Low-Cost Emergency Ventilator

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Abstract:
The current pandemic caused due to COVID-19 has led to shortages of various critical medical equipment, one such is mechanical ventilators. This shortage threatens our medical infrastructure at the regional level, which has caused spikes in mortality rates. Since mechanical ventilators are one of the most critical equipment in light of the current coronavirus, this has created a dire need for its immediate supply. It is challenging to ease the demand, because the conventional mechanical ventilators are quite expensive, complex in design and the time needed to manufacture is more, around 120 days. These conventional ventilators cannot induce the shortage gaps, unlike emergency ventilators. So, various companies and universities are now looking at lucrative ways to adapt to the shortcomings of these ventilators. This paper mentions various ventilator prototypes, which are low cost, easily deployable, and light weight, which makes these ventilators portable. The design mentioned in this paper works as the simple automated manual resuscitator device, that is usually used before initiating the mechanical ventilation. The system uses common off-the-shelf parts that are easily available in the supply chain. The system can be operated with minimal training by any non-clinicians and does not require any skills. This paper aims to bring light upon emergency ventilators which can be created swiftly and also meets the basic requirements of the conventional mechanical ventilators while being low cost and rapidly deployable.

Keywords: Emergency ventilator, low-cost, portable, COVID-19.

I. INTRODUCTION

The novel coronavirus disease 2019 (COVID-19) is a severe acute respiratory syndrome that causes an upper respiratory infection. COVID-19 patients are diagnosed with severe acute respiratory distress syndrome (ARDS) when the virus enters the body, it comes in contact with our mouth, eyes, mucous membrane lining in the nose, evades the airway, and infects either upper or lower tract, sometimes both. SARS-CoV-2 infects both the upper and lower respiratory tract. Once the virus entered the lower respiratory tract, the disease progresses to a severe lung infection, called pneumonia. As the virus reaches the lungs, it causes inflammation which results in the accumulation of fluids and difficulty of breathing. When this fluid enters the alveoli or the air sacs in the lungs where gas exchange occurs, it leads to low blood oxygen levels. This condition is known as pneumonia. Patients with chronic obstructive pulmonary disease are more likely prone to infection with coronavirus exacerbates preexisting conditions which increase the respiratory effort of lungs already laden with the disease.

II. RELATED WORKS

- Deepthi Nacharaju, Whitney Menzel [1] focuses on a rapid solution to induce supply chain shortages by Three Dimensional Ventilators. 3D technology uses parts that are small, lightweight, and cost-effective that are readily available around the world. If the implants have been custom-designed, success rates in surgery patients are higher and the recovery time will be lower. Smaller manufacturing production runs will be more profited if printed on demand and site. The strategy is more advantageous because people can share open-source ideas across the globe. 3D printed ventilators come with their challenges. A fraction of a millimetre can cause a huge variability which makes the product unusable. The printing type like fused deposition modeling in which a nozzle extrudes polymer in three dimensions. The large porosities within the devices pose challenges for sterility and repeatability when exposed to the environment. To ensure the patients are not affected by infection or hypersensitivity from synthetic material, safety testing of the device is mandatory.

- Wu Yaoou, Liu Jijun [2] aims to develop a miniature smart ventilator, which can be used for critical in-patients with respiratory failure before their hospitalization and in need of first-aid in transport. The model design uses the principle of electro-pneumatic control that has a digital display. The model would weigh around 1 kg making it lightweight and is a portable ventilator. This system has parameter detection along with an alarm that rings over a. This working principle is the electro-pneumatic control to ventilate with a certain frequency, and tidal volume and a feedback control monitor the corresponding sensors of their pressure, flow, frequency, and other data. The model adopts several miniature sensors and microcomputer chip control technology equips it with A/C, SIMV, SPONT. This system enables the breathing control of patients by setting the respiratory rate, VC per minute, trigger pressure, airway pressure floor limit, airway pressure upper limit then it adopts built-in air-oxygen mixture technology, enabling the switch from 50% oxygen concentration to 100% oxygen concentration thus ensures adequate tidal volume for patients. The model has different ventilation modes namely control, auxiliary, manual to meet the different patient's ventilation requirements.

- Daoud, Ehab G [3] designed Airway Pressure Release Ventilation (APRV) for clinical purposes as an alternative for mechanical ventilation for patients who have difficulty in breathing caused by acute lung injury/ acute respiratory distress syndrome (ALI/ARDS). Continuous positive airway pressure (CPAP) is used by APRV with an appropriate release time. The high pressure is given for a longer time to maintain sufficient lung volume and alveolar
recruitment, with a time-cycled release phase to a lower set of pressure for a lesser period where removal of CO₂ occurs. If the patient has no spontaneous respiratory effort, APRV acts as pressure-controlled ventilator or inverse ratio pressure according to patients’ requirements. Spontaneous breathing is the main manifestation key in APRV which allows the patient to control his/ her respiratory frequency without being confined to an arbitrary pre-set inspiratory- expiratory ratio (I: E), thus improving patient comfort and patient-ventilator synchrony with reduction of the amount of sedation necessary. This system should not be used in patients who require deep sedation for the management of their underlying disease.

- Joshua M. Pearce [4] reviews various emergency ventilators that are open source and follow FDA regulations which were designed for the aftermath of COVID-19. This paper determines whether the designs are open-source both in terms of the license as well as practical details like possessing production files, accessible design source files, PCB circuits layouts, list of materials required, bill of materials, wiring diagrams, assembly instructions, firmware, and software as well as operation and calibration instructions. The output of the review paper if the ventilator is open source is in terms of Yes or No.

<table>
<thead>
<tr>
<th>Device Name</th>
<th>Open Source</th>
<th>Food and Drug Administration Authorization</th>
</tr>
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<tbody>
<tr>
<td>MIT E-Vent</td>
<td>Yes</td>
<td>EDA approved</td>
</tr>
<tr>
<td>Ambo Vent</td>
<td>Yes</td>
<td>EDA approved</td>
</tr>
<tr>
<td>Vermentorlator</td>
<td>No</td>
<td>EDA pending</td>
</tr>
<tr>
<td>Project Open Air</td>
<td>Yes</td>
<td>EDA approved</td>
</tr>
<tr>
<td>V+Pro</td>
<td>No</td>
<td>EDA pending = Emergency Use Authorization</td>
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- V. Gusti [5] implemented the COSMIC Bubble Helmet as an initiative to treat mild to moderate COVID-19 patients with acute respiratory distress syndrome which uses low-cost materials, easy to manufacture, affordable, and easily sourced. The CBH model design is a neck seal that is transparent and flexible. The materials used to compose the CBH hood and neck seal are biocompatible thermoplastic polyurethane (TPU). The PEEP value, tidal volume, and the rate of airway pressure are controlled by varying the resistance provided by the PEEP valve. CPAP, BiPAP, or ventilator machines are used to adjust the air pressure independently. CPAP hood is primarily used in meeting the specified clinical treatment requirements and also reduce risks involved like aerosolization. The performance and efficiency of CBH in ventilating patients should be tested clinically on a larger patient sample.

- Abdul Mohsen, Al Husseini, Heon Ju Lee [6] prototyped a new low cost, portable mechanical ventilator which can be used during times of a pandemic such as this or any other resource-poor environments. This system is proposed to work in a manner that will deliver breaths by the depression of a conventional Ambu Bag or a BVM. This is achieved with the help of a pivoting cam arm mechanism. This system will remove the necessity of a human operator for the Manual Bag mask. The pioneer prototype of this system was built with the specifications of 11.3 x 6.8 x 8.3 inches (285 x 170 x 200 mm) and weighing 9 lbs (4.1 kg). The prototype was made out of acrylic. It was powered by an electric motor of a capacity - 14.8VDC battery. Another striking characteristic was the adjustable tidal volume which extends to the highest range of 740ml. This system posses many user-friendly knobs which can be used to feed in the TV and number of bpm. It also posses’s various safety features like the assist control mode and a warning system which will indicate over pressurization of the specific system. Further developments of the unit will also be inculcating a controllable inspiration to expiration time ratio, a pressure relief valve, PEEP capabilities, and an LCD screen. The cost of this project sums up to $420 and the projected estimation for the wholesale production is $200.

- OEDK – Rice University [7] designed the ApolloBVM is an automated version of a bag valve mask that uses many easy to acquire and simple components. It provides accurate and well-established mechanical ventilation for the patients affected due to the pandemics. The mechanism used currently is a dual ruck and pinion mechanical design which converts the mechanical motion of the motors present to translational motion for the bag compression. This device needs to be supplied with a 120V AC and has a power rating of <15W. The following are the settings observed in the ApolloBVM. Firstly, the respiratory rate as provided by the prototype is 5-30 BPM with 1 BPM increments. The tidal volume is set at 300-650ml with 50ml increments. This device holds a wall or tank-based oxygen through the low-pressure oxygen intake port.

- Taylor Vinters, Cambridge [8] implemented OxVent as a cost-effective ventilator which is approximately 5% the cost of a regular Ventilator. It is easily serviceable as it is built from standardized parts that are just as easily replaceable. It is robust and very handy in low resource areas as it will work for more than 1 hour only on its internal battery just in case of power failure. It is a rapidly deployable and scalable low-cost mechanical ventilator especially designed for the Covid-19 pandemic. It has two ventilation modes i.e., Volume Controlled Ventilation (VCV) and Assist Controlled Ventilation (ACV). It is a pressure driven ambulatory bag. It has a lifetime that will last greater than 500 hours before resuscitator bag replacement. The one drawback will be that it is more suitable for Invasive-ventilation rather than non-invasive ventilation. It has a tidal volume of 250 to 600 ml and has a breathing rate of 10 to 30 breaths per minute. It weighs around 7kgs which is 9kgs including the packaging and kit. The dimensions run up to 480x290x240 mm.

- Á. de Salem Martínez-Casasoa [9] implemented a ventilator using servomechanism. Due to the rapid spreading of the novel Coronavirus (COVID-19), it is very difficult to manage and control the affected patients. Also, due to the swift increased number of COVID-19 cases there is shortage of ventilators and air flow control is the main problem that is mainly associated with the servomechanism linking the bio-hydraulic system. To deal with this problem there is a need to develop other ventilators that can be designed easily and to reduce the complexity of the ventilators hence making them more useful. It is hard to design an expensive system always under these circumstances there needs to be a system in place which is handy and at the same time reliable, in providing the necessary needs. Thus, they propose to develop an open-source Mechanical Ventilator that can provide the feedback vector controller. It is more reliable and it gives the student more opportunities to create more experiments based on this project.

- B. F. Giraldo, J. A. Chaparro [10] discussed PSV mechanical ventilation. The process of discontinuation of mechanical ventilation called weaning is causing side effects to the patients after using it. We need to rectify this drawback in the ventilator and in order to correct this defect we need to analyse the respiratory pattern variability and for this, we need
to consider two different Pressure Support levels of Ventilation (PSV) before the use of the mechanical ventilation. Autoregressive models (AR), autoregressive moving average models (ARMA) are various autoregressive modeling techniques that are available. The main aim was to provide information on the respiratory levels of the patients before the weaning process. The results of this particular study were found out to be 95% accurate with 93% sensitivity and 90% specificity.

- L. Mertz, [11] introduced a method to convert an invasive to non-invasive. As the Corona virus spread became massive destruction to the whole world. There was a shortage of ventilators because the United States alone started reporting 30,000 cases every day. As each hospital had a limited number of ventilators it became very difficult to supply ventilators to the patients affected by the disease. Due to this, the chances of deaths were high. In order to avoid this the Government decided to produce more ventilators so the Government proposed the plan, this plan was already made by my Innovative-companies like Ford Motors and General Motors. Thus, to convert an invasive BiPAP machine into a non-invasive ventilator, just 48 hours transpired from the initial idea through the working prototype, according to medical staffs.

- H. Y. Al-Hetari, M. Noman Kabir [12] utilized volume-controlled ventilation. One of the most important types of ventilation is mechanical ventilation which is used to recover the breathing process by providing support to the respiratory non-function which happens due to the diseases like Coronavirus or Pneumonia. We make use of the VCV (Volume Controlled Ventilation) mode to simulate and stimulate the respiratory signal and this mode studies a single compartment made by real-time mechanical ventilation pressure of the lung model and this also explains what is PEEP (Positive end Expiratory Pressure). The artificial lung model gives results with the negative feedback which gives the same results as that of the pressure and flow outputs without the negative feedback with a 2% of error. This shows more accuracy of the lung model.

- Zecong Fang, Andrew I. Li [13] designed AmbuBox as a low-cost feasible ventilator making use of a pneumatic system and standard manual AMBU bag which are developed during the pandemic. It is designed to replace the expensive ventilators while giving more life span than the usual ventilators with precise flow control and easy operative apparatus. It is used in producing a large number of products since it is less expensive. The designs are given by the lung simulator and the overall design, operational principle are the device characterization of the AmbuBox.

- The scientists at Dr. APJ Abdul Kalam Missile Complex, RCI, DRDO [14] have designed and developed a low-cost and, portable ventilator named “Deven”. It acquired its name DEVEN which stands for DRDO’s Economical Ventilator. Along with being used in the hospitals, these systems can also be used in fields because of their portable features; all that’ll be needed is a reservoir and a portable air compressor and a portable air compressor. This feature also allows its access in a transportation vehicles, or any mobile vehicles such as ambulance, that can be used in any remote/rural area. This system is designed to operated by solenoid valve via micro-controller. This has been developed by slightly modifying existing technology which is currently in use for hot gas reaction control systems i.e., the HRCS. Exo-atmospheric missiles is the key manifestation of HRCS. The flow of oxidizer and fuel is controlled by actuating solenoid valves through a microcontroller. Apart from this DEVEN uses various other solenoid valves for inspiration.

- Seyed M. Mirvakili, Douglas Sim, and Robert Langer [15] have implemented Inverse Pneumatic Artificial muscles for application in low-cost ventilators. There are two primary modes of operation for modern ventilators which are CM and AM that have been successfully replicated. Along with this, they have been successful in getting both consistent and accurate results that match that of a certified conventional ventilator. They also explain how the system can be easily upgraded as it is easy to implement more modes of operation as the architecture and design are in a way to accommodate the same. Along with this, it also posses’ sensors for monitoring the blood oxygen saturation level, the output CO2 level, it also includes temperature sensors. This system can be fitted to possess an ECG and heartbeat. The present design functions in a way as the two primary modes are demonstrated. These modes are mainly the controlled and the assisted mode. These are different from conventional ventilators as they don't require a high-pressure air pipeline to operate. The specifications of this system are as follows: The tidal volume range is 150-100ml and it also has the capacity of 10 to 30 b/min for its respiration rate. This system can be built at a cost of less than USD 400.

III. METHODOLOGY

Working principle
The Glasvent is an inexpensive and easily developable emergency ventilator that makes use of the basic components and requirements of a mechanical ventilator. The system operates in three different modes:

a) Power supply or mains operation
b) Li-ion battery operation
c) Manual operation by rotating small handle connected to the rotating disc of the motor.

The working principle of the system is to convert the rotational motion of the motor to continuous linear one-directional motion using the crank-slider mechanism. To get maximum compression of the bag and to control the tidal volume exerted by the system, the base of the motor will slide toward or away from the AMBU bag. The key parameters such as tidal volume, PEEP value, respiratory rate, minute respiration that need to be regulated are connected as local controls that are monitored regularly by healthcare workers. The local controls are connected to Arduino due which is a 32-bit arm core microcontroller with 54 input pins. The Arduino
due is programmed using Arduino software IDE. The system utilizes the printed circuit board (PCB) stepper motor driver module (DRV8825 Stepper Motor Driver module). A simple PCB is utilized and designed to drive the motor. All inputs and outputs of the motor controller PCB module are connected to Arduino due. The stepper motor driver module activates the stepper motor which compresses and expands the BVM utilizing crank-slider mechanism. The BVM is connected to the PEEP valve that can be adjusted by a medical person underlying the patient’s requirements. Tidal volume can be controlled and measured by the speed of the stepper motor. For the safe operation of the system, monitoring the pressure is important. Any commercial pressure sensor is placed at the PEEP valve to measure the pressure and respiratory rate which are all connected to Arduino. The output pin(5V) of the Arduino is supplied to the pressure sensor. The output of the sensor is 0–5 V which corresponds to 0–6 Kpa range in terms of pressure. The range of analog pins of the Arduino Due is between 0 and 3.3 V, hence a voltage divider is required to meet the output range of the sensor to acceptable voltage for the microcontroller. A display is connected for further monitoring of parameters and inform the user if there exist any potential problem with the system. The Arduino is connected with a Computer (PC) or tablet where all the information about pressure and other important parameters are displayed which allows the user to have a detailed look at the system. For safe operations as a backup, three Li-ion batteries are provided when power is not available. This makes the system portable emergency ventilator in transport such as ambulance or in remote regions where the availability of mechanical ventilators is low. The Arduino requires a voltage from 6.5 to 13 V supply. The stepper motor driver can be powered up from 7V up to 42V. The battery pack can provide 0.6 V and above the 11V for the microcontroller. The battery pack can last up to 3 and a half hours.

IV. CONCLUSION

The shortage of mechanical ventilators has led to the expeditious increase in the number of cases and the death of COVID-19 patients has shaken the world. To induce the shortcomings in ventilators and overcome the crisis, various medical care and expert manufactures have come together to prototype emergency ventilators. Emergency ventilators can induce a shortage of mechanical ventilators. Some of these systems have been compared and discussed here along with a detailed description of Glasvent. Though none of them will match or replace existing complex mechanical ventilators in terms of performance and stability, they do ease the manufacturing processes and time in the current situation. Emergency ventilators are low cost, portable as it uses 3D printed parts and has backup battery options. The Food and Drug Authorization (FDA) has given emergency use authorization only (EUA) for most of the systems mentioned before. To improve the performance, further development, testing, and regular approval recognize these opportunities and can thrive for ideal ventilator definition protocols that can be redefined by medical health workers.

V. REFERENCES


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