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Research article

NISHASH: A reasonable cost-effective mechanical ventilator for COVID affected patients in Bangladesh

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ABSTRACT

COVID-19 has elapsed all over the world with massive losses which indicate the lack of availability of medical equipment during the pandemic such as a ventilator. This is exemplified by the densely populated country Bangladesh who unable to maintain COVID-affected people because of the ventilator. Due to the higher price, unavailability, and manufacturing defection, most medical are unable to purchase this ventilator which causes terrible death for a respiratory problem. Of these cases, this paper represents a way to escape this problem and proposed a mechanical ventilator named "NISHASH" which will help to anticipate COVID affected people and higher price of the ventilator. Through the electromechanical instruments, a prototype lightweight easily moveable where preciously it automatically controls with digital feedback system ventilator which fulfills oxygen flow based on patient requirement are developed with different selection mode. The aim was to design and develop inexpensively automated easy to build to minimize the extreme shortage of the ventilator in Bangladesh. In this model of a mechanical ventilator, the cost is less than $90 where components are available all over the world.

1. Introduction

On December 31, 2019, China announced the first instance is COVID-19 which has arisen as the trouble of coronavirus. Later World Health Organization (WHO) described it as a pandemic on 11 March 2020 [1]. COVID-19 turns the patient to pneumonia involvement, additional of the air sacs become full of fluid leaky from the little blood vessels within the lungs. Subsequently, breathing problem takes to lung failure which is called Acute Respiratory distress syndrome (ARDS) [2].

Many individuals infected with COVID-19 will undergo mild to moderate failure of the respiratory and without hospitalization patients will recover with special care. Many times, before Ventilator-induced lung injury (VILI) was under consideration. Overall, other possible causes of lung damage were found in most patients with dysfunction of lung needing mechanical ventilation and many patients tended to endure mechanical ventilation for extended periods without any harmful sequelae. Nevertheless, owing to several studies over the decades, it is widely agreed that mechanical ventilators can initiate and intensify lung injury and lead to patient morbidity and mortality as a consequence of numerous research [3].

Slightly over 101 million people are affected while 2.1 million people died and many more still fighting with death [4]. Around 15 percent of cases of COVID-19 are serious in a hospital, approximately 5 percent of individuals have serious infections and require a ventilator to serve oxygen. Due to the shortage of Intensive Care Units (ICU) and the high rate of price, many peoples are unable to get proper respiratory treatment whereas ventilators are the most effective ones. Even though a well-developed country US, Italy were not sure if the virus attack and all their reserved ventilator were used then they will fall into trouble [5].

Bangladesh's public health sector is heavily burdened, were fewer facilities in medical equipment, and COVID patients are unable to get proper treatment [6]. The densely populated country is Bangladesh where half a million were affected and about 9 thousand people are died by COVID. On 8 March 2020, Bangladesh has announced its first case, 49 reported cases, and 5 more deaths until 30 March 2020 because of COVID-19 [7, 8]. Considerably less than 2 thousand ventilators are reserved for 165 million populated countries of Bangladesh. At this time, an estimated ventilator is accounted for every 93,273 people in Bangladesh [9]. So it's clear that Bangladesh is having a huge lack of ICUs with ventilators and other medical equipment [10]. As considered before

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the shortage of ventilators is only about the higher rate of price [11]. Hence, this mechanical and electronic design and development will be considered the cost problem in developed and underdeveloped countries.

1.1. Quondam art

In the competitive world market, many different kinds of ventilator are available but the problem is a better lower price ventilator aren't considerable during this pandemic situation. Most of the ventilators are not reachable due to their higher rate of price. Meanwhile, BVM (Bag Valve Mask) is an affordable one, which was first invented in 1956 by Holger Hesse and Henning Ruben, was also called "Ambu bag" a self-inflating bag or manual resuscitator [12]. Ambu bag is a basic self-inflatable unit that is required to push oxygen by hand or manually to keep forward artificially boost into the lungs through pressure. Also, establishing a way to manually supply positive pressure into the Ambu bag. Therefore, instinctive disadvantages of supplying constant manual ventilation, while patient needs a regular amount of oxygen, that not possible in a manual system to ensure the same amount of oxygen. The expert needs to maintain for ill patients and sometimes family members or attendants also need to participate to compress BVM which omen the risk of patients [13, 14]. An automatic operating-based ventilator is suitable at this position for a serious patient, which can easily operate and maintain in any situation. Besides, these are so expensive and not affordable for lower-income densely populated countries. Already several researchers designed and simulated [28] low-cost mechanical ventilators such as VENT19 [26], MADVent [27] and many more but most of them are expensive and difficult to build for an emergency purpose. Existing huge level lack and demand of ventilator, this paper proposed a comparison between proposed cost-effective mechanical ventilator and different kinds of ventilator which are control the ventilators market [15] (see Figure 1).

1.2. Clinical criteria require for device

In a circumstance, clinically acceptable and cost-effective with safety guaranteed device needs to develop where it can evaluate device effectiveness those are following this section [16].

***A. Clinical Requirements*:** An adequate requirement is essential to follow a clinical-based ventilator, those are in below.

- ➢ Ventilation mode should be followed as invasive and non-invasive
- ➢ Controls boundary
- ➢ Discipline of infection
- ➢ It must include high/low Volume of tidal,
- ➢ A range of peak and off-peak pressure.

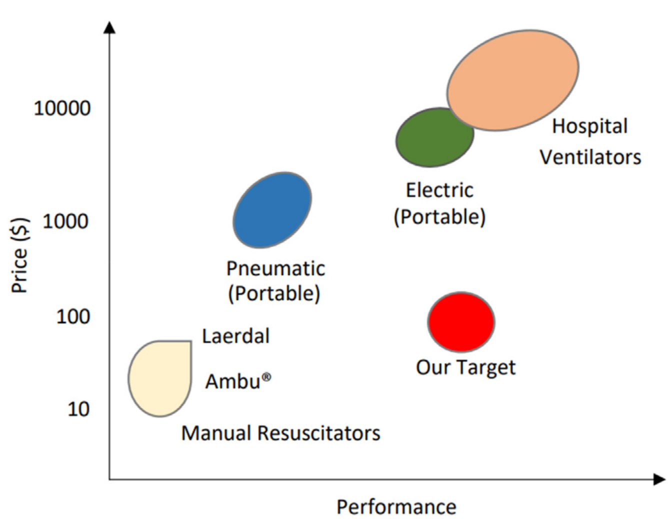


Figure 1. Comparison between different ventilators price.

- ➢ Dead-space has to determine.
- ➢ PEEP (Positive End-Expiratory Pressure) must be included.
- ➢ Respiratory rate
- ➢ Airway pressure

***B. Mechanical Requirements*:** Mechanical requirements are observed for the ventilator, those are in below.

- ➢ Ventilators should move anywhere based on patients' requirements, which means it could be a portable functionality.
- ➢ It must be capable to operate the whole system independently.
- ➢ It must be a well-organized mechanical design, protective electrical, and easy operating system to handle smoothly.
- ➢ Selective spare parts should be familiar and easily changeable
- ➢ Lowest power requirement or battery-equipped
- ➢ Digital display
- ➢ An idle size and shape required
- ➢ Friendly user interface

***C. Cost Consideration*:** The perspective of the device should be a minimal cost

It is highly recommended lower price ventilators, cost range could be <$100.

2. Mechanical design

The mechanical design supports the most valuable feature to construct an idea to visualize, the necessity of materials and structure accomplish to the desired purpose of the proposed device. In a ventilator design, have chosen two types of materials in the proposed design of ventilator, which are described below:

2.1. Structure and connector

Manufacturing and mechanical design are nearly dependent on many individual items. Two pairs of Joint clamps 1.18 × .90 inch are used, which can hold, rigid connection and linkage of any within two-metallic or aluminum component and five pairs of the thin clamp are used to the wooden box. Aluminum is lightweight and indissoluble materials, screw installation, stability much better than other materials. Due to its availability, less weight, and eco-friendly, this design, focused on lower weight materials wood. Plywood is high strength and durability and easily can hold screws and nails very well. Meanwhile, it has less susceptible to damage by water. Also, termite resistance with warping and cracking. A pair of 15 × 14 inch square shapes, and other rectangle, trapezium shapes are required followed as Figure 2.

2.2. Formation design

In proposed ventilator, used many mechanical [17] features to lead to design this as a mechanical ventilator. The whole design is formed mainly of six parts, which can be seen in below Figure 3.

2.2.1. Stander

Well, an aluminum extrusion stand was selected for this ventilator. It can hold a whole breathing chamber, and pressure of spiral spring and slider-crank. Vertically two stand 12 × 1.5 inches and horizontally one 10.5 × 1.5-inch aluminum extrusion stand has been chosen to make a Stander frame. Two sliders moving rail appointed with the vertical stand, to help slider moved through up and down. This Stander frame also adjusted with those slider-moving rails and ground wooden box by angle clamp pointed this in components 1 and 2 in Figure 3. Below space one, Ambu Bag will appear and a positive force will occur into the Ambu Bag to make a breathing chamber.

2.2.2. Slider

Slider is one of the most common useful and fundamental components in the mechanical ventilator. In this work, two sliders 6 × 1 inch are used on two opposite sides, which will move on top of the moving rail

Figure 2. Aluminum joint clamp and well-shaped plywood box.

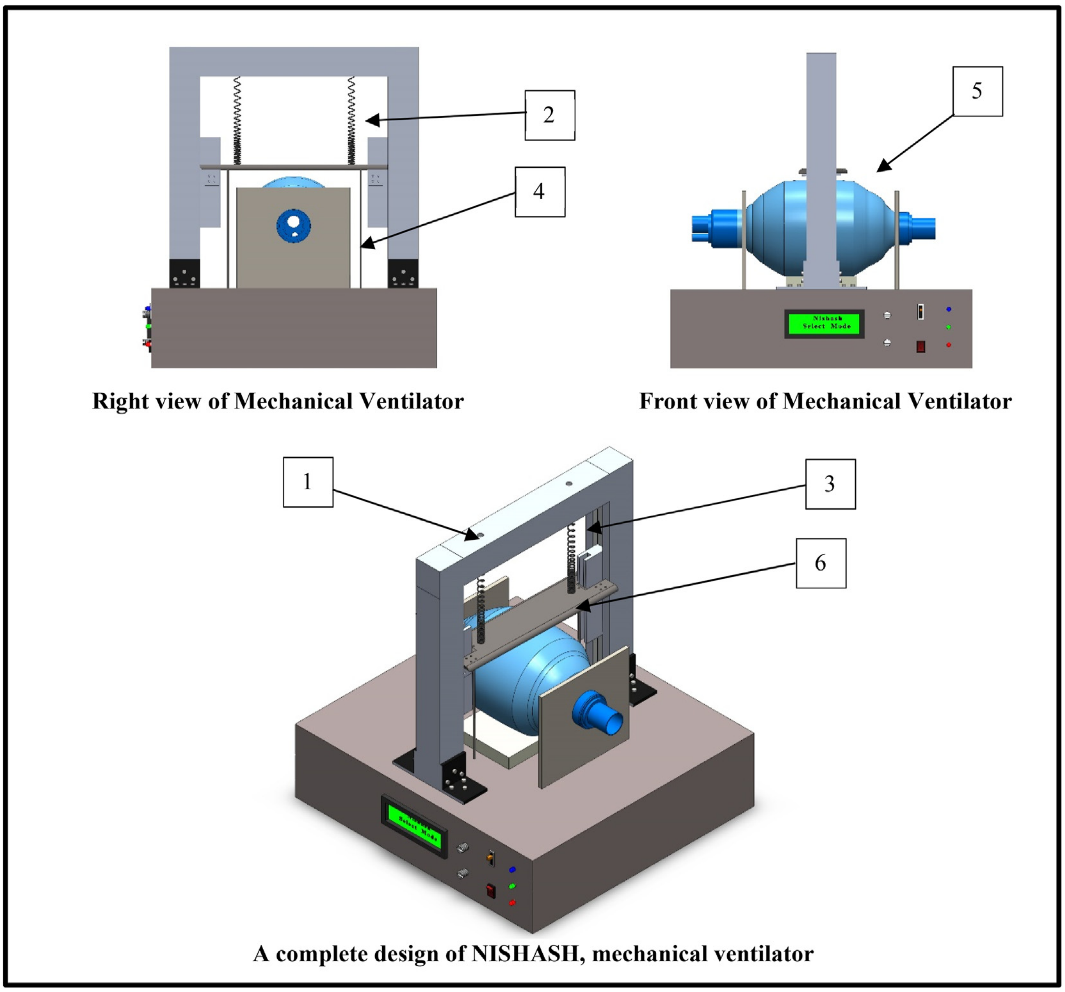


Figure 3. Solidwork® Design of the mechanical ventilator of NISHASH. 1. Stander. 2. Slider. 3. Mechanical Spiral Spring. 4. Nylon wire. 5. AMBU Bag. 6. Pressure plate.

illustrates components 2 in Figure 3. An aluminum 9.5-inch plate is connected by a joint clamp with a slider, which will change directions altogether.

2.2.3. Mechanical coil spring

In the manufacturing industry, springs are largely used as representatives that consume the shock energy to reestablish the initial position of the part on deformation to initiate a given function. Coil springs are shrinkage springs that are resistant to shrinkage force applied axially [18]. The upper side of the two coil springs account above the body frame and the lower part of the coil spring connected with another frame showed components 2 in Figure 3, which will push the Ambu Bag to flow the air to the patient based on the patient's requirement.

The relationship between applied force (F) and the extended distance in the spring is described by Hooke's Law. The extended length Δx is straightly proportional to the applied force (F) for extending or compressing the spring. When a force occurs to the spring, that time it extended towards the direction of the force applied, the same time a restoring force is also applied to get back springs idle position which is related with the Newton third law of the Motion see in Figure 4

$F_a \infty \Delta x$ or $F_a = k\ \Delta x$

where K is the constant of the spring

$$\text{Hence, } K = \frac{F_a}{\Delta x} \tag{1}$$

According to the Newton's second law, $F = mg$.

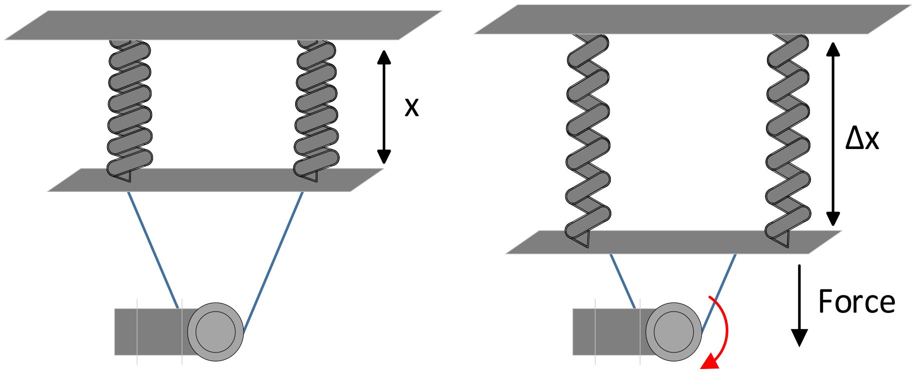


Figure 4. Force applied to spring extended.

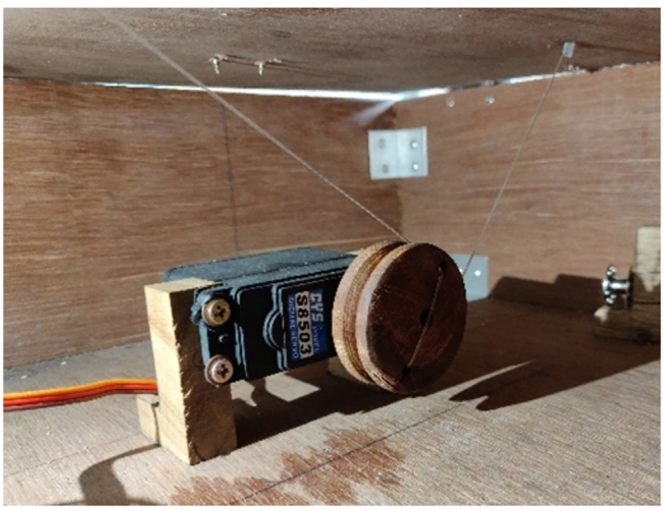


Figure 5. Circuit design of the device.

As a result of spring, constantly describe how many forces N occur to the per meter M

$$K\left(\frac{N}{M}\right) = \frac{mg}{\Delta x} = \frac{\text{mass} \quad \times 9.8}{x_2 - x_1} \tag{2}$$

2.2.4. Pulley mechanism

Pulley is a wheel, where it helps to change the direction of any particle movements to using a flexible belt or cable to transfer its power in any direction (see Figure 5). In this work, the pulley is connected with a DC servo motor which operates the pulley in two directions, forward and reverses the movement. It assists to apply force towards the plate to create air out to the Ambu bag.

3. Circuitry design

Circuitry design describes the whole electrical and electronics function, while device turn on or off and it depicts how electrical flow will occur through the electronics devices. A full of design describe below.

3.1. Servo motor control

A DC servo moto maintained the key role in this ventilator, which controls the oxygen airflow towards the patient. Servo motor gets a high torque-to-transmission ratio and thus a quicker frequency response. Servo motor controlled by pulse with modulation (PWM) [19] via electrical wire, where minimal pulse, maximal pulse, also repetitive pulse.

Typically, a servo motor can only spin at 90° with a complete rotation of 180° shown in Figure 6. The neutral state of the engine is known as the position in which both the clock- or counter-clock-sense of the servo have the same possible rotation. Pulse with modulation passes the signal to the origin of the shaft, as well as this period of the pulse sent through the electrical wire, which leads to the motor to its expecting direction. This

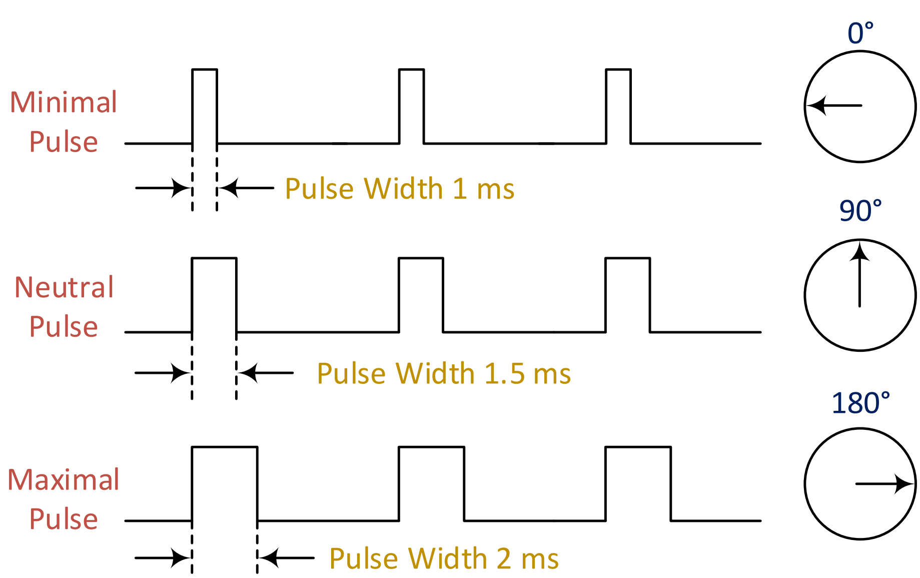


Figure 6. Servo control motors Pulse Width Modulation signal.

motor needs to observe a pulse per twenty milliseconds and the pulse duration decides the motor's turning distance. A 1.5 m pulse, for example, would transform the motor at 90°. It shifts in the reverse direction into a position of 0° less than 1.5 m and turns the servo in the direction clockwise in a 180-degree position no longer than 1.5 m. Servos won't stand indefinitely but must repeat the spot pulse to remind the servo to remain in position.

3.2. Power electronics system design

In this given system, a power on/off switch is placed to run or turn off the device and set up a charge controller to transfer AC 220 v to DC 12 V. This charge controller has a dual function where one is connected with the 12 v battery cell to charge it, another portion is fixed with a step-down buck converter. This converter is responsible to regulate DC to DC voltage e.g. 12v to 5v. In this work, have chosen a 7v Dc input voltage to run the servo motor and microcontroller. A slide switch is an import to control the whole process of the work, it regulates in three different modes. When Child mode (C) is placed, a signal is sent to the microcontroller to operate the motor and same time Blue LED will appear same time as an output. Similarly, switching the slide switch of Adult mode (A) and Manual mode (M) different signals will act as an input to the microcontroller and different types of rotation will happen towards the motor with Green and Red LED respectably. In a Manual mode, it is possible to associate different levels of airflow by the motor operation, where two variable resistors will assist the motor speed rate and air volume. A buzzer is set for safety purposes, when motor speed will be high from the given parameter setting in any mode for any kind of internal fault or manually selection then this buzzer will make an alarm for 1 min, it will turn off the whole system. Meanwhile, if electricity will go in any time then this device can run with the external power source of 12v battery cell for two hours, tagged for emergency purpose of electricity, which is the solution of any emergency either inside of the hospital or ambulance. Finally, a display is connected with the microcontroller to visualize the full process of operation to understand the operator in every section. Figure 7 showed the whole circuit diagram of the system.

4. Device working procedure

Firstly, 1 litter an AMBU bag is fitted into the given model of the mechanical ventilator, where the AMBU bag inlet is connected with the

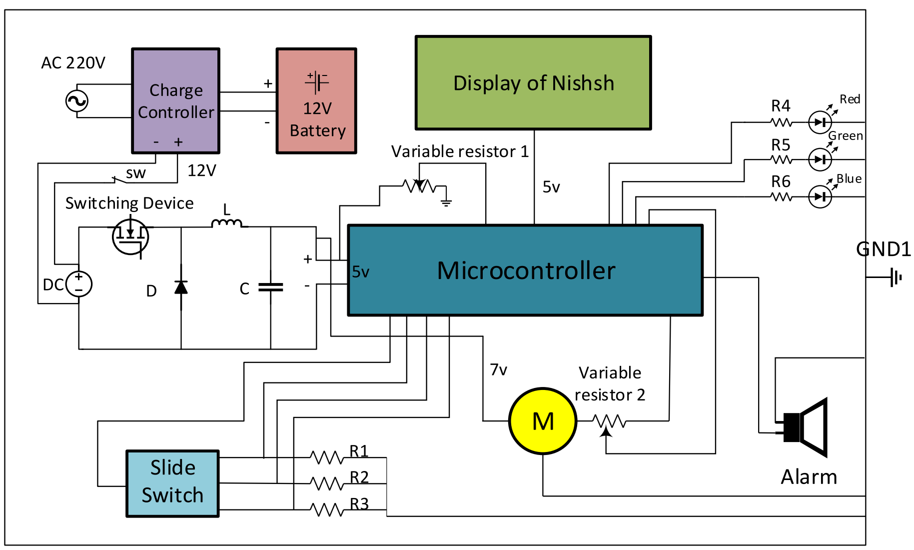


Figure 7. Circuit Design of the whole Device.

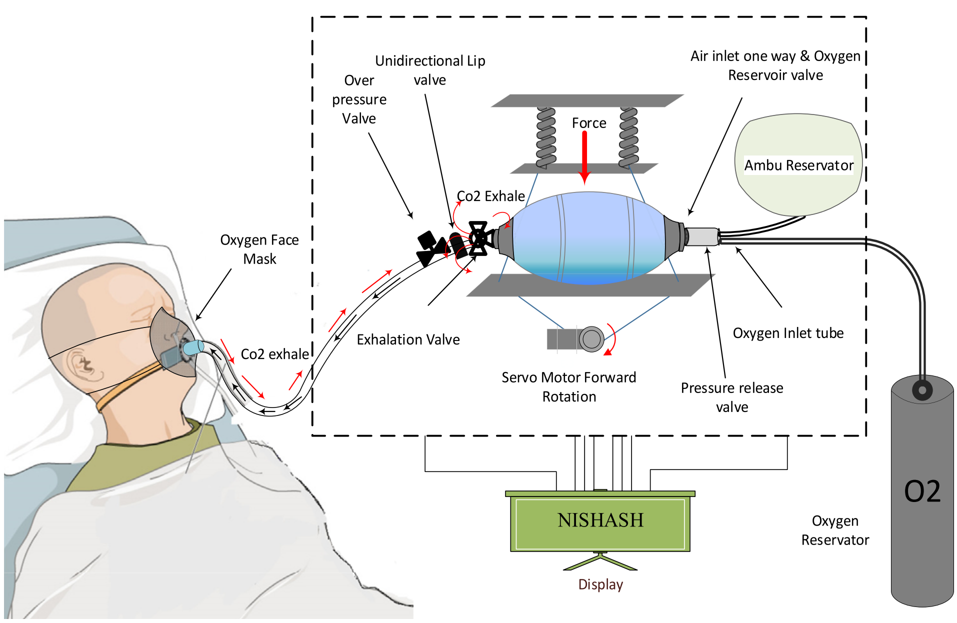


Figure 8. Overall working procedure of the ventilator.

oxygen sources. Without being hooked to an oxygen source, a bag-valve-mask may be used to supply the patient with 21% oxygen from the room air [20]. On the other hand, AMBU bag can also be connected with an individual reservoir [21] bag through an oxygen reservoir valve, which will be loaded with purified oxygen from an external source of oxygen either it can be in a mini cylinder or supplied from the hospital central oxygen plant, in this way 100% amount of oxygen supplied towards to the patient by the AMBU bag. A force-fed plate of mechanical ventilator always creating and releasing a force to create oxygen airflow to the AMBU bag, which arrives patient through the unidirectional lip valve and pipe with the help of servo motor control after a given period of the time in Figure 8, then the air is preferably supplied by a mask into the throttle, bronchi, and lungs of the recipient.

Normally, AMBU bag-valve musk will provide air 500–800 ml obviously for ordinary adult male patients, somehow if external 400 mL of pure oxygen supplied to the patient is also will be better enough in this case [22]. In this outlet of the bag, there is an overpressure release valve to reduce the extra pressure if the patient can't take that volume of air. A fish mouth valve is also situated with the exhalation valve (Co2 emission by this valve), also called a one-way valve to help to flow air from the bag to the patient but resist getting the CO2 from the patient. Overall, this working procedure is demonstrated by the display unit [23].

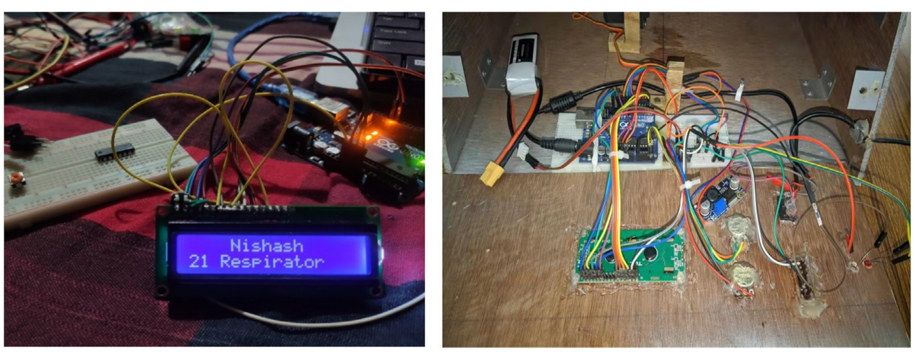
5. Result

This section described the simulation and physical experimental result of the robust mechanical ventilator to represent the prototype of the Nishash. When the machine starts by providing external power that time it's preparing for the further process of the work. Meantime it displays the system name can be seen in Figure 9

Both simulation results were carried out by using Proteus and compiling the code with Arduino software where experimental has done by Arduino Uno. In this whole process by Arduino Uno microcontroller [24]. It helps to process the whole work. The final prototype of the ventilator illustrates below in Figure 10.

The machine can work in three modes where two-mode are fixed and one can be changeable according to operators' or patients' demand. Child and Adult mode parameters are fixed with a standard value. At Child (C) mode when pressure plate occurs into the AMBU bag, it provides output 250 ml cm3 volume of oxygen, which can be useable for children based on their ages. Similarly, Adult (A) mode 400 ml cm3 volume of oxygen can supply in this mode, which is sufficient for an adult patient. Furthermore, it can flow from 200 to 400 ml cm3 in Manual (M) mode, which are changeable, in Figure 11 (b), represent all three modes volume and rate. The gap between two pressures towards the AMBU bag is 4 s, so it means within 60 s this can make pressure to the AMBU bag is 15 times at the Child mode to flow the oxygen towards the Child patient. On the other hand, this gap between two pressures is only 3.75 s, which indicates that in 60 s, 16 times can provide oxygen to an adult patient. Meanwhile, in the Manual (M) mode operators can change any value based on their expert suggestions.

This paper's main aim was to design a mechanical ventilator, which can afford high-density poor countries like Bangladesh. In this project, only used $93 to fulfill the work (see Table 1), which is proven that it is possible to develop this kind of mechanical ventilator at a low price if it is going to the bulk production.

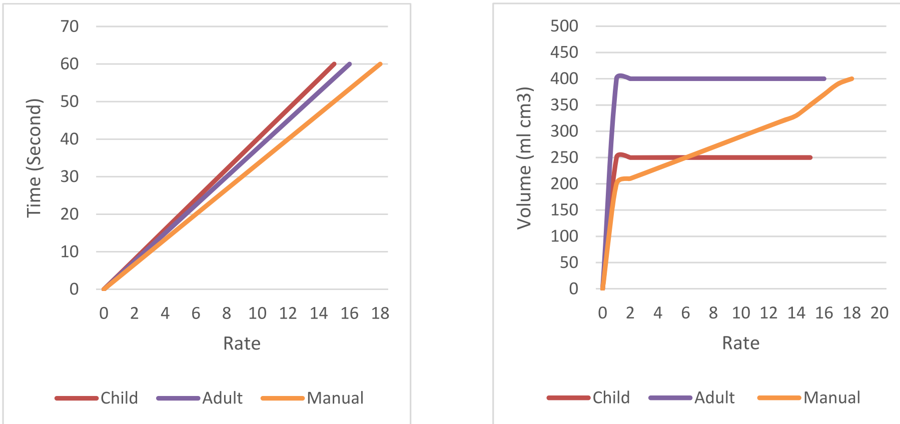


(a) (b)

Figure 9. The prototype of the experimental circuit.

(a) (b)

Figure 10. Final demonstrate of the Nishash, Mechanical Ventilator.



(a) (b)

Figure 11. Relation between rate, time, and the volume which can regulate by the regulator and also rate and the timing of the pressure, in Figure 11 (a) depicted the relation between time and the rate of pressure occurring onto AMBU bag while the maximum rate for the manual mode is 18 which can pressurize within 60 s. In addition, an external BMP280 air pressure sensor was used to measure the proximal pressure used at the end of the breathing mask and the readings of the sensors corresponding to the minimum permissible PEEP pressure and foremost crucial 40 cmH2O pressure can be determined in Figure 12.

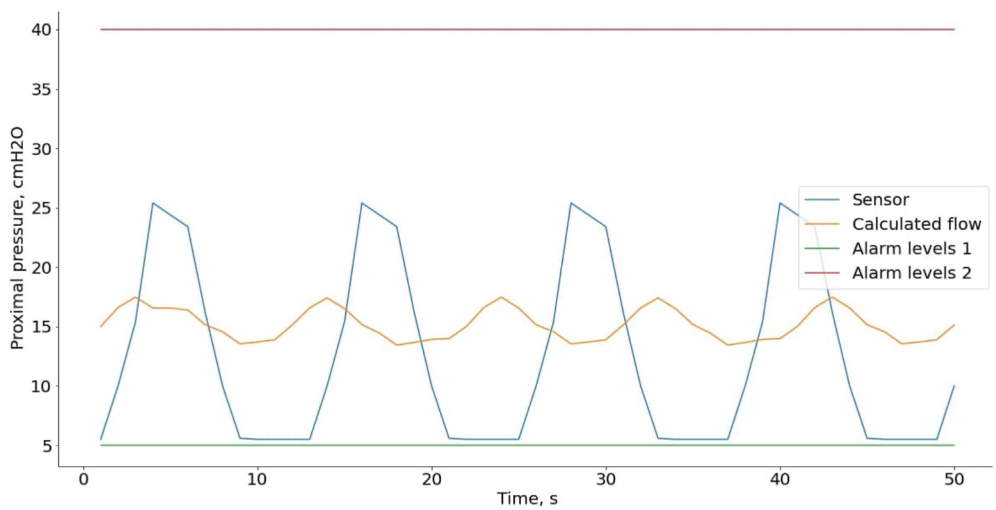


Figure 12. Response of BMP280 pressure sensor.

Table 1. The total cost of the ventilator.

Items	Quantity	Total Price in BDT
Microcontroller	1	450
Buck converter	1	60
Servo motor	1	2200
Display	1	120
Set of AMBU bag	1	2000
Register	6	3
Slide switch	1	5
Variable register	2	30
Burger	1	5
Led	3	15
Aluminum Thai		500
Wood		300
Wire		20
Ac/Dc converter	1	80
Breadboard	1	60
Spring	2	40
Pulley	1	50
Nylon String		50
On/Off Switch	1	5
Battery	1	1500
Charger	1	500
TOTAL		7946 BDT = $93

5.1. Limitations

Every type of product has some limitations, in given work it also has some limitations. The nylon wire can be broken 4–6 months later. But it's quite cheaper and easy to connectable with its forcing plate. No expert is needed to set this wire with the pulley and the pressure plate because it has measured the nylon wire and made several copies to support the organization.

6. Concluding remarks

COVID-19 pandemic still nightmare of every people's life. It not only takes lives but also destroyed a family, a society. Many researchers are looking for its vaccine and also medical support to revive the affected patient [25]. One of the most current attempts that have attracted the attention of the authors is the production of the cheap mechanical accessible ventilator. The motivation stems from the crisis of the mechanical ventilator globally and the expensiveness to buy for the emergency period of the time in a poor country.

This paper has shown a physical and reliable mechanical design of the ventilator which has a real-time monitoring option with alarm support. Lastly, this article has proven theoretically and practically.

The project is also visualized in this given link which was uploaded in 2020 but later we developed battery particle and some other functions https://www.youtube.com/watch?v=80XzkV7nS8E.

Declarations

Author contribution statement

Md. Hafizul Imran, Rifat Bin Mahi, Rony Saha, Md Hasan Islam and Imran Mahmud: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interests statement

The authors declare no competing interests.

Additional information

No additional information is available for this paper.

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