Low Cost and Portable Mechanical Ventilator

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Abstract

This paper presents a low-cost and portable mechanical ventilator in order to contribute towards the increasing demand for mechanical ventilators all over the world due to the global pandemic of COVID-19. The proposed system’s portability makes it different from the other ventilators which are currently used in different hospitals. It could be easily carried from one place to another without facing any difficulty because of its small size and low weight as compared to the previous versions of ventilators. Moreover, the aim is to design and provide an adequate amount of oxygen and clear CO₂ simultaneously to the patients and it will also prevent infection. The proposed ventilator is one of the simplest variations of a mechanical ventilator and the idea behind this vision is to make it too simple so that any ward nurse or a common man can easily operate it efficiently. Therefore, an expert can also invest his/her time while looking after much more severe cases as compared to not making much of his/her timeless productive while standing in front of the ventilators and taking care of patients in the early stage.

Index Terms: Mechanical Ventilator, Computer-Aided Design, Arduino, LabVIEW, Global Pandemic.

I. INTRODUCTION

Nowadays, the whole world is facing a global pandemic named ‘COVID-19’. Due to this pandemic, an enormous surge has been observed in the demand for ventilators in every corner of the world. In order to cope-up with this situation, bio-technological companies have increased their production. But the problem is still there where it was initially because there are approximately 7.9 billion people all around the world and this virus has affected almost every state, country, city, region, locality of the world. Therefore, the production of ventilators as 1:1 to cope-up with the human population is an unrealistic task. But still, efforts can be made to increase the production of ventilators as much as possible. Moreover, a surge has been observed in the price of ventilators which is also a big issue to tackle. In these crucial times, low-cost ventilators are needed that every clinic/hospital in the world can easily afford the most needed facility of the time. Along with the price, its portability also matters a lot, and these days’ ventilators cannot be easily transported from one place to different places because of their weights and sizes, therefore, the design is required to start producing ventilators which should be small in size and less weighted as compared to the ventilators available in the hospitals. A conceptual design for the physical structure of a basic level positive pressure ventilator has been proposed [1]. All the basic parameters were taken into consideration to make a basic level ventilator in order to contribute to this pandemic. A conceptual design is provided using SolidWorks. The rising difference between the need and availability of mechanical ventilators is discussed previously [2]. Furthermore, among the latest innovative technology, they emphasize more on the 3D printers in order to produce mandatory parts of ventilators. Comparative research on the basis of the ten properties such as Core Design, Operations, Documentation, Infra-Structure, Parts, Costs, Test, Certification, License, and Community has been given [3]. All these properties are analyzed on the basis of three principles which are Buildability, Adaptability, and Scalability. Moreover, weaknesses and strengths have been highlighted and authors have also considered OSH-MV as a newly emerging field.

Some authors have introduced a ventilator which is made up of PVC pipes and some basic plumbing and electronics stuff [4]. It is shown the control of Peak Inspiratory Pressure (PIP) and Positive End-Expiratory Pressure (PEEP) with the help of respective tubes length immersed in the reservoirs and obtains data with the help of a pressure sensor. The authors have made a low-cost ventilator with the help of the components which are easily available [5]. Two limbs have been provided, one for inspiration and the other one for expiration. For the inspiration limb, an inflating bag of 0.5L has been used in which size 3 soccer balls have been placed, thus, the soccer ball acts as a barrier to stop the inflation of the bag at the maximum desired point. For the expiration limb, inflating bag and PEEP valve have been used. Moreover, Mechanical Ventilator Milano (MVM) has been designed. It is basically a more advanced version of Manley Ventilator, which was introduced in the mid-twentieth century. The main difference of the proposed MVM was that the mechanical switches were replaced with pneumatic valves which were controlled electrically [6]. A group of authors has precisely worked on one of the major problems which could occur while operating the ventilator, especially in those areas where atmospheric air
is polluted due to different reasons [7]. In such conditions, the atmospheric air could be very harmful to the ventilation purpose. One of the most well-known filters 'HEPA Filter' was considered to be used with multiple modes of ventilation and air filtration with respect to the instantaneous particle concentration in the air. In addition, based on a systematic study in order to find a more economical solution in order to reduce Ventilator-Associated Pneumonia (VAP) with the help of Ventilator Bundles (VBs) taken through intensive care units [8]. The Atmospheric Mixture Optimization ventilator (ATMO-vent) provides multiple customizable functions like ratio of inspiratory oxygen (FiO₂) levels, Inspiratory/Expiratory ratio (I/E), PIP, Tidal Volumes (TV), and PEEP [9].

The main idea is to contribute and make a low-cost and portable ventilator. It works on both modes Continuous Positive Airway Pressure (CPAP) and Bi-level Positive Airway Pressure (BiPAP) as the proposed ventilator comprises two different assemblies for the inhale and exhale cycle [10]. Having both of these modes can be helpful in both types of respiratory failures. In respiratory failure Type I, the body has low oxygen levels and normal or low CO₂ levels, in order to tackle such failure CPAP mode is well enough because, in this mode, Inspiratory Positive Airway Pressure (IPAP) and Expiratory Positive Airway Pressure (EPAP) are both equal and also functioning in a continuous manner. Whereas in respiratory failure Type II, the body has low oxygen levels and high CO₂ levels and that’s where BiPAP mode is helpful, therefore, IPAP and EPAP both can be set differently which totally depends on the patient’s condition. Besides having these basic and important functionalities, the goal is to make a compact, simple and economical ventilator. Thus, the designed mechanical ventilator as small as it can be easily carried in the briefcase that defines its portability; it can also be carried to rural areas easily where hospitals and ventilators facilities are not available. And its cost is kept as low as possible while considering market competency. By providing a low-cost and portable ventilator, the gap can be minimized between the production and demand of the ventilator. And portability adds a plus point because making it, this much portable will also eliminate many of its transportation difficulties and hazards. And in this way, it could be easily circulated worldwide, thus, the aim of serving humanity would be well accomplished [11-17].

II. DESIGN OF EXPERIMENTATION

The proposed design replicates the two respiratory cycles that exist in every human body, i.e., inhale cycle and exhale cycle as shown in Figure 1 and Figure 2. For these two cycles, two different assemblies are arranged in the proposed ventilator. In the inhale cycle assembly, let’s say its path is ‘P1’, at the very beginning there is a pressure regulator through which a lay-man can also set it between the range 0 mbar to 800 mbar as per the required condition. After the pressure regulator, there is a check valve whose sole purpose is to stop the backward flow of air. After this check valve, the path ‘P1’ gets divided into two different paths named ‘P2’ and ‘P3’ respectively. Now, explaining the ‘P2’ path, there is a pressure sensor connected in the pipeline through which pressure feedback is gained and displayed at the Graphic User Interface (GUI) created through LabVIEW, and path ‘P3’ extends to a flow meter connected in series after which a flow regulator is connected to control the flow.

After the flow meter path, ‘P3’ gets divided into further two paths named ‘P4’ and ‘P5’. At path ‘P4’ there is only a safety valve connected at the end which is for the emergency purpose that whenever the pressure exceeds the maximum range, it can be used to lower the pressure. And path ‘P5’ is connected to a solenoid valve which serves as an On/Off switch for the inhale cycle after the solenoid valve, the air will go towards the artificial lungs which are connected at the end of the inhale cycle and in this way the inhale cycle gets completed. For the exhale cycle, the assembly is pretty much simpler as compared to the inhale cycle, and only a single path ‘P6’ serves solely for the entire exhale cycle assembly. At the very beginning of the exhaling cycle, a solenoid valve is connected which again serves as an On/Off but this time for the exhale cycle. After which a check valve is connected in series which again makes sure that there should be a no-return flow during the exhale cycle. After the check valve, a flow meter is further connected this is for the monitoring of the flow of the exhaling cycle via Graphic User Interface (GUI). And at the end of the exhale cycle assembly a HEPA filter is connected in order to avoid environmental viral diffusion.

Figure 1: The Proposed Design Replicates the Two Respiratory Cycles, i.e., Inhale Cycle and Exhale Cycle (Far View)

Figure 2: The Proposed Design Replicates the Two Respiratory Cycles, i.e., Inhale Cycle and Exhale Cycle (Closer View)

III. EXPERIMENTAL SETUP

In Figure 3, the proposed system’s block diagram is shown. In this block diagram, there are five blocks that are
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designated to specific constituents of the project. Firstly, the mechanical ventilator system on which all the work is being carried out, then the system’s actuators which do all the functioning part for our system. After that, the system’s sensors extract data, and the micro-controller where all fetched data is delivered and it also gives commands to the actuators which are according to the given parameters and these parameters can be are set in the Graphic User Interface or GUI. The GUI is created on LabVIEW and the Arduino Microcontroller is used. The actuators deployed in the system are pressure regulator, inhale solenoid valve, and exhale solenoid valve. And the sensors deployed for data extraction are pressure sensor, inhale flow meter, exhale flow meter, and pressure gauge.

In Figure 3, the block diagram of the proposed system is shown. The system’s actuators include a pressure regulator, inhale solenoid valve, and exhale solenoid valve. The sensors consist of a pressure sensor, inhale flow meter, exhale flow meter, and pressure gauge. The micro-controller connects the actuators and sensors, and the Graphic User Interface (GUI) is used to display the system's status and control parameters. The GUI is created on LabVIEW, and the Arduino Microcontroller is utilized to control the actuators.

In Figure 4, the schematic diagram of the proposed circuit is presented. The circuit consists of 9 components: one UNO Arduino as the brain and controller, two solenoid valves for inhaling and exhaling, two relays connected to the digital pins 11 and 12 of Arduino, one pressure sensor for inhaling, one Op-amp for amplifying pressure sensor data, and two resistors of 100K ohms for amplification purposes. The pressure sensor is connected to the Arduino's analog pin 'A0' for feedback on the pressure of oxygenated gas delivered to the patients. The GUI is created on LabVIEW, and the icon 'COM5' is selected before getting started.

Figure 3: Block Diagram of the Proposed System

Figure 4: Schematic Diagram of the Proposed Circuit

The system’s GUI is shown in Figure 5, which is designed on LabVIEW (Figure 6). Before getting started, select the icon ‘COM5’ given in Figure 5 and then select the micro-
controller as ’Arduino UNO’. Then select Arduino’s digital pins for Inhale and Exhale Channel and Analog pin for Pressure Channel as pins 10, 11 and pin 0 (pin 0 represents Arduino’s analog pin ‘A0’). This GUI facilitates the user, through which inhale time and exhale time can be set. And whenever the operator wants the operation to be turned off immediately, for that case stop button in GUI can be used. In most cases, exhale time is more than the inhale but it also varies from case to case. Therefore, this GUI could very helpful for specialist doctors because through this they will have a very easy interface on which they can easily set the parameters and could also change whenever needed as per the patient’s health. And the doctor can also have an accurate pressure reading through this GUI.

In Figure 7, the flow chart is depicted which shows the whole process of a mechanical ventilator. As the process starts there are two parallel operations going on. In Operation 1, the user manually sets the input pressure which is further read by the pressure sensor and is fed to GUI Display (which is the part of Operation 2). On behalf of the pressure reading a decision is made, if the instantaneous pressure is equal to or less than the desired pressure then in that case the supply of medical aid will be provided to the patient without any interruption. But if due to any malfunction or at any unknown circumstance the actual pressure goes beyond the desired pressure then, in that case, the operation would be turned off manually with the help of the stop button present at the GUI Display and in such a way the whole process will come to an end.

In Operation 2, as the process starts the GUI gets turned on. At the GUI display, the pressure would be shown and data would be fed with the help of a pressure sensor (previously discussed in Operation 1). After the display gets turned on, the user will do the connectivity setting in which the “Inhale Channel” and “Exhale Channel” can be selected. After doing the connectivity settings, the user will set the desired inhale and exhale time. Then the Inhale Solenoid Valve will get turned on until the desired time for the inhaling cycle is not achieved.
Once the instantaneous inhale time gets equal to set inhale time then both, Inhale Solenoid Valve gets turned off and Exhale Solenoid Valve gets turned on, simultaneously. Now the Exhale Solenoid Valve will stay on until the desired time for the exhaling cycle is not achieved. Once the instantaneous exhale time gets equal to set exhale time, then Exhale Solenoid Valve gets turned off, and Inhale Solenoid Valve gets turned on. And in this way, this loop
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**IV. OBSERVATION AND ANALYSIS**

Initially, geometry in the ANSYS workbench is imported which was made on SolidWorks. And selected fluid flow (fluent) module in which further have four steps, i.e., geometry, meshing, setup, and result. In geometry, simply the geometry has been imported. In the meshing option, the sizing is done of what size element is used in which the default option is selected. Then label the inlet and outlet of our geometry, and after updating the setting, the meshing step is finalized. Afterward, cores and Graphics Processing Units or GPUs of the system are selected. The four cores and one GPU are selected and after this precision level to maximum can be set. Then in general settings, the boundary conditions are selected in which defined the route and selected the walls or path through which the fluid is going to flow. Moreover, the model is selected on which fluid flow (fluent) analysis to be done, in which ventilator model is selected. Then the material is selected, which is going to flow through the cavity or path of the model, i.e., mechanical ventilator. The air is selected as the material in this option. After this, the last thing remains in the setup step, i.e., calculations. In the calculations, the standard calculations are performed which controls the system in the steady-state. In the end, ANSYS starts computing all the parameters for the simulation.

ANSYS gives the simulation as a result in Figure 8. In the simulation, it’s visible that there is no critical area found. In the flow trajectory, only mid-green and light blue colors (cyan) are visible all over. And according to the values mid-green is approximately equal to 1.25 KPa and light blue (cyan) is approximately equal to 0.57 KPa. At the endpoints near the elbows, it’s not even light orange or yellow, it is mid-green and except it, it is light blue (cyan) all over.

Thus, according to this simulation, one can say that the system is fully stable and perfectly planned. And there is no need to worry as the result shows there is no alarming situation predicted regarding the mechanical ventilator. 

**V. RESULTS**

In Table 1 below, one can see the working of our pressure sensor which is deployed in our mechanical ventilator as a verification mechanism. With the help of this sensor, it can be verified that the delivered input pressure in the inhale cycle is accurate. With the help of the above table, it depicts how the calibration was done in the project. From Table 1, it can be seen that at 0 bar pressure our pressure gives 0.13 V voltage as an output. Similarly, at 0.1 bar it gives 0.7 V, at 0.15 bar it gives 0.81 V, at 0.2 bar it gives 1.22 V, at 0.25 bar it gives 1.49 V, at 0.3 bar it gives 1.82 V, at 0.4 bar it gives 2.52 V, at 0.5 bar it gives 3.05 V, at 0.6 bar it gives 3.63 V, at 0.7 bar it gives 4.26 V, at 0.8 bar it gives 4.92 V.

| Pressure in Bar | Voltage Output (V) |
|-----------------|--------------------|
| 0               | 0.13               |
| 0.1             | 0.7                |
| 0.15            | 0.81               |
| 0.2             | 1.22               |
| 0.25            | 1.49               |
| 0.3             | 1.82               |
| 0.4             | 2.52               |
| 0.5             | 3.05               |
| 0.6             | 3.63               |
| 0.7             | 4.26               |

In Figure 9, the graph is obtained from the data provided by the pressure sensor which was shown in Table 1. Here from the graph, it can be seen that approximately a linear graph, which means the relationship between the input pressure and output voltage is directly proportional.

**VI. CONCLUSIONS**

The mechanical ventilator has been designed which is economical and highly portable due to its compact size that could be carried to any place easily. On behalf of flow analysis, simulation, and the data accumulated through the pressure sensor, one can say that the system is stable and controlled. Furthermore, improvements could also be made in the proposed design such as the addition of the assisted mode, which will automatically decide the inhale
and exhale time with the help of a closed system.

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Authors Contributions
Ehtisham Ahmed’s contribution to this study was the concept and technical implementation. The methodology to conduct this research work along with correspondence and supervision was proposed by Saim Ahmed. The data collection and paper writing was performed by Ahmad Khan. Zeeshan Rafiq facilitated the data compilation, validation, and project administration.

Conflict of Interest
There is no conflict of interest between all the authors.

Data Availability Statement
No testing data is available in this paper.

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