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Low-cost Ventilator using AMBU Bag

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Abstract*— During COVID-19, a huge crowd of COVID positive patients have been gathered. Due to the shortage of COVID facility wards, beds were not available for all the patients. Therefore, most of the patients were self-quarantining themselves at their homes and have been visited by their family doctor on routine basis. People were also buying personal oxygen cylinders as hospitals were unable to provide breathing oxygen. Some medical equipment is way more expensive to buy for personal use at home. A ventilator machine costs is about 1.5 – 10 Lakh Rupees. This paper proposes a low-cost ventilator machine using an AMBU bag which is also called Bag Valve Mask (BVM). This machine will be programmed to continuously help the patient to breathe oxygen at 2.4 atmospheric bar suitable pressure for lungs with a percentage of 21% to 100%.

Index Terms*— About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

Due to increase in COVID-19 Cases day-by-day a huge crowd of COVID positive patients have been gathered. Due to the shortage of COVID Facility Wards, beds were not available to all the patients. Therefore, most of the patients were self-quarantining themselves at their homes and have been visited by their family doctor on routine basis. People are also buying personal oxygen cylinders as hospitals are unable to provide breathing oxygen. Some Medical Equipment are way more expensive to buy for personal use at home. A Ventilator Machine Costs about 1.5 – 10 Lakh Rupees. So here in this project we are trying to make a low-cost Ventilator Machine using an AMBU Bag or also called BVM and some Arduino programming.

This machine will be programmed to continuously help the Patient to breathe oxygen at 2.4 atmospheric bar suitable pressure for lungs with a percentage of 21% to 100% Fraction of Oxygen at 12-40 (BPR) Breaths per minute with Breathing Volume of around 30-100% as per patient requirements, which can be adjusted by Buttons BPR+, BPR-, Volume+, Volume- provided on the control panel [1]. A Display will be provided on the panel to show the breathing rate in “BPR” Breathing Volume in “Volume” Breathing Pressure in “Pressure” Percentage of Oxygen in “FIO2” Solenoid Valve Status “On/Off” On as Valve Open and Off as Valve Closed. And a Button named “Mode” will switch between these readings.

This machine will help the people to breathe who are not able to breathe by their own, with the help of this machine Patient will receive a Positive End Expiratory Pressure (PEEP) which supports or recreates the process of breathing by pumping the lungs with positive airway pressure. If a person is experiencing failure in the respiration process, then they cannot get enough oxygen to the lungs and may also not be able to breathe out or expel carbon dioxide very well either, which will lead to a life-threatening condition. Some people who are COVID-19 positive have a severe difficulty in breathing as the lungs are damaged with the infection of COVID- 19 Virus and even develop acute respiratory distress syndrome (ARDS) which occurs when fluids build up in a tiny air sac called “Alveoli” in our lungs and closes the pores or holes which leads to deficiency of air and oxygen in lungs. However, this condition occurs to people those are critically ill.

II. TYPES OF VENTILATORS

A. Face Mask Ventilators

It is a non-invasive technique of ventilation for sustaining a patient's breathing also maintaining the level of oxygen. Continuous Positive Airway Pressure (CPAP) & Bilateral Positive Airway Pressure (BIPAP) machines moreover operates via this face mask, people often use this type of ventilation for chronic conditions like sleep apnea, and some doctors are also using it for COVID-19 patients.

B. Mechanical Ventilators

These machines can take over the entire breathing process of a patient. The doctor applies this type of ventilator whenever a patient unable to breathe self, so to make them breathe a tube is inserted down the persons throat for pumping the air to the lungs and transporting away the carbon dioxide. A mechanical ventilator is capable of regulating pressure, humidity and temperature of the air, which allows the healthcare professional to control the person’s breathing and maintain oxygen levels [2].

C. Manual Resuscitator Bags

Medical equipment called manual resuscitator bags enables a specialist to manually adjust the ventilator's airflow. These tools resemble a bladder or empty bag that can be squeezed to pump air into the lungs. If the patient is incubated, a doctor can add one of these devices to the tube, or a person can attach one of these devices to a face mask

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ventilator to pump air in. If there is a power outage, a person on a mechanical ventilator can utilize a manual resuscitator bag while waiting for the power to be restored.

D. Tracheotomy Ventilators

Those who have had tracheotomies need a different kind of ventilator. With a tracheotomy, a doctor makes a hole in the windpipe and inserts a tube, allowing air to pass in and out and enabling breathing without the need of the nose or mouth. Through this hole in the trachea or windpipe, patients who have had tracheotomies can also receive ventilator assistance. And doctors prefer to administer ventilation straight into the wind pipe rather than through the mouth.

III. RISKS WITH VENTILATOR

Ventilation is not all safe it also comes with some risks, and the longer a person requires a ventilation the higher the risks. Most of the complications are faced with a mechanical ventilator. Some potential complications of using a ventilator include

- Atelectasis—which is a complete or partial collapse of the entire lung or area of the lung.
- Aspiration or breathing some foreign substances into the airways.
- Lung damage which can happen due to high air pressure or high oxygen levels.
- Pulmonary edema which occurs when a fluid builds up in the air sacs or alveoli in lungs.
- Pneumothorax which is a collapsed lung and occurs when air leaks into the space between lung and chest wall.
- Infections, such as sinus infections and occasionally pneumonia.
- Airway difficulty.
- Extended term voiced cord damage due to intubation.
- Blood clots or bed sores which happen as a result of lying in one position for a long time.
- Muscles get weak if a person stays on the ventilator for a long time.

Fever that is severe trouble in mind ability that results in confused thinking and loses the consciousness of environs.

IV. VENTILATOR AND ITS WORKING

The ventilator in this project is a combination of face mask ventilator and a manual resuscitator bag, it consists of an AMBU bag along with a reservoir and an oxygen pipe inlet for transporting oxygen to lungs. In this ventilator the AMBU Bag is operated automatically via machine to support the breathing process. Breathing cycle or breathing rate that is breaths taken per minute is controlled as set by user in this machine. This machine will show you the pressure in the tube, breaths per minute set, and oxygen percentage as well on the LCD display [3]. This machine is suitable to be used with COVID-19 patients as it provides a positive airway pressure along with oxygen to help the patient/breathe.

A. Working

When the ventilator is switched on you need to press start button to start the ventilation, after starting Arduino board gives the command to the stepper motor drivers to run the motor as programmed by the programmer in the Arduino code. Stepper motor then squeezes the AMBU Bag to generate positive airway pressure, this positive pressure is then transported to lungs through the wind pipe or the mask [4].

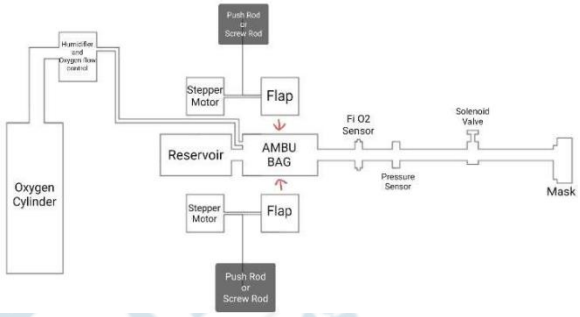

Fig. 1. Working of Ventilator

If ventilator is used with mask then the mask should be tightly covering the area of nose and mouth so there is no air leakage, or if the patient is intubated the pipe from the AMBU bag outlet can be directly connected to the pipe inserted in the trachea with the help of a doctor.

Now this positive airway pressure fills the lungs with air and oxygen and replicate the breathing process by inflating and deflating the lungs. When we are inflating the lungs, air is filled with oxygen and this oxygen is then carried away in the blood stream. And when deflating which is self-deflating by the body carbon dioxide is exhaled. The air mixed with oxygen travels through the medical breathing mask pipe, and during the process the oxygen percentage is measured via FIO2 Sensor present between the pipe and the pressure is also measured and displayed on the LCD display. If the pressure reaches above 2.4 atmospheric bar then the Solenoid valve is opened automatically by the Arduino board. At excess pressure Arduino gives command to the relay module and the relay give current to the solenoid valve to open.

B. COMPONENTS USED

Components used in this ventilator are mainly:

- ARDUINO MEGA 2560
- AMBU Bag with Oxygen Valve
- Oxygen Cylinder
- Humidifier for Oxygen Cylinder
- Servo/Stepper Motors
- Rods/Screw Rods
- FIO2 Sensor

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- Pressure Sensor
- Solenoid Valve
- Jumper Wires
- LED's
- Mask with Breathing Pipe
- A498 Driver
- Relay Module
- Computer Power Supply Old (Output 3V,5V,12V)
- PCB Board
- Resistors
- Capacitors

V. ARDUINO MEGA 2560

It is a microcontroller board based on the ATmega2560 which has 54 digital I/O pins, out of which 15 can be used as Pulse Width Modulation outputs, 16 pins for analog inputs(A0-A15), a 16 MHz crystal Oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller and the hardware used for the ventilator [5]. The mega 2560 is compatible with most shields and best suits the project requirements.

A. Programming

The mega 2560 board can be easily programmed with the Arduino (IDE) Software. The ATmega2560 on the mega 2560 comes pre- programmed with a bootloader that allows us to upload a new code to it without using an external hardware programmer. The ATmega2560 communicates using the original STK500 Protocol (reference, C header files) from Atmel Corporation, STK500 is a complete starter kit and development system for flashing Microcontroller. We can also bypass the bootloader and program the microcontroller according to our needs via the ICSP (In Circuit Serial Programming) header.

B. Memory

The ATmega2560 has a flash memory of 256 KB for storing the code which is enough as required by the project. Out of this 256 KB 8KB is used for the bootloader, 8 KB for SRAM and 4 KB of EEPROM which is read and write memory.

C. Input & output

The ARDUINO Mega 2560 have 54 digital input output pins which operates at 5 volts, and each can provide or receive a current of 20 mA as recommended for the operation and has an internal pull-up resistor of 20-50 K ohm for each pin and a current more than 40 mA can damage the microcontroller, so an external power supply is must for components requiring higher currents. Out of these 54 digital pins pin2-13 are for pulse width modulation (PWM), pins A0-A15 for analog signals.

D. Physical Characteristics and Shield Compatibility

The maximum length and width of the Arduino mega 2560 PCB board is 4 and 2.1 inches in dimension respectively. Three-five screw holes are also there on the PCB board which allows the ARDUINO to be fitted on a surface or a case. A physical reset button is also present on the board to reset the ARDUINO board and program a new Code to it, a USB port is mounted on the board to transfer the programmed code to the ARDUINO, a separate power point is also there to provide a separate power that is clean and continuous.

VI. AMBU BAG

AMBU bag is generally known as "manual resuscitator" or a "self-inflating bag". It is a portable device used to provide positive air pressure ventilation to those who are not breathing on their own or are not breathing enough. These devices are a part of medical emergency kits held by ambulance, for condition like out of hospitals these devices are used to make a person breathe without a ventilator. These devices are also used within the hospitals for providing individuals who require mechanical breathing temporarily when the mechanical ventilator needs to be examined for possible malfunction or when the patient is transported within the hospital [6]. The concept of the AMBU bag which is a bag valve mask was developed in 1956 by a German Engineer named Holger Hesse and his partner Henning Ruben a Danish Anesthetist.

Fig. 2. AMBU BAG

AMBU bag consists of some components or features like:

- Filters:

Between the mask and the valve's before or after chamber is a filter to prevent the contamination of Bag and Reservoir.

- Positive End Expiratory Pressure:

AMBU bag consists of a PEEP Valve that is called Positive End Expiratory Pressure for a better positive airway pressure maintenance.

- Medication Delivery:

For effective treatment of severe asthmatic respiratory arrest, a covered port may be fabricated into the valve assembly. This port will allow the flow of some inhalator medications into the ventilation system.

- Airway Pressure Port:

The valve assembly may also have a second covered port where a pressure sensor for pressure monitoring can be attached. This allows the rescuer to continuously track the amount of positive pressure produced during forced lung inflation.

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VII. STEPPER MOTOR

A stepper motor is a brushless DC electric motor in which a full rotation of motor is divided into steps and the armature covers or travels these steps to complete one revolution. As long as the motor is appropriately scaled for its application in terms of torque and speed, the armature or rotor position of the motor can be instructed to move and hold at one of these steps without any position sensor for feedback. While a stepper is known for its ability to transform a series of input pulse signals into a precisely defined increment in the position of the rotor shaft, and each pulse of signal rotates the shaft through a fixed angle and a fixed torque, brushed DC motors rotate continuously when a DC voltage is applied to the terminals. Stepper motors have a central rotor formed like an iron rod with gears and several electromagnets placed as spaced teeth in the stator. To make a stepper motor turn or move these tooth spaced electromagnets are energized one by one as steps creating a north and south pole for each step.

A. A498 Driver

This driver is used to run the stepper motor correctly and precisely with a pulse width modulation system. A pulse signal is sent via this driver to run the stepper motor, and each pulse signal is counted or recorded and is send via the help of a micro-controller. This driver is run via the help of an ARDUINO board using pulse width modulation signals, these signals are then sent to the A4988 Driver for the operation of Stepper motor. The A4988 Driver ha output of capacity of up to 35Volt and ±2Ampere and helps controlling of a bipolar stepper motor at up to 2Amp output current per coil, for example like NEMA 17 stepper motor.A4988 drivers comes with a 16 pin configuration out of which 4 pins are used for power, VDD & GND for powering the logic circuitry which can be 3-5 volts, VMOT & GND for powering the stepper motor which can be 8-35 volts, Pins (MS1, MS2, MS3) for controlling the steps of the motor and Pins(1B, 1A, 2A, 2B) as output pins for the stepper motor. And also consists of a current limiting potentiometer, etc.

B. Rods with flaps

Rods with flaps is a simple rod of steel or brass required as to connect the stepper with flaps to squeeze the AMBU bag for positive airflow pressure. Flaps here are just a piece of wood or plastic in a spherical shape with a hump towards the AMBU bag for a full Squeeze of AMBU bag to deliver 100% positive airway pressure if required. The main role of these rods is to connect the shaft of stepper motor to the squeezing flaps to squeeze or compress the air in the AMBU bag.

VIII. SENSORS

A sensor is a device that recognizes a change in an environment and reacts to it by sending an output to another system. A sensor, in essence, transforms a physical phenomenon into a quantifiable analogue voltage or digital signal, which is subsequently transferred and transformed into a readable format on a display.

A. FIO2 Sensor

The full form of FIO2 is “Fraction of Inspired Oxygen”, and this fraction of inspired oxygen is the concentration of oxygen in a gas or air mixture, thus a gas mixture at room air consist of a fraction of inspired oxygen around 20.9 or 21%. The percentage of oxygen at different altitudes remains the same for any individual’s altitude. We can say that a fraction of inspired oxygen (FIO2) is an estimation of the oxygen concentration a person inhales when put on a ventilator. Measurement of this estimated oxygen delivered and inhaled by the person is important for a proper treatment. If the concentration of oxygen is greater than required by the patient than it may damage the cells of the lungs or the alveoli and can cause a critical situation or even death, so it is important for us to maintain the oxygen concentration levels or the oxygen percentage [7].

Fig. 3. FIO2 Sensor

This FIO2 sensor gives an output of 30-60 mV and cannot be directly connected to the ARDUINO so we use an ADS1115 Analog to Digital Converter to give some gain to the signals and deliver these gained signals to ARDUINO for proper measurement.

B. Pressure Sensor

A device that measures the pressure of a gas or liquid is called a pressure sensor. The unit of measurement for pressure is force per unit of area. In most cases, pressure sensors serve as a transducer that produces a signal in response to the pressure applied to it. These sensors can measure pressure even at a rate of 10–40Hz and are utilized for pressure monitoring and control in systems.

We are using an HBX710B pressure sensor module to measure and control the pressure to secure any extra pressure entering the lungs, because any extra pressure can damage the Alveoli of the lungs blocking the airway holes of the lungs, which may result in lung failure and even death.

C. Solenoid Valve

A solenoid valve is an electronically controlled valve for automatic open and close operations. The mechanism of a solenoid valve is like plunger or a pivoted armature with a spring around it enclosed by a magnetic field coil, when the

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coil is energized it creates a magnetic field strong enough to lift this plunger or armature to open the valve, and when de-energized this plunger gets back to its initial position with the help of spring to close the valve. We will be using this solenoid valve as a pressure relief valve for getting rid of excess pressure in the breathing pipe. This valve will be operated by the ARDUINO board and pressure sensor monitoring.

IX. RELAY MODULE

A relay is basically a switch operated electronically as well as electromechanically for opening or closing of an electric circuit in a system. A relay used with ARDUINO Circuit consists of three pins as input for controlling a relay which are VCC, GND, IN0 which is for an input signal and VCC and GND for power, and have three pins for switching the circuit on or off which are NO, NC, Common pin which is used as common of circuit wire.

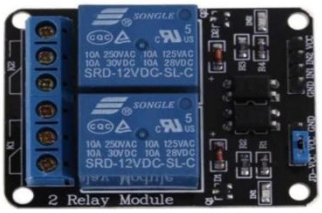

Fig. 4. Relay Module ARDUINO

When relay is switched common and NO, means circuit is open and when it switches with Common and NC means circuit is close and a current is flowing in the circuit. Relay module is a board consisting of a number of relays on it with a micro-controller for switching multiple relays at a time. These relay modules come with an option of 1 Relay, 2 Relays, 4 Relays, 8 Relays, and a 16 Relays configuration. This relay module is used for opening or closing of the solenoid valve.

X. LCD DISPLAY

Liquid crystal display, or LCD, is a flat panel made of polarized liquid crystals with some light modulating capabilities. Liquid crystals don't directly emit light; instead, they need a backlight or a reflector to create a monochrome or multicolored image. We are using here a 16x2 Characters LCD display which is capable to display character or any text in 16 columns and 2 rows format. These 16x2 LCD have an LED backlight which can display 32 ASCII characters in 2 rows with 16 characters on each row. Each column of the row consists of a rectangle and these rectangles are made of 5x8 pixels grid and these grids are lighten up in such a way that it displays a character or a text only.

Fig. 5. 16x2 LCD Display with inbuilt driver

A 16x2 LCD display already comes with a built display driver and consists of 16 pins for its interface pin no. 7-14 are data pins named as D0-D7 for transmitting data for the display, and GND, VCC pins for powering the module, and a VO pin for controlling the brightness of the display. This display is used display all the necessary data for monitoring the percentage of oxygen received and what the breathing rate the ventilator is set on, pressure through the wind pipe, pressure relief valve status on or off etc.

XI. POWER SUPPLY

Power supply is a device which provides a continuous supply of electric power to a circuit. The main function of a power supply unit is to covert the electric power to a desired power that is converting a voltage to a desired voltage and a desired current, for example converting a 230 Volt AC voltage to a 3V, 5V, 12V or 24V DC voltage with a maximum current of 1A, 2A, 5A, 10A, or 20A current ratings. Some power supply units come with a single voltage output and some comes with multiple voltage outputs, we are using here a multiple voltage outputs power supply unit that is an old version computer power supply unit. And will be using multiple capacitors or resistors for controlling the current and voltages for each power output for every component used in the ventilator to prevent them from any electrical damage with the help of a PCB board. We are needed with a computer power supply with voltage outputs at 3V, 5V, and 12V respectively. This power supply unit is main source of power for the whole ventilator system and can also work on a UPS for power cut.

XII. CONCLUSION

The aim of this paper is to make a ventilator at low cost for every individual's budget, a normal ventilator cost from 1.5 lakh INR to 10 lakh INR and so on. Here we have accomplished to make a ventilator machine for COVID-19 patients at a low cost with the help of an AMBU Bag which can imitate the same breathing process of a human, so it will be helping them in critical situation of breathing in COVID-19 disease by making them breathe clean air with oxygen concentration in it and will save lives. This machine is capable of breathing rates for an adult, child as well as aged person and can maintain oxygen percentage in the breathing air. This machine will be saving many lives of COVID- 19 patients at low cost.

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