Advanced Emergency Portable Ventilator for Covid-19 Patient

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ABSTRACT

Mechanical ventilators are devices that can assist people with breathing difficulty. The usage of mechanical ventilators is not rare but the necessity has become more vivid due to the outbreak of corona pandemic. With a view to responding the surge of emergency ventilator demand, the focus of this work is on design and implementation of a reliable ventilator for medical usage. Electromechanically functional ventilator backed by software platform is a promising venture to facilitate user friendliness and precision. Multiple sensors and cautionary alarms have been planted to ensure safety margin and accuracy. Increasingly, the ventilator has been tested with medical efficiency that can be used in emergency situation and incurs less cost in production given the utility it serves. Hence, the work paves the way for more improvement and further enhancement by providing a smooth base of research opportunity.

1. Introduction

Coronavirus disease 2019 (COVID-19) is a contaminated disease caused by novel coronavirus known as acute respiratory syndrome coronavirus 2 (SARS-COV-2, previously known as 2019-nCOV). The pandemic was first diagnosed amid a plague of respiratory illness instances [1] in Wuhan City, Hubei Province, China. On December 31, 2019, the World Health Organization(WHO) first received a report about it[2]. WHO announced COVID-19 a worldwide pandemic on March 11, 2020, and it was the first pandemic after the 2019 H1N1 influenza pandemic[3]. In the initial stage COVID-19 patients mostly suffer from breathlessness and cough; eventually they require assistance with oxygen in the further stage. Some patients suffer from worsening breathing difficulties along with low oxygen saturation in the blood. Diverse remedies can help these severe respiratory problems such as high-glide humidified oxygen, added through a nasal mask. The oxygen's humidity is artificially expanded as a way to keep the patient away from uncomfortable dryness. Medical ventilators can be used for lightly pumping oxygen into the lungs at a cushy charge that also lets the affected person to talk and eat. A ventilator is a machine that moves breathing air into and out of the lung and mechanically ventilates the lungs to inhibit those who cannot breathe or who are breathing poorly[4][5]. The ventilator is a computer-controlled and microprocessor-controlled machine. However, a simple manual valve ventilator can also be used to breathe the patient. Ventilators primarily offer as a standalone device and anesthesiology in an anaesthetic machine to provide home care and emergency treatment [6].

Though a ventilator is incapable to cure any respiratory disease it gives support to the patient until his lungs can work on their own. Mechanical air flow through ventilators can be both invasive and non-invasive (the use of a tight mask). Ventilators operate through the means of handing over oxygen to the lungs without delay. Nonetheless, it can operate to pump out carbon dioxide for sufferers who are not able to exhale on their own. The ventilator renders oxygen through a tube inserted via the patient's nostril or mouth in a manner called intubation or it is directly positioned into the trachea, or windpipe through a surgical operation called tracheostomy [7]. The contrary case of the tube is attached to a machine (the ventilator) that pumps an aggregate of air and oxygen via the tube and into the lungs. Before delivering into the body the air is warmed and humidified. The ventilator eventually performs a predominant role in preserving positive air pressure preventing small air sacs(alveoli) withinside the lungs from collapsing [8].

Considering the necessity of medical ventilators, many ventilator systems and designs have been introduced. Grimshadl, D. et al, 2020 introduced a ventilator [9] that performs airflow via mechanical compression of guide resuscitations and consists of control electronics, flow and pressure sensors, and a data visualization unit along with a tracking unit. Mechanical Ventilator Milano (MVM) [10] is an electromechanical equivalent of the old and reliable Manley ventilator based on "the possibility of using the pressure of the gases from the anaesthetic machine as the motive power for a simple apparatus to ventilate the lungs of the patients in the operation theatre" [11] and maybe operated in both independent ventilation (pressure-controlled ventilation, PCV) and patient-assisted control modes (pressure-supported ventilation, PSV).

ORCID(s):

The Low-Cost Portable Ventilator facilitates breathing via compressing a traditional bag-valve mask BVM with a pivoting cam arm, removing the need for a human operator for the BVM. It is driven through the means of an electric motor powered by a 14.8 V DC battery and functions as a tidal volume up to at least 750 m controllable [12]. To provide intermediate therapy for patients between hospitalization and complete discharge, a portable lightweight high-frequency ventilator is introduced with a re-configurable oxygen flow rate, applied pressure, and air quantity for the needs of the patients. Increasingly a miniaturized transportable high-frequency ventilator with a virtual controller and feedback system for stabilization and precision is conducted using a small tidal volume. By keeping regulated inflation of the lung over a precise period, this ventilator can improve the air alternate quantity using lower airway pressure. Besides, the small injection quantity can prevent lung damage from the use of ventilators and can save from irrelevant airway pressure elevation and over-inflation of the alveoli [13].

However, all these ventilator designs are marked for either high-performance or low-cost production. Hence to give ventilation support to corona-infected patients, in our ventilator version 1, we have proposed a low-cost and highly reliable medical ventilator design and prototype. The proposed emergency ventilator version 1.0 provides the advantage to control it in two modes: AC mode and Manual mode. These modes can be easily interchanged according to necessity. 5 different kinds of alarms make their security issue guaranteed and these alarms will make the user alert about any malfunction. By turning on the Bluetooth and connecting the user's phone with the ventilator one can easily control it with the help of the android app and using a web app one can easily control it from anywhere via the internet. Nevertheless, in version 2.0 some other features are added to make it more reliable and user-friendly. In this paper, the newly added features in Ventilator Version 2.0 are discussed in a detailed manner. Besides the overall results and cost are discussed in the result and analysis section.

2. Literature Review

A medical ventilator is a device that pushes air in and out of the lungs to breathe or to breathe inadequately for patients who are unable to breathe or who are incapacitated. Today, around 1.5 million Americans use a ventilator every year. Ventilators help premature babies breathe until the lung is more formed and help patients recover from anesthesia and preoperative sedatives. Patients with heart disease, lung disease or Pulmonary Disease, Chronic Obstructive, accident victims and other emergency care which also may require mechanical ventilators [14]. Patient safety gets more secured when alerts generated by medical devices can be recognized by medical personnel [15] [16].

When doctors work in ICU and the same area for a long term , they find those alarms are used in many medical equipment applications, but they are often less than optimal because the design and implementation of alarms do not always take the customer's idea and need [17]. Whereas ventilators are alarm-fitted and crucial occurrences are observed. Ventilator alarms are audible beeps that can be heard outside the room of the patient. In addition to the increased number of false-positive alarms created by medical equipment, because fan alarms might be combined with other usual sounds in the ICU. [20]. Healthcare management is highly essential. If ventilator alerts are incognizable, it may lead to irreversible damage or death to the patient. A new Sentinel Event Guideline has been issued by the Joint Accreditation Commission of Healthcare Organizations in 2002 to prevent ventilator-related death and injury [18][19]. In 2002, 23 reports of deaths or injuries in connection with mechanical ventilation were examined by the Joint Committee on Accreditation of Medical Organizations[20]. Nineteen of these occurrences led to death and four to coma; 65% related to alarms. The questions involved delaying or no alarm response; alarm disruption or wrong setting; no alarm for certain types of fan disconnections; or alarm in all fields of patient care not audible [21]. Alarm failures of the fan are still occurring. Interestingly, people cannot readily learn and memorize the meaning of more than 8 sounds under strained circumstances, and the results of a study were fascinating in the sense that people did not recognize all the alerts[22].

The ICU nurses correctly identified only 39% [23]. A few studies were done that detected response times to alarms in ICU healthcare. Workers who were reviewed in the study to see anaesthetist's responses, responded quicker to visual alarms or auditory alarms [24]. Another research also revealed that out of 1,455 ICU alarms, just eight (0.5 per cent) indicated life-threatening conditions. Medical personnel were often the first to answer to the ventilator incidents. In certain instances, the ventilator alarm is listened to, but precious time is lost while the nurses try to determine the alarm on the fan. In crucial places such as the intensive care unit. There are several reported concerns with auditory alerts (ICU) [25]. Based on our experience, we had to find a means to warn medical personnel of significant ventilator events which would be precise, dependable, quickly identifiable and also find a way for fan alarms not to fuse in with other customary intensive care sounds (especially in multi-chamber ICU type).

For the critically ill COVID-19 patients, fans are required. The virus can harm alveoli, air-filled bags, in the lungs that insert oxygen into the stream of the blood when it enters the lower air system. Instead air-fluid starts to fill the alveoli, which deprives all regions of the body of oxygen. A ventilator is the finest way to return oxygen to the body rapidly and efficiently while the lungs are trying to cure[26].

A ventilator employs air pressures into the lungs. The pressure is referred to as positive pressure. In general, a patient exhales the air alone, but sometimes the ventilator does it for them as well[27]. A monitor connected to the ventilator can control the quantity of oxygen that the patient receives. The monitor is set up to trigger an alarm to the caregiver that shows a higher air pressure in a particularly fragile state. The machine operates with the suppression of oxygen to the lungs and CO2 from the lungs[28]. This enhances the right amount of oxygen for a patient who has problems breathing. It also assists the patient's body to heal, as it does away with superfluous breathing energy.

Table 1
Basic features in an ideal medical ventilator.

Sources of supply	Monitoring	Power conversion and transmission
1.Oxygen supply 2.Power supply (220V- 240V AC) 3. Pressure generator (DC gear motor and ambu bag)	1.Sensors 2.Oxygen concentration 3.Flow 4. Pressure 5. Volume	1.External compressor 2.Internal compressor 3.Output control valves
Control of oxygen delivery	**Safety features**	**Alarms**
1.Oxygen blender 2.Oxygen accumulator 3.Inspiratory flow regulator 4.Humidification equipment 5.Patient circuit 6.Expiratory pressure regulator (i.e PEEP valve)	1. oxygen intake particle filters 2.Pre-circuit bacteria filters 3.Moisture traps and heat/ moisture exchange systems 4. Expired gas filter	1.Input power alarms 2.Loss of electric power 3.Loss of pneumatic power 4.Control circuit alarms 5. General systems failure 6. Incompatible ventilator settings 7. Warnings (e.g., inverse inspiratory-to- expiratory timing ratio) 8.Output alarms (high/low conditions) 9. Pressure/Volume/Time/FIO2
Input		**Output**
1. Pneumatic 2. Electric: AC and DC		A. Pressure waveforms B. Volume waveforms C.Flow waveforms

Table 2
Some main parameters of medical ventilator to be controlled.

Name of Parameter	Minimum Range	Maximum Range	Unit
1.Breath Per Minute (BPM)	5	40	Per minute
2.I/E Ratio	1:4	1:2	-
3.Tidal Volume	-	500	mL/per inspiration
4.Plateau Pressure	-	5	cmH2O
5.Triggered breathing	0	1	-
7.PEEP	3	20	cm H2O
8.FiO2 or Oxygen concentration	21	100	percentage
10.PIP	-	40	cmH2o

2.1. Some important terms regarding Medical Ventilator

2.1.1. Breath Per Minute (BPM)

The amount of inspiring and expiring movements by unit time. In practice, the breathing rate is commonly measured by the number of times the chest rises or lowers per minute. The objective of respiratory rates is to evaluate if the breaths are normal, abnormally fast(tachypnea), abnormally slow, (bradypnea) or nonexistent, (apnea). Respiration can increase with fever, disease or other situations[29].

2.1.2. I/E ratio or Inspiratory:Expiratory

This ratio refers to the ratio of inspiratory time: expiratory time. The expiratory period is approximately twice as long as typical spontaneous breathing. This results in an I: E ratio of 1:2 [30]

2.1.3. Tidal volume of lungs

The tidal volume is determined by the amount of air carried to and from the lung in each breathing cycle. Tidal volume (VT or TV symbol) is the lung volume, which indicates normal air volume displaced between normal inhalation and exhalation if there is no extra effort. For a young and healthy person, the tidal volume is around 500 mL/kg or 7 mL/kg body mass per inspiration. Tidal volume in millilitres is measured and ventilation volumes are approximated by patient ideal body weight. Measured tidal volume (often over-estimated) can be influenced by leaks in the respiratory system or by extra gases such as when nebulizing medications are introduced. [31].

2.1.4. Trigger Breathing

The trigger refers to the process by which the ventilator feels an inspirational effort and provides airflow or breathing in conjunction with the inspiration of the patient. In current ventilators, either a fall in pressure (pressure trigger) or a change in flow triggers triage of the demand valve (flow trigger) [32].

2.1.5. Peak Inspiratory Pressure(PIP)

The highest pressure applied to the lungs during the inhalation is the peak inspiratory pressure (PIP). The value shows a positive pressure in centimetres of water pressure during mechanical ventilation (cmH2O). With any airway resistance, the peak inspiratory pressure increase. Increased secretion, bronchospasms, ventilation tubing and lung compliance could be things that may raise PIP [33]. Unless the patient has acute respiratory distress syndrome, PIP should never be continuously above 40(cmH2O)[34].

2.1.6. Positive End Expiratory Pressure (PEEP)

The air can't emit all the air when air is pressed into the lungs, which results in many lung pressures. The ventilator should stop, therefore. It is a form of ventilation using a mechanical impedance, usually a valve, within the circuit, that keeps airway pressure above ambient pressure at the end of exhalation [35]. PEEP aims to increase the gas volume remaining in the lungs to reduce blood shift across the lungs and enhance the exchange of gasses at the end of the expiration. PEEP (ARDS) is performed to reduce the level of oxygen delivered in ARDS (Acute Respiratory failure Syndrome).

2.1.7. Dead Space

Dead space simply implies the volume in the passageway that does not exchange gas in the lungs. Considering the alveoli in our lungs that exchange gas can be regarded as "dead space," each anatomic structure above it: nasal/oral passageways, pharynx, larynx, trachea, and primary / secondary/third bronchi. Extending the tubing via which the inhaled/exhaled gas mixture bidirectionally flow is produced merely increases dead space.

2.1.8. Plateau Pressure

We stop the ventilator 0.10 s before opening every time the arms close. This does not influence the I/O ratio, but the air must be kept in the patient. The airway pressure is measured and shown throughout this period. This indicates the "plateau pressure" and guides the decision-making processes. This pressure is shown and updated by the next cycle.

2.1.9. FiO2 or Oxygen concentration

The amount of oxygen provided to the patient in the air mixture. The molar or volumetric fraction of the oxygen in the inhaled gas is the inspired oxygen fraction (FiO2). Oxygen-rich air is delivered to medical patients with difficulties breathing. Natural air contains 21% oxygen, corresponding to 0.21 FiO2. The FiO2 is more than 0.21, up to 1.00

that signifies 100% oxygen. Even with mechanical ventilation, FiO2 is normally maintained at 0.5 to prevent oxygen toxicity, yet there are uses when frequently up to 100% are employed [36].

2.1.10. HEPA Filtration

Filters of the ventilator play a major role in safeguarding the safety and risk of cross-contamination of patients with mechanical ventilation. Filtration can protect the hospital or the environment by preventing hazardous bacteria from inhaling. It helps prevent contamination of germs and viruses and prevents the spread of infection in hospitals, particularly ventilators. Bacterial and virus protection without moisturizers is offered by mechanical air filters. The usage in OR, ICU and other parameters of mechanical filtering, as well as other breathing filters, can assist address cross-infection, a problem typically connected with mechanical ventilation.

2.1.11. Ambu Bag

A bag valve mask, abbreviated to BVM and sometimes known by the proprietary name Ambu bag or generically as a manual resuscitator or "self-inflating bag", is a hand-held device commonly used to provide positive pressure ventilation to patients who are not breathing or not breathing adequately. The full form of AMBU is Artificial Manual Breathing Unit. An Ambu bag is a self-inflating bag resuscitator from the company Ambu, which still manufactures and markets self-inflating bag resuscitators.

2.2. Mode of Ventilator

Ventilating mode can be defined as the procedure through which the mechanical ventilator determines whether or not the mechanical respirations are supplied to the patient, therefore determining the respiratory pattern of the patient during mechanical ventilation. For classification purposes, an international consensus or standardization is necessary, since vocabulary is unstandardized and unclear. This is further aggravated by the adoption of the mechanical ventilator of different commercial brands, often in modes with comparable functionality. [37].

The modes are given below: 1. Manual Mode 2. Assist Mode:

2.3. Pressure Sensor

RSC Series is a silicon piezoresistive pressure sensor that provides digital output for pressure reading over the recommended entire pressure range. The measured and temperature adjusted through 24 bits analogue to digital converter with inbuilt EEPROM for sensor Offset, Sensitivity, Temperature Effects and non-linearity. Pressure data may be collected from an SPI interface at rates from 20 to 2000 samples per second. It is designed and manufactured according to ISO 9001 standards and is REACH and RoHS compliant to use with non-corrosive non-ionic gases, such as air and other dry gasses[38]. MPX5050 pressure sensor is another model with the previous one to make output more accurate near mouth of patient

2.4. Oxygen Sensor

Long existence molecular that indicates sign imbalance at low interferences to anaesthesia gases mixed with advanced linearity over the whole spectrum. All traits are primarily based on a temperature of 25 degrees Celcius,50% relative humidity, and a pressure of 1013hPa. Specifications may be described as follow: 3.5 mm single plug electrical connection with 0 to 100 vol% measuring range. The service life of the sensor is given greater than 1000000 vol %h. The expected service life is at least six years in ambient air. The output signal is 13 in dry ambient at 17 mv and response time t90 is at least 12s [39].

2.5. Flow Sensor

The digital flow meter Sensirion SFM3200 series is a mass flow meter that is especially suited for evaluating inspiratory flow.The measurement accuracy at low rates is characterized by a large dynamic measuring range of up to 250 SLPM. The particular system of the flow channel reduces the pressure across the sensor's flow body. The thermal sensor element guarantees very rapid data processing time and two-way measurement with an internal linearization of the signal, and compensation of the temperature.

Another flow sensor SFM3300 is used in this project. It is a sensor for measuring proximal flux in respiratory applications like ventilation or anaesthesia. The SFM3300-AW is autoclavable and washable while the SFM3300-D can be used for one-time operations[40].

3. Methodology

3.1. Mechanical Designing

All the parameters and topic regarding medical ventilator was studied. First of all, the design of the medical ventilator with Ambu bag was done in SolidWorks with proper measurement of mechanical hand, rack and pinion and Ambu bag size. In a metallic body structure, the whole device has two parts. Upper part and Bottom Part

3.1.1. Upper Part

Upper part contains rack and pinion, slider, Ambu bag and limit switch. In a base, the Motor shaft came through a hole in the middle point, attached with pinion. The outer dia of pinion was 25.5 mm and the inner dia was 18.75 the number of teeth was 15. The rack length was 165 mm and had 35 teeth. The rack was set with a slider which allows the rack to move linearly with less friction force. Two mechanical hands were also designed to press the Ambu bag. The area of the hand was 3781.45 mm2 and fixed on a rack and slider which could move along the rack. There was also a specific shape on two sides of the body to keep the Ambu bag and a cover to hold it tightly.

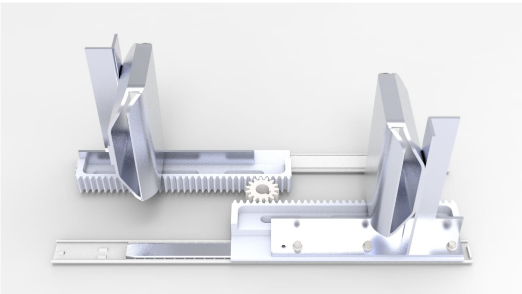

Figure 1: 3D design of rack and pinion

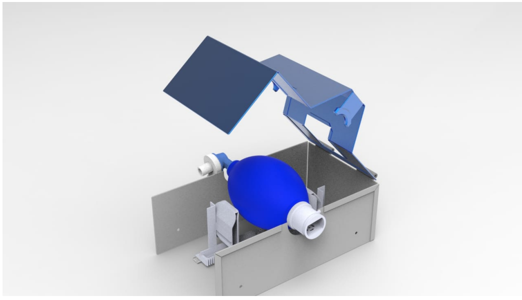

Figure 2: 3d design of Upper part of Ventilator

3.1.2. Bottom Part

The bottom Part was consisting of a Motor, Circuit, Power supply, Power button, Display, Keypad and sensor box holder. It was designed as a motor that could be attached with the top part which shaft enter through hole toward upper part. Besides the motor, all the electrical equipment and display were placed in this box

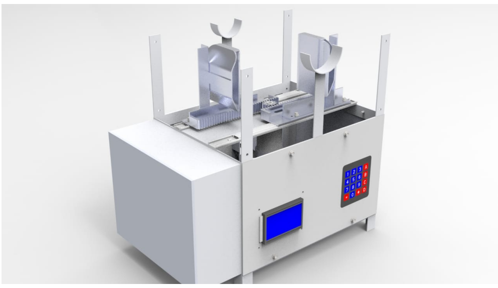

Figure 3: 3D design of Bottom part

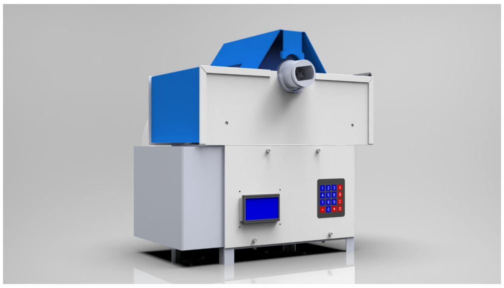

Figure 4: 3d design of Full part of Ventilator

3.2. Circuit Designing

The circuit part was also separated into two parts: Control Unit and User Interface (UI). Different types of sensors were also included for measuring different parameters. All the component was selected after doing the calculation of some parameters which should be in a ventilator.

3.2.1. Control Unit

Both of the units was embedded in the same board, designed compact and professionally. Arduino Mega Pro was used as a microcontroller and BTS7960 motor driver to control the motor. This motor driver had enough voltage and current to drive the selected motor. The circuit had 12V, 5V and 3.3-volt power to run different components. So, a DC-DC buck converter was used to power up the right components according to their tolerable voltage with references to the datasheet. There was a buzzer for alarm. It was designed as all the sensors could easily connect with it. There was also a Real-time controller (RTC). The fuse was also included in the design. Capacitor and resistors were placed where necessary. There were also two limit switches to ensure exhale and inhale.

3.2.2. User Interface

Some part of User Interface was on PCB and other was on the body of Mechanical structure. Here Arduino mega pro was also used as a microprocessor. The display and keypad were attached to the main board. In addition, the Bluetooth module and wifi module was in design to make this device relevant to an IoT device. All the components were powered with a buck converter and capacitor and resistors were used where necessary.

3.3. Implementation of design

3.3.1. Mechanical Body

All the metal part was cut, bent and electric arc soldered according to design. A frame is formed and drilled for the bolt. The acrylic board was cut and set in the base of the bottom part with the nut. The motor was also attached to the top side of the bottom part. Then the circuit was placed below the motor. The display, Button, Keypad were attached outside and the Power supply was screwed in the inner side of the bottom part in support of the acrylic board.

Figure 5: Medical Ventilator(a)

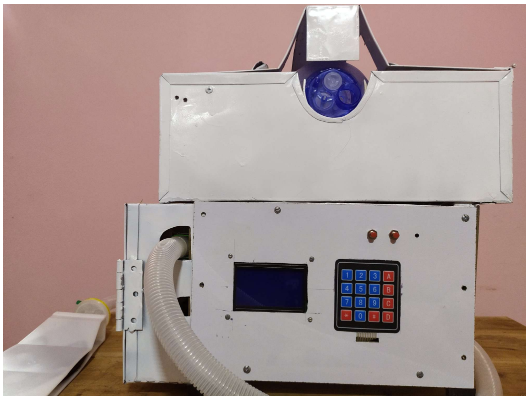

Figure 6: Medical Ventilator(b)

The pinion was screwed tightly with the shaft. On both side of pinion two sliders was attached vertically and both were parallel. On the top of the slider, the rack was set with a nut having a contact of teeth with pinions. The Mechanical hand was also set upon it and two limit switches were also set on the edge of the slider's highest move. All four side was covered with a metallic sheet and a cover was set to protect rack, pinion and Ambu bag from unnecessary disturbance.

3.3.2. Circuit

PCB was made and all the components was soldered. All the part of circuit was tested carefully with multimeter and oscilloscope. All the electrical connection was established successfully. Current and voltage in different part of the circuit was also checked.

3.4. Programming

For programming, Arduino IDE was used. Firstly, All the sensors and motors were run and response time was checked separately by Arduino serial monitor. The pressure sensor was run and calibrated in coding. Monometer was used as a reference. And so, on oxygen sensor and flow sensor. The equation regarding sensors data was taken from the datasheet. All the pin was declared according to circuit design. The sensor reading was taken in Arduino and observed in Serial monitor. GLCD display, Keypad and limit switch was tested and calibrated. The value of the motor encoder was observed and PID was included to control the motor. Some of the Arduino libraries were created to reduce complexity. After completing testing all the component, all the programme was merged. The User Interface was made user friendly. Keypad and display code was according to the algorithm and flow chart. Here, a Mobile app and web app input system was also included. All the programme was review and tested several times. All the data was stored in the data table.

The algorithm of the control system is arranged based on electrical equipment and mechanical design. The input is taken from the user interface part and sent to the control system. Parameters are selected that can be achieved by the existing prototype. The value of the encoder and limit switch is also taken to ensure the final destination of the arm. In the meantime, pressure is measured which clarifies PIP, Pplat, PEEP etc. The displacement is calculated from the tidal volume. Then the motor will run until the encoder value reaches the desired displacement. Thus, the tidal volume is controlled. In Assist Controlled mode, triggered breathing is initialized by monitoring pressure. When the value of pressure is less than PEEP, the system triggers a breathing cycle. Besides these, different alarms are used for safety. If the arm is stuck, it will not reach the limit switch, the buzzer will trigger as a result. This LCD shows the condition of the patient and other necessary parameters. These parameters can be changed from Settings Menu using Keypad.

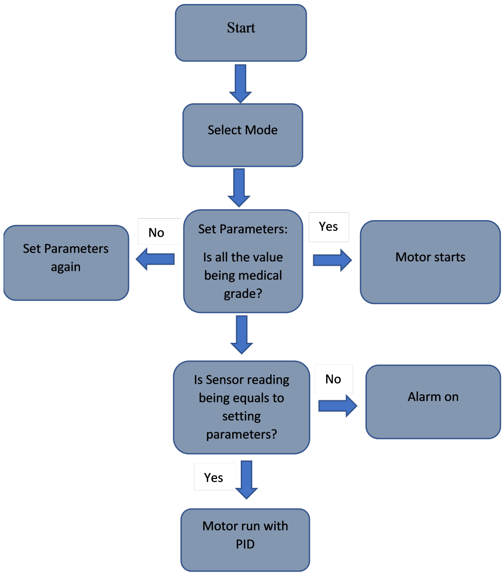

Figure 7: Block Diagram of programming algorithm of Ventilator

3.5. Software Design

This ventilator has a software parts which is dived into two parts,

(1) Android Applications.
(2) Web application.

3.5.1. Android application

This Ventilator has an android application for controlling the mechanical ventilator and monitoring patients. The application uses wireless Bluetooth and wired serial communication to communicate with the ventilator. The ventilator uses an HC-05 Bluetooth module to communicate. The ventilator can be controlled wirelessly from 10 meters away using an android device with this app. Besides one can control all the parameters of a ventilator using this. Different modes of the ventilator can be selected and changed, just by some simple touches. The smart UI can be compared with other high-performance ventilators as it shows pressure and flow graphs and other important numerical values as well. From the graphs and other values, doctors can easily understand the condition of a patient from distance. Due to the COVID-19 pandemic, controlling a ventilator and monitoring a patient from far can save our doctors from being infected.

This mobile app of emergency ventilator version 2 can monitor the state of a patient through begin connected with the ventilator via Bluetooth. Firstly, when the app is opened there appears the option of connection. This app can be

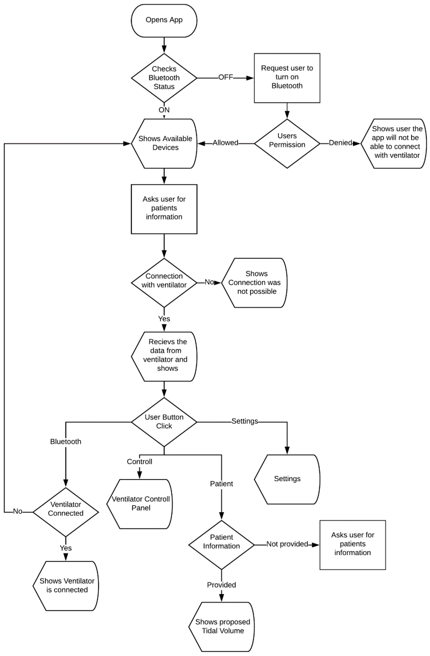

Figure 8: Block Diagram of Ventilator App

connected to the ventilator through wire or Bluetooth. In the pandemic of covid 19, it very prominent strategy to help patients away as covid 19 is a contagious virus that is why this concept of ventilator app come across. The state of a patient can be observed by this app and the needed oxygen level of the patient can be controlled through this app via Bluetooth. When the app is opened then first it checks the Bluetooth status, if it is not connected then it sends a request to the ventilator to connect via Bluetooth with available devices. When the ventilator is connected then it starts showing the ventilator state for that specific patient. There are a lot of features such as settings, ventilator control panel, patient information is added to control the whole process and progress or regress of patient.

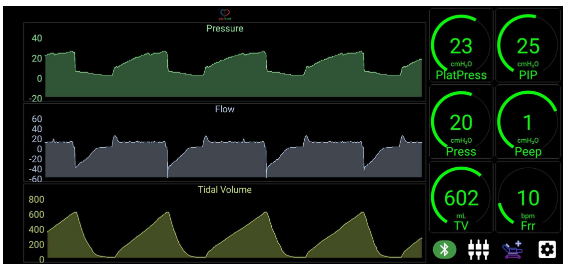

Figure 9: App Interface

3.5.2. Connection Page

Here is the first page of this app which asks for connection (Fig 2). There are two options of connection:

(1) Connection Via Bluetooth: To connect and operate the ventilator being far from it.

(2) Connection Via Wire: To connect ventilator with wire and operate it.

3.5.3. Android application

When the connection via Bluetooth is clicked available devices are shown on a page. By clicking one of the available devices this app is connected with the ventilator.

3.5.4. *Device to connect*

After clicking the connect via Bluetooth button app will lead us to this page to show available devices (Fig 3) and by clicking any of them, we can connect this app with any of them but connect with this app the device should enable its Bluetooth.

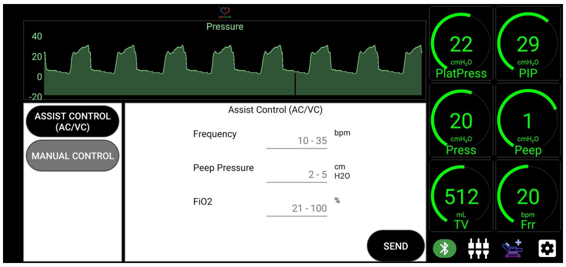

Figure 10: Assist Control Mode

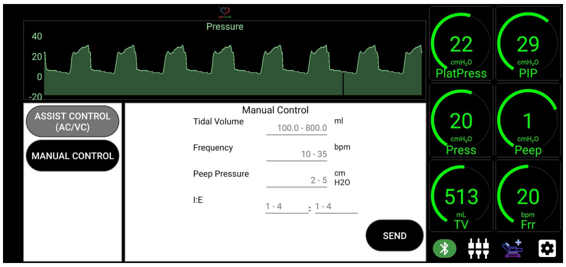

Figure 11: Manual Control Mode

3.5.5. *Alerting View*

If there is an alarming situation for a patient or any effective step is needed to save the life of a patient then the ventilator shows alarms and which is perfectly visible to a user as the alarming system is created in such a way that it is noticeable for a user. This process and interaction system is shown in Fig 9. In this way, this app alerts users based on the patient's state.

Figure 12: Alerting View

3.6. Web application

The application uses an internet connection or Wi-Fi to communicate with all ventilators connected with it. Up to fifty ventilators can be controlled and monitored simultaneously using this web app. The ventilator uses a Node MCU 8266 Wi-Fi module to communicate. All connected ventilators can be controlled wirelessly from any internet available place using any browser by this app. Besides one can control all the parameters of any ventilator using this. Different modes of the ventilator can be selected and changed, just by some simple touches. The smart UI can be compared with other high-performance ventilators as it shows pressure and flow graphs and other important numerical values as well. From the graphs and other values, doctors can easily understand the condition of a patient from distance.

3.7. Application Window

3.7.1. *Intro page*

This part is description of LCD display output as the response of command given by keypad This page is displayed when the ventilator is on. The action may not create any hold situation for ventilator operation. Following that ventilation mode 2 appears. This page will not appear if the ventilator is off initially. Options can be selected by keypad action.

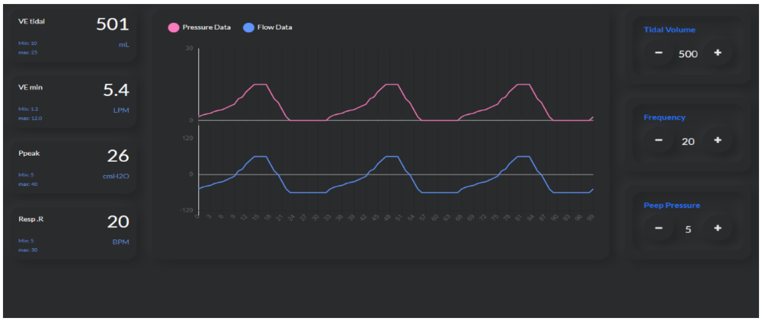

Figure 13: Web app user interface

Figure 14: Intro Page

Figure 15: Display Mode

3.7.2. Provide "Manual Settings" information from keypad

"C" should be pressed for clearing out data. For going to ventilator options "B" should be pressed. Each field is responded with a confirmation window.

3.7.3. Provide "Assist Control (AC/VC)" information from keypad

By pressing "1" previously chosen options can be confirmed. To reset the settings and to return to ventilator window options "B" should be pressed.

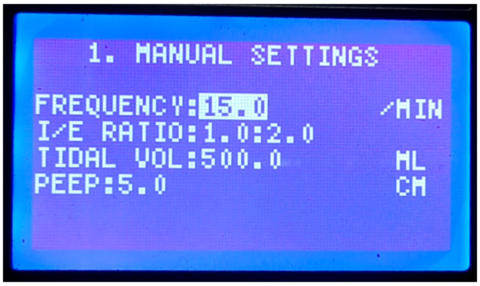

Figure 16: Manual Control Settings

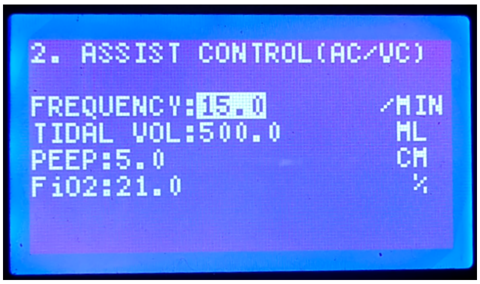

Figure 17: Assist Control Settings

subsubsection Settings confirmation window

To confirm previously selected settings "1" should be pressed. Pressing "2" shall display the ventilator options and reset the settings. "ON/OFF" should be pressed for ventilator activation according the settings selected. The reset the settings "B" should be pressed.

The window represents the recorded ventilation parameters

1. **Respiratory Rate/ Breath Per Minute (BPM):** The number of movements indicative of inspiration and expiration per unit time. In practice, the respiratory rate is usually determined by counting the number of times the chest rises or falls per minute.
2. **Tidal volume of lungs:** Tidal volume is defined as the volume of air moved into and out of the lungs during each ventilation cycle. Tidal volume (symbol VT or TV) is the lung volume representing the normal volume of air

Figure 18: Confirmation window

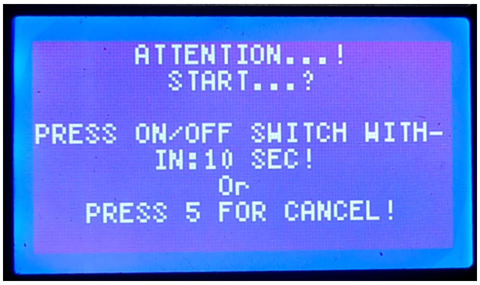

Figure 19: Final confirmation window

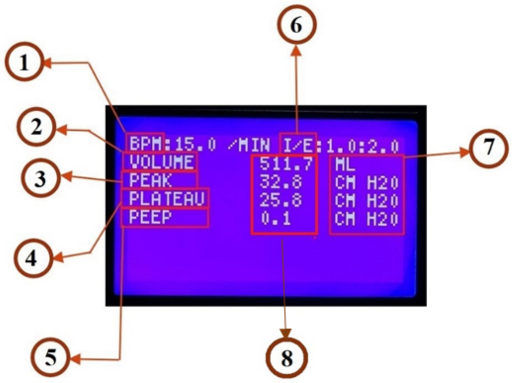

Figure 20: Stand by window

displaced between normal inhalation and exhalation when extra effort is not applied. In a healthy, young human adult, tidal volume is approximately 500 mL per inspiration or 7 mL/kg of body mass.

3. **Peak Inspiratory Pressure(PIP):** Peak inspiratory pressure (PIP) is the highest level of pressure applied to the lungs during inhalation. In mechanical ventilation the number reflects a positive pressure in centimeters of water pressure (cmH2O). PIP should never be chronically higher than 40(cmH2O) unless the patient has acute respiratory distress syndrome.
4. **Plateau Pressure:** Each time the arms close, we implement a 0.10 s pause before they open. This does not affect the I/E ratio, but it is necessary to hold the air into the patient
5. **Positive End Expiratory Pressure (PEEP):**When air is pressed on lungs, all the air cannot emit, as a result a number of pressures increase in lungs.
6. **I/E ratio:** Inspiratory: Expiratory ratio refers to the ratio of inspiratory time: expiratory time. In normal spontaneous breathing, the expiratory time is about twice as long as the inspiratory time. This gives an I:E ratio of 1:2.
7. **Unit:** It is used as a standard for measurement of the same kind of quantity .
8. **Value:** These are the corresponding parameter's value.

Alarm can Trigger for following cause:

(i) HIGH PRESSURE ALARM
(ii) LOW PRESSURE DISCONNECT
(iii) HIGH RESIST PRESSURE
(iv) BAD PLATEAU PRESSURE
(v) UNMET TIDAL VOLUME
(vi) NO TIDAL PRESSURE
(vii) OVER CURRENT FAULT
(viii) MECHANICAL FAILURE

3.7.4. Third party Info received window

When any change or operational info coming from third party devices like (Mobile Phone, Web browser etc.), then this window will appear. Press "1" for confirming or press "2" for resuming running window. But any modification was not possible in this window. "1" should be pressed for showing settings info. For rejecting this window "2" should be pressed and the running window gets resumed.

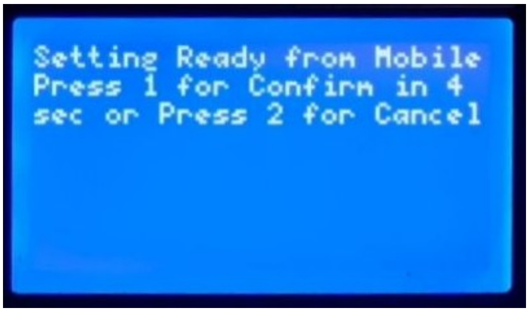

Figure 21: After connecting with android app

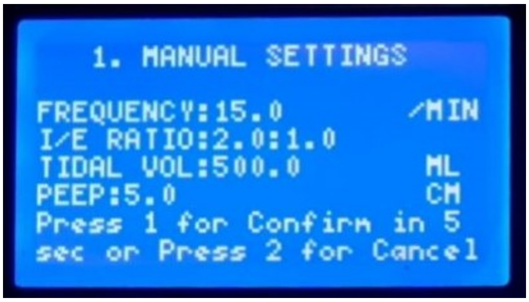

Figure 22: Manual setting with android app

For confirming "1" should be pressed and "2" should be pressed for resuming window. This window does not offer any modification. The ventilator starts in accordance with the selected settings when "On/Off" is pressed. The settings can be reset by pressing "ON/OFF". By pressing "5" the settings get reset and the ventilator option pops up. When any change or operational info coming from third party devices like (Mobile Phone, Web browser etc.), then this window will appear. For shutting down "1" should be pressed and if the window needs to be rejected the "2" should be pressed which follows in resuming running window.

3.7.5. Alarm representation:

This is an internal fault, if this cannot be solved than device should take to technician.

Figure 23: Device Faulty

Figure 24: Displaying Alarm

When ventilator is on and any alarm is present then at the bottom of the LCD, first line displays number of alarms and the last line display actual alarming info. If multiple alarm is present then all those alarms info is shown one by one. When ventilator is on and all previous alarms are cleared by ventilator itself then last two lines will disappear.

4. Torque Calculation for Ventilator Motor and Rack Pinion

4.1. Area of contact between AmbuBag and Pressing Arm

Pressing Arm -Ambu Bag contact Width, width = 0.083138m
Pressing Arm -Ambu Bag contact Height, height=0.083138m

$PressingArm - AmbuBagcontactArea,$
AreaRackHead $= width \times height = 0.083138 \times 0.083138 = 0.006911927 m^2$

4.2. Maximum allowed Inspiration Time for the highest BPM and the extreme I/E Ratio

Breath per minute, BPM=40 (This is the maximum range the ventilator will support)
IE Ratio, IER=0.2
Maximum I/E Ratio = 1:4 (The maximum allowed time for BPM (40) with IER 1:4)

$$Inspirationtime, t = \frac{IER \times 60}{BPM} \tag{1}$$

$$= \frac{.2 \times 60}{40} = 0.3second$$

4.3. Acceleration of the Pressing Rack or the pressing Arm

Displacement of Rack, S = 0.15 meter
$S = 160 \times 2 = 320mm == 0.320m$, Distance between hand
$u = 0m/s^2$, initial velocity
Inspiration time, $t = .3s$

$$S = ut + \frac{1}{2}at^2 \tag{2}$$

$$a = \frac{2S}{t^2} \tag{3}$$

$$a = \frac{(2 \times 0.320)}{3^2} = 0.072m/s^2$$

4.4. Force Required for pressing the Ambu-Bag

Maximum pressure, $P = 40cmH_2O = 3922.55Pa$, (Max PIP pressure)
Maximum pressure which will develop inside Ambu-Bag in Inspiration phase
AreaRackHead, $A = 6912mm^2 = 6.912 \times 10^{-3}$

$$P = \frac{F_e}{A} \tag{4}$$

$$F_e = P \times A = 3922.55 \times 6.912 \times 10^{-3} = 27.113N$$

F_r = force on rack (N)
F_e = pressing force due to the application; if applicable (N)
$m = 750g = 0.75kg$, moved mass; includes the application load, plus any system components that are being moved, such as the pinion, gearbox, motor, etc. (kg)
$g = 9.81m/s^2$, gravitational constant
$\mu = 0.002$, coefficient of friction of guide mechanism (typically 0.002 to 0.003 for ball or roller recirculating guides)
a = maximum acceleration the system will experience (m/s^2)

$$F_r = m.g.\mu + m.a + F_e \tag{5}$$

$$F_r = (0.75 \times 9.81 \times 0.02) + (0.75 \times 0.072) + 27.113 = 27.181N$$

Torque on the pinion
The torque on the pinion is simply the tangential force (force on the rack) divided by the pinion radius.
T_p = torque on pinion (Nm)
r_p = pinion radius (m)

$$T_p = F_r . r_p \tag{6}$$

$$T_p = 0.0192522 \times 0.01275 = 2.454656 \times 10^{-4} N.m$$

The pinion diameter will divide by 2 to get the radius, and by 1000 to convert from mm to m.
Pinion Radius,

$$r_p = \frac{d_p}{2000} \tag{7}$$

$$r_p = \frac{25.5}{2000} = 0.01275m$$

5. Result

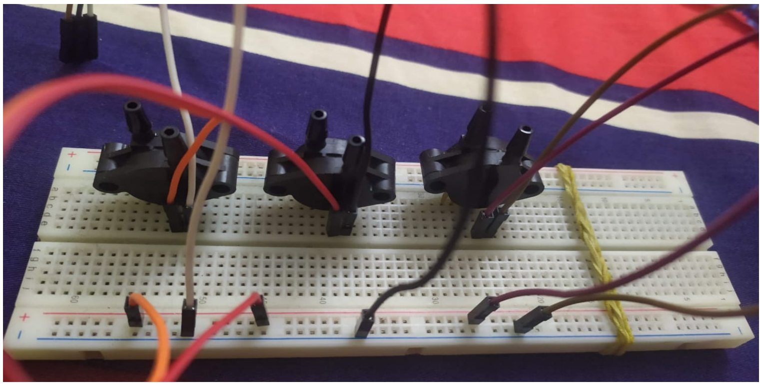

Figure 25: Pressure sensor testing and tuning

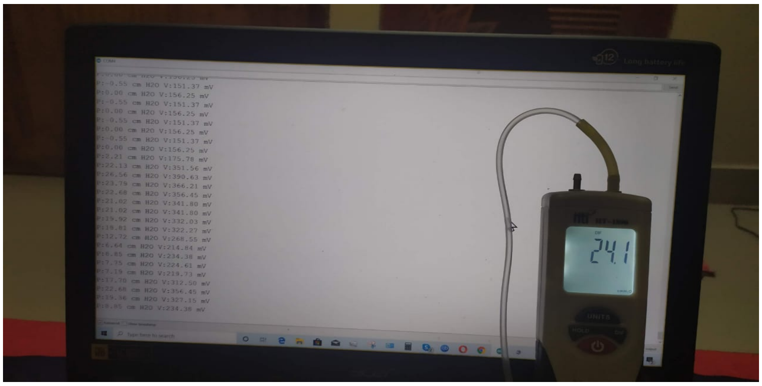

Figure 26: Pressure sensor testing and tuning

6. Conclusions

Due to the recent global spread of the coronavirus, the demand for ventilators has grown rapidly. As a result, many countries are facing a shortage of ventilators required to meet the demand. Hence, we have initiated on producing low-cost emergency ventilators suitable for rapid deployment to meet short-term needs. In response to the COVID19 pandemic, we designed, developed, and tested a rapid constructible ventilator enabling user-controlled tidal volume.

Table 3
RSC PRESSURE SENSOR and digital monometer pressure value at 5, 15, 25,30,35,40 Pa

SI		5 Pa		15 Pa		25 Pa		30 Pa		35 Pa		40 Pa
	Sensor	Mono meter	Sensor	Mono meter	Sensor	Mono meter	Sensor	Mono meter	Sensor	Mono meter	Sensor	Mono meter
1	4.98	5	14.99	15	24.99	25.01	30	30	35	35	40	40
2	4.99	5	14.99	15	25.01	25	30	30.01	35	35	40.01	40
3	4.99	5	14.99	15	25	25	29.99	30	34.91	35	40	39.99
4	4.99	5	15	15.01	25	25	30.01	30.01	35	35.01	40	40
5	4.99	5	15	15	25.02	25	30	30	35	35	40	40
6	5	5.01	15	15	25.01	25.01	30.02	30	35	35	40.01	40
7	5	5.01	15	15	25	25	30	30	35	35	40.02	40.01
8	5	5.01	15.01	15	25.01	25	30	30	35.02	35	40	40
9	5.01	5.01	15.01	15	25	25	29.99	30	34.98	35	40	40
10	5.01	5	15	15.01	25.01	25.01	30	30	35	35	40	40
11	5	5	15	15	24.98	25	30	30.01	35	35	40	40
12	5.01	5	15.01	15	25	25	30	30	35	35.01	39.98	40
13	5	5	15	15	25	25	30.02	30	35.02	35	40	40
14	5	5.01	15	15.01	25	25	30	30	35	35	40	40.01
15	5	5	15	15	25.02	25.01	30	30	35.01	35	40.02	40

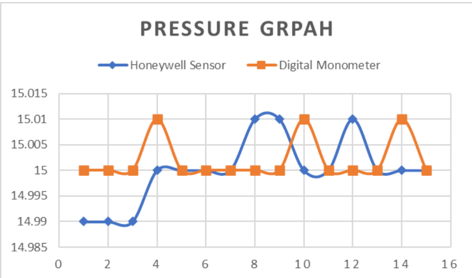

Figure 27: Pressure Sensor vs Monometer grap

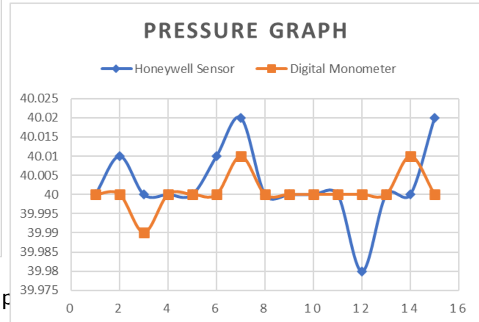

Figure 28: Pressure Sensor vs Monometer graph(b)

The created prototype demonstrates the simplicity and reliability of the approach of handling emergency mechanical ventilators in resource-limited environments. This pragmatic design leads to cost-effectiveness. The improvement of the ventilator has been performed through rapid design iterations, functional testing. The incorporated app demonstrates records of ventilator functions and provides an alarm whilst the tool fails or the affected person's breathing stops. Detailed mechanical layout, functional testing, sturdiness checking mentioned withinside the paper proves the competence of the ventilator. The ventilator layout, user manual, training materials, and the electronic monitoring system through the app have additionally been mentioned very well in the course of the paper. It is envisaged that this technology may provide access to simple ventilation in healthcare settings in emergency scenarios. This low-cost ventilator can serve the emergency needs of breathing support. This design meets the ideal medical ventilator standards and some additional features are added to this ventilator like an electronic monitoring system through mobile application control and alarm system. This prototype has been tested through different stages using various software platforms and finally, a low-cost prototype is developed. Future work can be conducted regarding the ventilator's design to make it more cost-efficient and effective.

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Table 4
Flow Sensors and anemometer

SI mL/min		SFM3200 mL/min Value	Avg1	SFM3300 mL/min Value	Avg1	Avgs mL/min	Area of breath Circuit Pipe A (m)	Velocity of Air V m/min	Air flow rate Q=AxV mL/min	Avgt
1		200.01		200.03				40.75244	200.013	
2	200	200.01	200.013	200.02	200.026	200.019		40.79279	200.211	200.118
3		200.02		200.03				40.77669	200.132	
4		400.05		400.02				81.56275	400.31	
5	400	400.01	400.023	400.01	400.023	400.023		81.52649	400.132	400.181
6		400.01		400.04				81.52037	400.102	
7		500.01		500.03				101.8955	500.103	
8	500	500.01	500.01	500.03	500.023	500.016		101.8975	500.113	500.11
9		500.01		500.01				101.8979	500.115	
10		600		600				122.2498	600.002	
11	600	600.03	600.013	600.03	600.016	600.014		122.2559	600.032	600.118
12		600.01		600.02				122.3148	600.321	
13		650.01		650.01			4.908	132.4637	650.132	
14	650	650.01	650.006	650.01	650.013	650.095		132.4637	650.132	650.158
15		650		650.02				132.4798	650.211	
16		700.01		700.04				142.6447	700.1	
17	700	700.03	700.02	700.03	700.023	700.021		142.6514	700.133	700.123
18		700.02		700				142.652	700.136	
19		750.01		750.03	750.026			152.8358	750.118	
20	750	750.01	750.016	750.02		750.021		152.8362	750.12	750.119
21		750.03		750.03				152.8364	750.121	
22		800		800.01				163.0238	800.121	
23	800	800	800.003	800.03	800.023	800.013		163.0267	800.135	800.129
24		800.01		800.03				163.0261	800.132	

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