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DIY Remote Ventilator

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Abstract: Coronavirus Disease 2019 (COVID-19) threatens to overwhelm our medical infrastructure at the regional level, causing spikes in mortality rates because of shortages of critical equipment, like ventilators. Various variants of coronavirus are still being found in various parts of the world, like South Africa, Switzerland, and China, and also there is a threat of the 4th wave of Covid-19 to hit India in August. Fortunately, with the recent development and widespread deployment of small-scale manufacturing technologies like open-source microcontrollers, mass distributed manufacturing of ventilators has the potential to overcome medical supply shortages. In this study, after providing background on ventilators, we review the academic literature to find the existing and already openly published, vetted designs for ventilators systems.A mechanical ventilator is a medical device that is usually used to ventilate patients who cannot breathe adequately on their own. Among many types of ventilators, Bag Valve Mask (BVM)/ Ambu Bag is a manual ventilator in which a bag is pressed to deliver air into the lungs of the patient. In the present work, a mechanical system along with microcontroller has been developed to automate the operation of BVM. Although the developed device cannot compress the bag completely due to low powered servo motors, it proves the concept of automating the operation of BVM using the mechanical system for developing a portable ventilator.

Index Terms: Coronavirus, COVID-19, ventilators, BVM, Ambu Bag .

I. INTRODUCTION

Mechanical ventilation is an important treatment which is usually utilized to ventilate patients who cannot breathe adequately on their own.

Patients with underlying lung disease or have some breathing problems may develop respiratory failure under a variety of challenges and can be supported by mechanical ventilators.

These are machines which mechanically assist patients inspire and exhale, allowing the exchange of oxygen and carbon dioxide to occur in the lungs, a process referred to as artificial respiration.

There are many techniques and methods of artificial ventilation, both manual and mechanical. While modern ventilators are computerized machines, patients can be ventilated with a simple, hand-operated bag valve mask (BVM) also.

Although there are many elegant positive-pressure ventilators with sophisticated safety controls, they are rarely available in the field, thereby forcing a rescuer to resort to manual methods of ventilation. Most of the time these high end ventilators are not easily accessible and are difficult to use as well.

In the present work, designing principle of a low-cost portable mechanical ventilator based on the BVM, along with the methodology for its construction and performance test has been described.

The prime objectives of the project are described below :
1) To design and construct a portable mechanical ventilator by automating the operation of bag-valve- mask or 'Ambu bag'.

2) To assess the cost of production of the designed ventilator to justify its use instead of manual resuscitators and existing portable ventilator.

3) To check whether the remote ventilator is providing proper aid to the patients who need oxygen.

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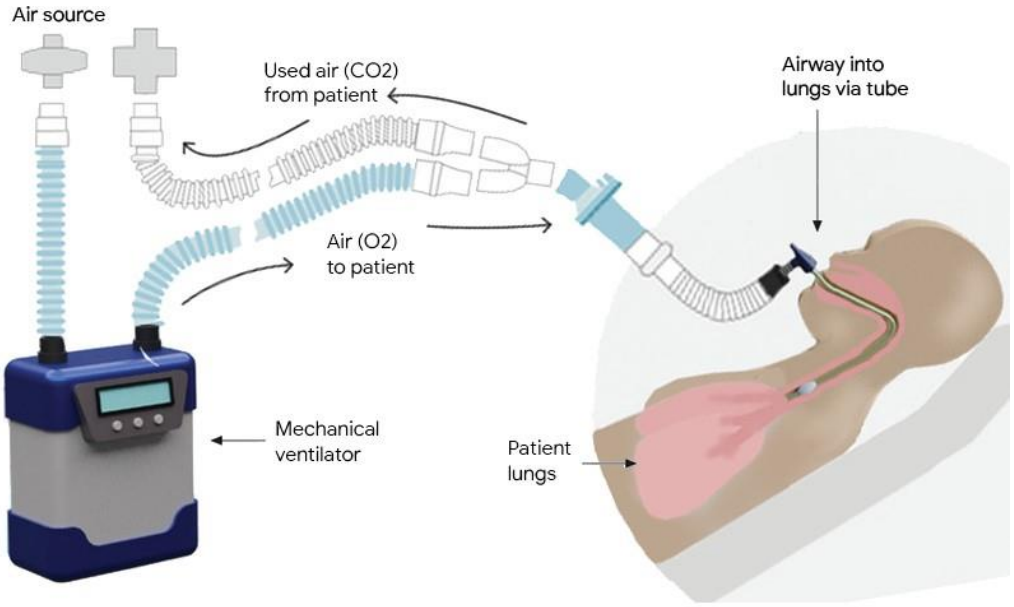

FIG.1 Mechnical Ventilator Example

II. ANALYSIS OF LITERATURE

Oxygen therapy coupled with mechanical ventilation is meant to support patients so that an adequate oxygen saturation (>88%) in arterial blood is maintained. The mechanical repository cycle has four parts: 1) inspiration, where the exhalation valve of the ventilator is closed and the ventilator uses pressured air to cause gas to flow into the lungs; 2) cycling, where changeover from inspiration to expiration occurs; 3) triggering, where the changeover from expiration to inspiration occurs, and 4) expiration, where the main ventilatory flow is interrupted and the exhalation valve opened to allow gas to escape from the lungs

Building a low-cost ventilator utilizing an AMBU bag that is not based on constant blower use. The study by Mr. M Shahid showed the AMBU setup was able to perform all the functions of a conventional commercial ventilator for a far lower cost (less than 7600 IND rupees). The automated AMBU device was able to adjust the breathing rate and the volume of the air, which is also seen in the old ventilators as well as ventilators that are already in use. However, it was also able to regulate the inspiration to expiration ratio and PEEP rate. Shahid's system comes with two modes: 1) mandatory ventilation (as in older models) and 2) assisted ventilation (as with most current systems). Thus, the medical personnel can choose to use either the built-in triggering mechanism (assist boosted mode), which alters the respiration pattern once it detects a change in air pressure, or set a time interval for the respiration pattern. The article contains pictures, an electric schematic, a control loop diagram, and very basic results. Again, this can be used as starting point, but there is not enough shared to replicate in the open hardware fashion. As more improvements are being made in the making of portable low-cost ventilators for the future.

III. THEORY AND PRINCIPLES

3.1 PRINCIPLE OF OPERATION OF MECHANICAL VENTILATORS:

A mechanical ventilator is a machine that helps a patient breathe (ventilate) when they are having surgery or cannot breathe on their own due to a critical illness. The patient is connected to the ventilator with an endochondral tube that goes in their mouth and down into their main airway or trachea. They remain on the ventilator until they improve enough to breathe on their own. Some patients have a surgical hole placed in their neck and a tube (tracheostomy or "trach" tube) is connected through that hole. The trach tube is able to stay in as long as needed and is more secure than an ET tube. At times a person can talk with a trach tube in place by using a special adapter called a speaking valve. The ventilator blows gas (air plus oxygen as needed) into a person's lungs. It can help a person by doing all of the breathing or just assisting the patient's breathing. The ventilator can deliver higher levels of oxygen than delivered by a mask or other devices. The ventilator can provide a pressure (PEEP pressure) that helps hold the lungs open so the air sacs don't collapse. The tube in the windpipe makes it easier to remove mucus if someone has a weak cough.

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3.2 WORKING OF AMBU BAG:

In Fig. 2 the various parts of an Ambu bag are identified. Manual resuscitators cause the gas inside the inflatable bag portion to be force-fed to the patient via a one-way valve when compressed by the rescuer; the gas is then ideally delivered through a mask and into the patient's trachea, bronchus, and lungs. The tidal volume and the respiratory rate has to be maintained as per the conditions of the patients by the rescuer.

Typical tidal volume is 500 to 800 mL of air and typical respiratory rate is 10 to 12 respiration per minute for adults and 20 respirations per minute for infants. Professional rescuers are taught to ensure that the mask the portion of the BVM is properly sealed around the patient's face.

The term "Ambu bag" comes from the acronym for "artificial manual breathing unit" and is used to refer to bag valve masks. The company that invented the Ambu bag was originally called Testa Laboratory and rebranded as Ambu in the 1980s.With the mask pressed over the patient's airway, air is forced into the lungs by squeezing the bag. The bag then refills itself with air when released, allowing it to return to its original shape. The bag can be squeezed out and re-inflated rapidly and repeatedly to resuscitate the patient and provide oxygen, even if the patient can't breathe on their own.

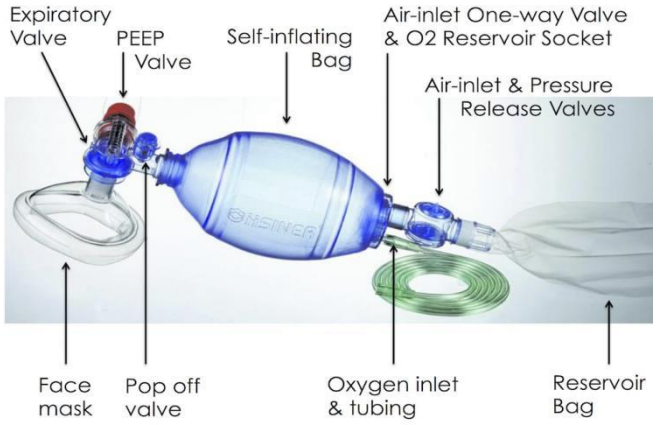

FIG.2 Various parts of Ambu Bag

IV. DESIGN AND CONSTRUCTION

4.1 DESIGN ASSUMPTIONS:

The design of the proposed DIY Remote Ventilator for adult patients was done based on the following assumptions—

i. Tidal volume to be delivered = 200 to 750 mL.
ii. Breath rate to be maintained = 10 to 20 BPM .
iii. Maximum power required by the motor = 30 W .
iv. Maximum torque to be delivered by the motor = 1.5 N.m.

The design assumptions are based on the work by Husseini et al. [2], as they determined the assumptions after necessary experiments taking the mechanical properties and dimensions of the Ambu bag into considerations. So, their assumptions can be taken without further experimentations.

4.2 PRINCIPLE OF PROPOSED DESIGN:

Most emergency and portable ventilators are designed with all custom mechanical components, it was chosen to take an orthogonal approach by building on the inexpensive BVM, an existing technology which is the simplest embodiment of a volume-displacement ventilator. Due to the simplicity of their design and their production in large volumes, BVMs are very inexpensive and are frequently used in hospitals and ambulances. They are also readily available in developing countries. Equipped with an air reservoir and a complete valve system, they inherently provide the basic needs required for a ventilator. The main drawback with BVMs is their manual operation requiring continuous operator engagement to hold the mask on the patient and squeeze the bag. This operating procedure induces fatigue during long operations and effectively limits the usefulness of these bags for temporary relief. Moreover, an untrained operator can easily damage a patient's lungs by over-compression of the bag. The methodology taken has been, therefore, to design a mechanical device to actuate the BVM. This approach will result in an inexpensive machine providing the basic functionality required by the mechanical ventilator standards. In Fig.3, the diagram of the the proposed system is illustrated. To

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automate the operation of Ambu bag, the mechanical system developed to compress the bag must be synchronized with the ideal motion that is maintained by a professional rescuer.

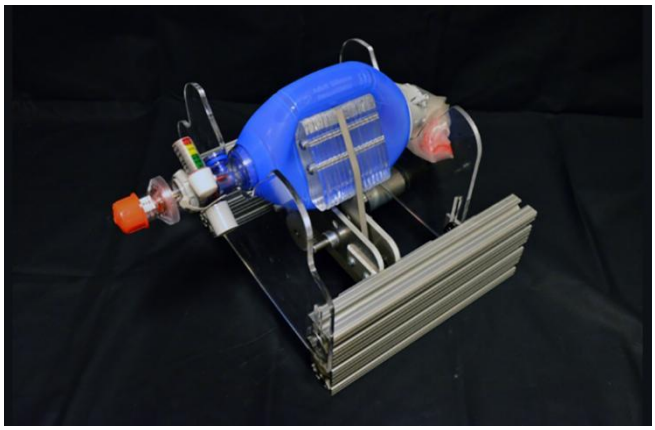

FIG.3 Diagram of Remote Ventilator

4.3 COMPONENTS USED:

The materials and equipment were selected on the basis of the design assumptions discussed previously. Materials and component needed to construct the prototype are presented in Table 1.

Table1. Components and it's specifications

Component	Rating And Specifications	Quantity
1.Ambu Bag	BVM Bag	1
2.Servo Motor	-	2
3.Frame and Arm	-	1
4.Microcontroller	Arduino Uno	1
5.Project Board	-	
6.LCD Display	LCD	1
7.Battery	9V DC	1
8.Potentiometer	10k Ohm	1
9.Wires / Jumpers	-	As per required

V. RESULTS AND DISCUSSION

5.1 RESULTS:

The DIY Remote Ventilator delivers in the range of 10 – 30 breaths per minute, with the ability to adjust rising increments in sets of 2. Along with this, the ventilator mechanism can deliver in the range of 10 – 30 breaths per minute, with the ability to adjust rising increments in sets of 2. Along with this, the ventilator has the ability to adjust the air volume pushed into the lungs with each breath. Last but not least is the setting to adjust the time duration for inhalation to exhalation ratio.

Apart from this the ventilator is able to monitor the patient's body temperature and exhaled lung pressure to avoid over/under air pressure simultaneously.

The ventilator we here designed and developed using Arduino encompasses all these requirements to develop a reliable yet affordable DIY ventilator to help in times of pandemic.

We here use an Ambu Bag coupled driven by DC motors with two side push mechanisms to push the ventilator bag. We use a toggle switch for switching and a variable pot to adjust the breath length and the BPM value for the patient.

Our system makes use of a temperature sensor along with a sensitive pressure sensor to monitor the necessary vitals of the patient and display them on the LCD screen. Also, an emergency buzzer alert is fitted in the system to sound an alert as soon as an anomaly is detected.

The entire system is driven by Arduino controller to achieve desired results and to assist patients in COVID pandemic and other emergencies, ventilator must have the ability to adjust the air volume pushed into the lungs in each breath. The last but now the least is the setting to adjust the time duration for inhalation to exhalation ratio.

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5.2 UNIQUENESS OF THE PROJECT:

The present work is based on the automation of the AmbuBag to construct an emergency portable mechanical ventilator, similar to the work by Husseini et al.[2]. But in present work, mechanical arms, and servo motors have been used to actuate the BVM, whereas, Husseini et al. Used cam mechanism for the purpose. The technique used in the present work proves to be more effective as it permits programming the required compression pattern, while in can mechanism . The compression pattern is fixed and unchangeable. So, more controllability is achieved by implementing mechanical arms and servomotors to actuate the Ambu Bag.

5.3 DISCUSSIONS:

The prototype could not compress the Ambu Bag completely.
It compresses the bag partially. The reason behind this might be—
i. The motors were not powerful enough to compress the bag completely.
ii. The frictions among the mechanical linkages absorbed reasonable power.
iii. The prototype could not be built precisely due to a lack of precise construction tools.
Though, the prototype works as a proof-of-concept in automating the operation of the Ambu Bag. In future developments of the prototype, these problems may be resolved.

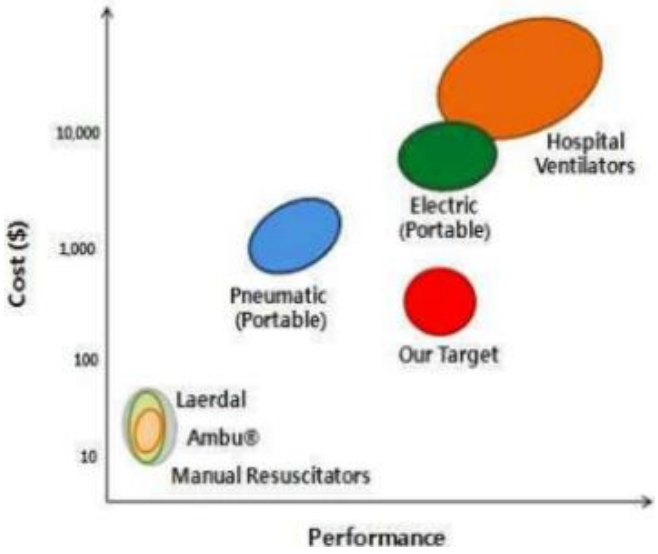

FIG 4. Cost Factor

5.4 COST FACTOR:

Cost-performance distribution is depicted in Fig.4 with manually operated BVMs on the low end of cost and performance, and full-featured hospital ventilators on the other extreme.
The Middle section of the chart includes the existing portable ventilators which can be broadly categorized as pneumatic and electric. Pneumatic ventilators are actuated using the energy of compressed gas, often a standard 50 psi (345kPa) pressure source normally available in hospitals.
But, to generate constant ventilation for pneumonia cases such as COVID-19 patients an automated and low-cost Ambu bag airflow system is effective to save a life.

VI. FUTURE DEVELOPMENT SCOPE

Following developments might be implemented for a usable portable mechanical ventilator—
i. More powerful servo motors can be used.
ii. DC motors can be used along with DC motor controllers to reduce the cost and increase the driving torque.
iv. More features can be implemented to control various ventilation parameters like tidal volume, inspiration to exhalation time ratio, etc.

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VII. CONCLUSION

The project work proves the concept of automating the Ambu bag or BVM for developing a low-cost portable mechanical ventilator. Improvements to the model will lead to successful and useable portable mechanical ventilator for actual emergency cases where existing sophisticated devices are not present. Although the device cannot perform like existing devices, its low cost justifies its use in emergency cases. With 9V battery as a power supply the prototype can operate continuously for one hour. It also has a feature to control the breath rate and an LCD shows the BPM the device is operating with.

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