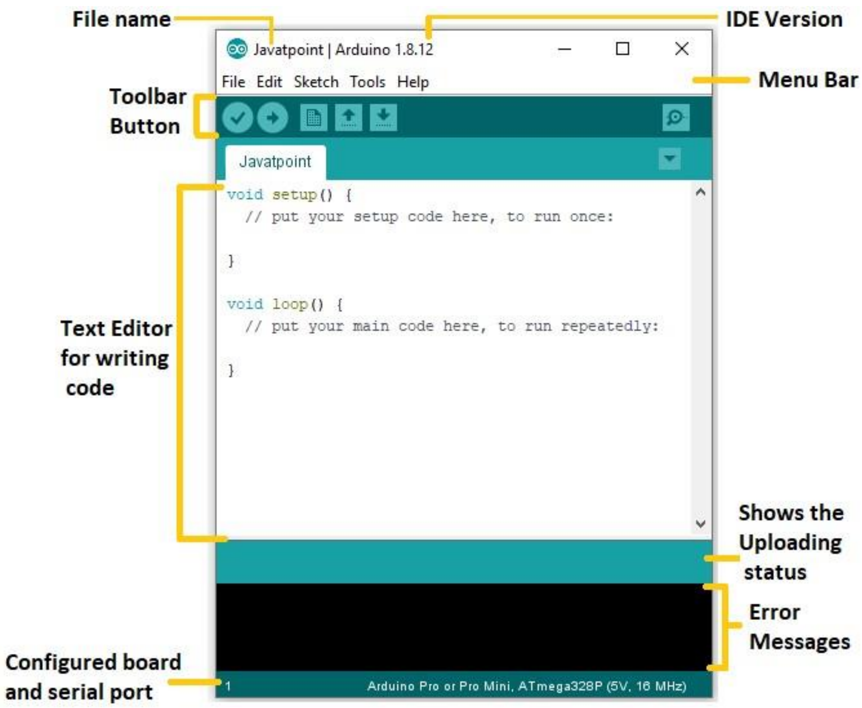

Fig 6.1.1 Arduino IDE interface

The open-source Arduino Software (IDE) makes it easy to write code and upload it to the board. It runs on Windows, Mac OS X, and Linux. The environment is written in Java and based on Processing and other open-source software. This software can be used with any Arduino board. The Arduino Integrated Development Environment is a cross-platform application that is written in functions from C and C++. It is used to write and upload programs to Arduino compatible boards.

6.2 WRITING SKETCHES

Programs written using Arduino Software (IDE) are called sketches. These sketches are written in the text editor and are saved with the file extension .ino. The editor has features for cutting/pasting and for searching/replacing text. The message area gives feedback while saving and exporting and also displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information. The bottom right-hand corner of the window displays the configured board and serial port. The toolbar buttons allow you to verify and upload programs, create, open, and save sketches, and open the serial monitor.

6.2.1 TOOLS

- **Auto Format:** This formats our code nicely: i.e., indents it so that opening and closing curly braces line up, and that the statements inside curly braces are indented more.
- **Archive sketch:** Archives a copy of the current sketch in .zip format. The archive is placed in the same directory as the sketch.
- **Fix Encoding & Reload:** Fixes possible discrepancies between the editor char map encoding and other operating systems char maps.
- **Serial Monitor:** Opens the serial monitor window and initiates the exchange of data with any connected board on the currently selected Port. This usually resets the board, if the board supports Reset over serial port opening
- **Board**: Select the board that you're using. See below for descriptions of the various boards.
- **Port:** This menu contains all the serial devices (real or virtual) on your machine. It should automatically refresh every time you open the top-level tools menu

- **Programmer**: For selecting a hardware programmer when programming a board or chip and not using the onboard USB-serial connection. Normally we won't need this, but if we're burning a bootloader to a new microcontroller, we will use this.
- **BurnBootloader**: The items in this menu allow you to burn a bootloader onto the microcontroller on an Arduino board. This is not required for normal use of an Arduino or Genuino board but is useful if you purchase a new ATmega microcontroller (which normally come without a bootloader). We should Ensure that we have selected the correct board from the Boards menu before burning the bootloader on the target board. This command also set the right fuses.

6.2.2 SKETCHBOOK

The Arduino Software (IDE) uses the concept of a sketchbook: a standard place to store our programs (or sketches). The sketches in our sketchbook can be opened from the File > Sketchbook menu or from the Open button on the toolbar. The first time we run the Arduino software, it will automatically create a directory for your sketchbook. we can view or change the location of the sketchbook location from with the Preferences dialog.

6.2.3 UPLOADING

Before uploading our sketch, we need to select the correct items from the Tools > Board and Tools > Port menus. The boards are described below. On the Mac, the serial port is probably something like /dev/tty. usbmodem241 (for an Uno or Mega2560 or Leonardo) or /dev/tty.usbserial-1B1 (for a Duemilanove or earlier USB board), or /dev/tty. USA19QW1b1P1.1 (for a serial board connected with a Keyspan USB-to-Serial adapter). On windows,it's probably COM1 or COM2 (for a serial board) or COM4, COM5, COM7, or higher (for a USB board) - to find out, we look for USB serial device in the Ports section of the Windows Device Manager. On Linux, it should be /dev/ttyACMx , /dev/ttyUSBx or similar. Once you've selected the correct serial port and board, press the upload button in the toolbar or select the Upload item from the Sketch menu. Current Arduino boards will reset automatically and begin the upload. On most boards, we'll see the RX and TX LEDs blink as the sketch is uploaded. The Arduino Software (IDE) will display a message when the upload is complete, or show an error. When we upload a sketch, we're using the Arduino bootloader The bootloader is active for a few seconds when the board resets; then it starts whichever sketch was most recently uploaded to the microcontroller. The bootloader will blink the on-board (pin 13) LED when it starts (i.e., when the board resets).

6.3 BLYNK

Fig 6.3 Blynk

Blynk was designed for the Internet of Things. It can control hardware remotely, it can display sensor data, it can store data, visualize it and do many other cool things.With Blynk, we can create smartphone applications that allow you to easily interact with microcontrollers or even full computers such as the Raspberry Pi. The main focus of the Blynk platform is to make it super-easy to develop the mobile phone application. With Blynk, we can control an LED or a motor from our mobile phone with literally zero programming. Blynk is free to use for personal use and prototyping.

There are three major components in the platform:

- **Blynk App** - allows us to create amazing interfaces for our projects using various widgets we provide.
- **Blynk Server** - responsible for all the communications between the smartphone and hardware. We can use our Blynk Cloud or run our private Blynk server locally. It’s open-source, could easily handle thousands of devices and can even be launched on a Raspberry Pi.
- **Blynk Libraries** - for all the popular hardware platforms - enable communication with the server and process all the incoming and outcoming commands

6.4 PROGRAM

```
// Libraries:
#include<Wire.h>
/* Built-In Library */

#include<LiquidCrystal_I2C.h>
/* Add Zip: https://github.com/fdebrabander/Arduino-LiquidCrystal-I2C-library */
#include <Servo.h>
/* Built-In Library */
#include <Q2HX711.h>

// Pin Numbers:
#define APS_OUT_Pin 2   /* Connect OUT pin of the Air Pressure Sensor */
#define APS_SCK_Pin 3   /* Connect SCK pin of the Air Pressure Sensor */
#define Buzzer_Pin 4      // Connect to the I/O pin of Buzzer Module.
#define LftServo_Pin 5    // Connect to Servo Motor
#define RytServo_Pin 6    // Connect to Servo Motor
#define EmergencySwitch_Pin 7  // (Input) Connect to push button.
#define OnOffSwitch_Pin 8   // Connect to switch.



// Constants: Potentiometer Pins
const int RR_Pot_Pin = A0;        // (I/P) Connect to potentiometer.
const int TidalVol_Pot_Pin = A1;  // (I/P) Connect to potentiometer.
const int IERatio_Pot_Pin = A2;   // (I/P) Connect to potentiometer.

// Constants: LCD Configuration
const uint8_t I2C_Addr = 0x27; // I2C Address
const uint8_t lcdNumCols = 20; // LCD's number of columns
const uint8_t lcdNumRows = 4;  // LCD's number of rows
// Constants: Buzzer Module
const bool buzzerOn = HIGH, buzzerOff = LOW;
```

```
// Constants: Servo Position
const int Lft_SrvPullPos = 180;
const int Ryt_SrvPullPos = 0;

const int Lft_SrvPushPos = 60;
const int Ryt_SrvPushPos = 120;

// Constants:
const int RR_RangeMin = 10;
const int RR_RangeMax = 20;

const int TidalVol_RangeMin = 10;
const int TidalVol_RangeMax = 100;

const int IERatio_RangeMin = 2;
const int IERatio_RangeMax = 4;

// Objects:
LiquidCrystal_I2C lcd(I2C_Addr, lcdNumCols, lcdNumRows);

Q2HX711 objAPS(APS_OUT_Pin, APS_SCK_Pin);
Servo objLftServo;
Servo objRytServo;

// Variables:
int Resp_Rate;
int Tidal_Vol;
int IE_Ratio;
bool EmergencySwitchState;
bool OnOffSwitchState;

int angleLft = 160;
int angleRyt = 20;
```

```
int angle;
int Lft_SrvPos;
int Ryt_SrvPos;

unsigned long pullDelay = 1500;
unsigned long pushDelay = 1500;
unsigned long millisB4Entry;

float apsAvgValue;
int avgSize = 10;

  void setup() {
  /* Define Input Pins: */
  pinMode(EmergencySwitch_Pin, INPUT);
  pinMode(OnOffSwitch_Pin, INPUT);



// Define Output Pins:
  pinMode(Buzzer_Pin, OUTPUT);
  digitalWrite(Buzzer_Pin, buzzerOff);

  /* Begin serial communication with Arduino and Arduino IDE (Serial Monitor) */
  Serial.begin(9600);

  // Initialise the LCD display:
  lcd.begin();
  lcd.backlight();  // turn on backlight.
// Print a message on LCD Display:
  lcd.print("     Ventilator     ");
  delay(2000);

  lcd.clear();
```

```
  lcd.setCursor(0, 0);  //(ColIdx, RowIdx)
  lcd.print("Resp Rate: ");
  lcd.setCursor(0, 1);
  lcd.print("Tidal Vol: ");
  lcd.setCursor(0, 2);
  lcd.print("I:E Ratio: ");
  lcd.setCursor(0, 3);
  lcd.print("Pressure : ");

  objLftServo.attach(LftServo_Pin);
  objRytServo.attach(RytServo_Pin);
  objLftServo.write(Lft_SrvPullPos);
  objRytServo.write(Ryt_SrvPullPos);
  delay(3000);
}



  void loop() {
  OnOffSwitchState = digitalRead(OnOffSwitch_Pin);
  if (OnOffSwitchState) {
  lcd.setCursor(17, 0);
  lcd.print("ON ");

  objLftServo.write(Lft_SrvPullPos);
   objRytServo.write(Ryt_SrvPullPos);
millisB4Entry = millis();
    while (millis() - millisB4Entry <= pullDelay) {
      ReadInputs();
    }

    objLftServo.write(Lft_SrvPos);
    objRytServo.write(Ryt_SrvPos);
    millisB4Entry = millis();
```

```
    while (millis() - millisB4Entry <= pushDelay) {
      ReadInputs();
    }
  } else {
    lcd.setCursor(17, 0);
    lcd.print("OFF");

    ReadInputs();

    EmergencySwitchState = digitalRead(EmergencySwitch_Pin);
    if (EmergencySwitchState) {
      lcd.setCursor(19, 2);
      lcd.print("E");
      Buzzer(3, 500, 500);

  lcd.setCursor(19, 2);
      lcd.print(" ");
    }
  }

  delay(100); //Delay of 100ms
}

void ReadInputs() {
Resp_Rate = GetPotRangeValue(RR_Pot_Pin, RR_RangeMin, RR_RangeMax);
  Resp_Rate = Resp_Rate < RR_RangeMin ? RR_RangeMin : Resp_Rate;
  Resp_Rate = Resp_Rate > RR_RangeMax ? RR_RangeMax : Resp_Rate;
  lcd.setCursor(11, 0);
  lcd.print(Resp_Rate);

  Tidal_Vol = GetPotRangeValue(TidalVol_Pot_Pin, TidalVol_RangeMin,
TidalVol_RangeMax);
  Tidal_Vol = Tidal_Vol < TidalVol_RangeMin ? TidalVol_RangeMin : Tidal_Vol;
```

```
Tidal_Vol = Tidal_Vol > TidalVol_RangeMax ? TidalVol_RangeMax : Tidal_Vol;
lcd.setCursor(11, 1);
lcd.print("    ");
lcd.setCursor(11, 1);
lcd.print(Tidal_Vol);
lcd.print("%");
angle = map(Tidal_Vol, 10, 100, 20, 120);
lcd.setCursor(16, 1);
lcd.print("    ");
lcd.setCursor(16, 1);
lcd.print(angle);
lcd.print((char)223);


Lft_SrvPos = Lft_SrvPullPos - angle;
Ryt_SrvPos = Ryt_SrvPullPos + angle;
Serial.print(Lft_SrvPos);
Serial.print(":");
Serial.println(Ryt_SrvPos);

Lft_SrvPos = Lft_SrvPos < Lft_SrvPushPos ? Lft_SrvPushPos : Lft_SrvPos;
Ryt_SrvPos = Ryt_SrvPos > Ryt_SrvPushPos ? Ryt_SrvPushPos : Ryt_SrvPos;
IE_Ratio = GetPotRangeValue(IERatio_Pot_Pin, IERatio_RangeMin, IERatio_RangeMax);
IE_Ratio = IE_Ratio < IERatio_RangeMin ? IERatio_RangeMin : IE_Ratio;
IE_Ratio = IE_Ratio > IERatio_RangeMax ? IERatio_RangeMax : IE_Ratio;
lcd.setCursor(11, 2);
lcd.print(IE_Ratio);

apsAvgValue = 0;
for (int i = 0; i < avgSize; i++) {
  apsAvgValue += objAPS.read();
  delay(100);  // delay between readings
}
```

```
  apsAvgValue /= avgSize;
  lcd.setCursor(0, 3);
  lcd.print(apsAvgValue);

  delay(100);
}

int GetPotRangeValue(int Pot_Pin, int rangeMin, int rangeMax) {
  int potValue = analogRead(Pot_Pin);
  int setValue = map(potValue / 10, 0, 102, rangeMin, rangeMax);
//  Serial.print(potValue);
//  Serial.print(":");
//  Serial.println(setValue);
  return setValue;
}

void Buzzer(int n, int onDelay, int offDelay) {
  for (int i = 1; i <= n; i++) {
    digitalWrite(Buzzer_Pin, buzzerOn);
    delay(onDelay);
    digitalWrite(Buzzer_Pin, buzzerOff);
    delay(offDelay);
  }
}
```

CHAPTER 7

WORKING AND TESTING OF MECHANICAL VENTILATOR

7.1 WORKING

The basic function of portable mechanical ventilator is rack and pinion mechanism. A rack and pinion is a type of linear actuator that comprises a circular gear engaging a linear gear, which operate to translate rotational motion into linear motion. Driving the pinion into rotation causes the rack to be driven linearly. Driving the rack linearly will cause the pinion to be driven into a rotation. In this we have used plastic gear in order minimize the sound and weight of the ventilator. Then this rack and pinion is connected to the arm that is designed and 3D printed. Two servomotors are used to control rack and pinion mechanism. Power is supplied through adapter. Ambu bag is placed in-between two rack and pinion and with desired volume and rate is can be squeezed. Arduino nano is used to have controllable access. three potentiometer is used one to control tidal volume, respiratory rate, and Inspiration/expiration r Tidal volume has a setting of minimum 10% to maximum 100% volume delivery. Respiratory rate from 10 bpm to 30 bpm. Inspiration/expiration have 3 setting i.e., 1:2,1:3,1:4. Also we have used a buzzer module for emergency situation. Arduino is also connected to pressure sensor in order to measure the pressure of air coming out of ambu bag. Other important feature of this ventilator is it can display the reading in LED and also in Android phone with the help of node MCU. Then the air coming out of Ambu bag is supplied into patient through mask to the patient at desired control.

7.2 TESTING

The ventilator was tested in different position in order to check for its motion at different base angles. Also, the ventilator was operated continuously for around 2 hours and wear and tear of gear was analyzed.

CHAPTER 8

CONCLUSION

The lack of adequate ventilatory support has already caused preventable deaths in the first two waves of the COVID-19 pandemic, and more can be expected unless ventilators can quickly be provided to areas overburdened with COVID-19 patients, both now and in the inevitable future surges of other infection.

- This ventilator is capable of safely meeting the diverse ventilation requirements of COVID-19 patients because its parameters are adjustable over the broad ranges required for ARDS patients.
- The combination of easily available components and CNC routed parts in addition to our choice of mechanically Assembly and mobile display make our design both Unique, low cost and rapidly manufacturable.
- Our ventilator is not a substitute for well-designed, high end and produced systems. Instead, our system—like many other recent low-cost ventilators arising in this emergency—is a ventilator of last resort during a pandemic or mass casualty event.
- The design focuses upon patient safety, simplicity of manufacturing and modularity.

CHAPTER 9

LIMITATIONS AND FUTURE WORK

9.1 LIMITATIONS

Even though we have designed low-cost ventilator this cannot replace the high-grade mechanical ventilator. The concerned limitation of this ventilator is its size. Also, other limitation is it require continuous power supply. Even though it is used treat less critical patient It also cannot be operated for long periods in a resource-poor environment.

9.2 FUTURE WORK

Our main objective was to have cost effective ventilator. Scope for future work can be of including an additional battery in order to operate in power loss situation. In life saving device like ventilator there has to many parameters which has to be observed. This is possible with using sensors. Many cost-effective and precise sensors that interact with the human body can be added. and ensure that air is administered deliberately and accurately. Using mobile to control the parameters would make it high modern and effective ventilator.

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APPENDIX

COST REPORT

Sl No	Name	Quantity	Price(Rs)
1.	Ambu bag setup	1	4500
2.	Servomotor	2	4200
3.	LCD display	1	500
4.	Arduino board and accessories	1	2000
5.	Oximeter sensor	1	350
6.	Adapter, sensors	2	1500
7.	Sun board	1	900
8.	3D printing and laser cutting		4500
9.	Miscellaneous		4000
Total			22,450