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IOT based Ambulatory bag mechanical ventilator

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Abstract: Due to the damage caused by the deadly coronavirus, and its highly contagious and asymptomatic nature causing increased infections and deaths. Amidst this crisis, the fact of scarcity of ventilators in not just remote places but also in cities has made a prominent impact. The high cost of the mechanical ventilators in the market make sure to keep their prices high during this time of need. These costs in turn make holes in the pockets of the user. Thereby the affordability is only to the financially stable part of the population. The more makeshift of this complex mechanical ventilator is the Ambulatory Bag (AMBU bag). This works when a healthcare worker manually presses the bag to force in air to the patient who has difficulty in breathing. As manual pressing cannot happen for a long duration, a mechanical smart device is attached to this simple medical equipment for automating the process and to connect it to the internet making monitoring and diagnosis easy and also affordable.

This project has 2 main parts:
I) The automation of the simple AMBU Bag.
II) Making this device smart by connecting multiple sensors and connecting them to the internet.
<u>Automation of the simple AMBU bag</u>
The simple AMBU bag is connected to an electrical circuit that is controlled by a microcontroller. The movement of compression of the bag is obtained by wiper motor mechanism. The speed of the motor is controlled by the micro-controller there by having different operation states like Adult, child and Older people. This part of the entire project automates the AMBU bag.
<u>IoT network</u>
This part of the project deals with the connection of multiple sensors that acquire required parameters that help in monitoring and diagnostics. Multiple sensors are connected together in a network and the acquired data is then displayed to the healthcare worker in-charge of the patient. This enables accurate monitoring of many patient and connects them to their healthcare worker in real time. This task helps the healthcare team to organize their task and also gives them a heads up of the immediate future.

Keywords: Ambulatory Bag, IoT network, wiper motor mechanism, mechanical ventilators.

I. INTRODUCTION

A ventilator is a machine that provides mechanical ventilation by moving breathable air into and out of the lungs, to deliver breaths to a patient who is physically unable to breathe, or breathing insufficiently. Modern ventilators are computerized microprocessor-controlled machines, but patients can also be ventilated with a simple, hand-operated bag valve mask. Ventilators are chiefly used in intensive-care medicine, home care, and emergency medicine and in anaesthesiology.
Ventilators may also be equipped with monitoring and alarm systems for patient-related parameters (e.g., pressure, volume, and flow) and ventilator function (e.g., air leakage, power failure, mechanical failure), backup batteries, oxygen tanks, and remote control. The pneumatic system is nowadays often replaced by a computer-controlled turbopump.
A bag valve mask (BVM), sometimes known by the proprietary name AMBU bag or generically as a manual resuscitator or "self-inflating bag", is a hand-held device commonly used to provide positive pressure ventilation to patients who are not breathing or not breathing adequately. The device is a required part of resuscitation kits for trained professionals in out-of-hospital settings (such as ambulance crews) and is also frequently used in hospitals as part of standard equipment found on a crash cart, in emergency rooms or other critical care settings. Manual resuscitators are also used within the hospital for temporary ventilation of patient's dependent on mechanical ventilators when the mechanical ventilator needs to be examined for possible malfunction or when ventilator-dependent
patients are transported within the hospital.

II. LITERATURE SURVEY

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 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.

In 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 test the performance of the constructed mechanical ventilator using BIOPAC airflow transducer.
(3) To assess the cost of production of the designed ventilator to justify its use instead of manual resuscitators and existing portable ventilators. [1]. Requirements of ventilator: [5] Mechanical ventilators assist or replace spontaneous breathing when a patient's own breathing is not sufficient. Typical requirements of a mechanical ventilator are given below; the values for parameters are taken from references (Medicines and Healthcare 2020) and (World Health Organization (WHO) 2020):

- i) Mixes oxygen and air to achieve the required inspired oxygen concentration (FiO2) set by the user (30%–100%, typically 40%). In the envisaged scenario of a shortage of oxygen/medical air, the ventilator is designed to work with atmospheric air
- ii) Delivers the required volume (specified by the user as tidal volume) of the gas mixture to the patient during inspiration (in volume-controlled ventilation).
- iii) Delivers the mandatory breaths per minute specified by the user.
- iv) Controls the expiratory valve setting (specified by the user) to maintain a minimum positive pressure in the breathing circuit throughout ventilation. (Positive End Expiratory Pressure (PEEP) recorded at end of expiration)
- v) Supports 3 basic modes of ventilation namely Volume Control Ventilation (VCV) where the volume delivered per breath is controlled, Pressure Control Ventilation (PCV) where the inspiratory pressure is maintained constant and Pressure Support Ventilation (PSV) where inspiration is triggered based on patient's attempt to breath.
- vi) Detects inspiratory attempts from the patient (based on breathing circuit pressure momentarily going below PEEP) and initiates/supports the delivery of gas to lungs. This is required for Pressure Support Ventilation (PSV) or Synchronized intermittent mandatory ventilation (SMIV).
- vii) Records inspiratory and expiratory flow, pressure & volume. Provides a graphical display of the same for analysis by the user to assess patient health. Bluetooth interface and android app may be developed for data transfer and plotting. This may be required if large numbers of ventilators are to be monitored simultaneously by available staff. Essential parameters can be displayed in the ventilator.
- viii) General specifications of mechanical ventilators are Tidal volume setting in the range 200–600 ml in steps of 50 ml, Inspiration pressure up to 70 cm of water, Respiratory Rate of 10–30 breaths per minutes in increments of 2, Inspiratory: Expiratory ratio (I:E) in the range of 1:1 to 1:3 and Fraction of inspired oxygen (FiO2) between 30 to 100% in 10% steps.

It is worth mentioning here that adequate intensive care services may not be available especially in rural areas where 70%–80% of the Indian population resides and the situation will be very much similar in other low-income countries also. In such a scenario, the burning need is to design a cost-effective, easy-to-operate mechanical device which operates AMBU mechanically and spares manual effort [4]. Working principle, the device will work on the principle of an electric linear actuator which converts the rotary motion into a linear motion. The designed device will be connected to a regular adult AMBU. It will have a mechanism to rhythmically compress the AMBU. [4]

This paper [2] proposes a simplified structure of microcontroller based mechanical ventilator integrated with a Bag-Valve-Musk (BVM) ventilation mechanism. Here, an AMBU bag is operated with computer-aided manufacturing (CAM) arm that is commanded via a microcontroller and manual switches by sending a control signal to the mechanical system and according to this control signal, the mechanical computer-aided manufacturing (CAM) arm

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simultaneously compresses and decompresses the AMBU bag. It is a self-inflating bag and like a one-way valve around its inlet and outlet corner. By compressing the AMBU bag it delivers air and by relaxing, it takes air from the environment through a mechanical scavenger. The control signals are designed with three modes named adult mode, pediatric mode, and child mode based on the respiratory rate.

The device is in assist-controlled mode by dint of fixing the tidal volume for all unique control signals. The control signal is visualized by a platform known as the BIOPAC student's lab system. The proposed device is portable, compact, low weight, and efficient performable. It can be supplied around the rural area hospitals for immediate medication with cost efficiency and risk avoidance. Anyone can operate it as no need to study or training of ventilation rules like ICU ventilator. The proposed system is safe, riskless, and repairable. The angle, volume, and respiratory measurement have found 95%, 92%, and 90% accuracy respectively. By applying this portable ventilator system immediate attention can be taken up in rural or general hospitals and in ambulances. Child mode (1-12) month aged child has a tidal volume of (4-6) millilitre per kilogram. Pediatric mode (6-11) years an aged person has a tidal volume of (5-8) millilitre per kilogram. Adult mode (18 or more) years an aged person has a tidal volume of 7 millilitre per kilogram.

So, for example generally, the tidal volume of 23 years and 61-kilogram weight adult person is equal to (7 ml/kilogram×61 kilogram) or 427 ml. In this way, we can calculate the general tidal volume of all aged person. The diameter of the pulley is 4.3 centimetre, so the circumference of the pulley is 27 cm approximately. As we have two servos operating on 180 degrees or two right angles at a time, so the cot wire can oscillate within (27/2) ×2 = 13.5×2=27 centimetres. Arm length is 40.50 centimetre. Relax angle or initial angle is 37.94 degrees or 5.1/7.7 radian and compress angle or final angle is 18.2 degrees or 2.45/7.1 radian for an adult.
Now we want to find out the angle between two CAM arms because the output volume depends on the angle between two arms. We know that the arc length of a circle is $S = r\theta$, where the angle θ is in radian and r is the radius. We have three circles, two pulleys which act like a circle and another imaginary large circle is considered where CAM arm is the radius of that large circle. As we have two pulleys, we take $Sp = Sp1 + Sp2$ where $Sp1$ is the arc from the first servo motor and $Sp2$ from the second servo motor. For 180 degree or π radian rotation of pulley the imaginary circle covers a small arc Sa. So, it can be said that Sa is equal to Sp, then $ra\theta a= rp\theta p$.

[3] Understanding the complex dynamics of cardio-respiratory coupling sheds light on the underlying mechanisms governing the communication between these two physiological systems. Previous research has predominantly considered the coupling at respiratory rates slower than the heart rate and shown that respiratory oscillations lead to modulation and/or synchronization of the heart rate. Whereas the mechanisms of cardio-respiratory communication are still under discussion, peripheral nervous regulation is considered to be the predominant factor. This work offers a novel experimental design and applies the concept of instantaneous phase to detect cardio-respiratory entrainment at elevated respiration rates, close to the resting heart rate. If such 1:1 entrainment exists, it would suggest direct neuronal communication between the respiration and heart centres in the brain. We have observed 1:1 entrainment in all volunteers, with consistently longer synchronization episodes seen in physically fitter people, and demonstrated that cardio-respiratory synchronization at both low and high respiration rates is associated with a common underlying communication mechanism. By studying this we could try implementing a machine learning algorithm that control the entire device by monitoring the patient. This could be implemented once the main goal is achieved thereby would become the future scope of our project.

[4] The components of this respiration control device (RC Device) are enumerated in. A direct current (DC) motor (12–24 V) will give the linear motion through electric linear actuator arrangement. In addition, this DC motor will have a speed regulator which will be used to modulate the frequency of respiratory rate (varying from 12 to 20 squeezes per min) for supplying the air oxygen mixture into the lungs of the patient. There will be a provision of the common platform so that the AMBU bag can squeeze automatically as per the regulated speed setting in the speed regulator of the DC motor. Each rotation of the motor will create one complete linear motion of squeezing the bag and then coming back to the start.

This paper [5] describes the design and development of three low-cost ventilators which can be mass produced to meet a surge in demand for such equipment. Each of these ventilators is having unique features while meeting standard functional specifications of mechanical ventilators. The first design works on compressed air source as control gas and does not require electrical power for its operation. Parameters like tidal volume, breathing rate etc. can be set mechanically in this ventilator. Second one is an automated AMBU bag-based system, which has digital controller providing closed-loop control of critical ventilator parameters and a very unique geared actuation system that ensure long cyclic life to AMBU bag and fine control of parameters.

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The third design is an air blower based pneumatic circuit* ventilator which is a state-of-the-art ICU ventilator. Mathematical modeling of the systems is carried out to design the mechanical/electrical control elements and to simulate the performance of the system. Prototypes of ventilators were developed, testing and simulation runs were carried out and critical parameters were measured ensuring satisfactory performance of the system.

**Pneumatic ventilators: Vast majority of ventilators used in hospitals belong to this class. These ventilators use compressed gas and converts them to the required pressure and can achieve very high flow rate. Solenoid valves are generally used as the control element which releases pressurized gas into a gas mixing chamber*.

[5] The mathematical model of the ventilator is developed by considering the following subsystems.

i) Actuator stroke results in a variation of AMBU bag volume. Stroke to volume change is modelled by assuming a curve-fit which can be experimentally derived.

ii) AMBU bag volume to the pressure of the gas in the AMBU bag is derived using gas equations with isothermal assumption.

iii) Pressure in the AMBU bag results inflow from the ventilator to lung. Flow is a function of the lung characteristics. Lung is modelled as a combination of resistance and capacitance to simulate the resistance and compliance of the lung. In this model, lung is represented as a transfer function between AMBU bag pressure and flow from AMBU bag.

iv) A mathematical model of the humidifier is also developed. In the control system, two measurements are assumed—the pressure of the gas in the AMBU bag and flow from the AMBU bag. Based on these measurements, a pressure control system and volume control system are designed using PID controllers. Detailed mathematical models and corresponding equations are not presented here.

[5] AMBU bag is typically used for non-invasive ventilation with a mask and does not require much control on the bag-compression. However, the invasive ventilation requires precise control of pressure, flow rate and tidal volume. To achieve this, the ventilator is characterized as following:
I. The AMBU bag is considered as a positive displacement pneumatic source. Hence, the calibration of volume flow with bag compression is the first and the foremost crucial step. The rate of bag compression would also decide the flow rate.
II. The pressure rise in the ventilator as well as in the lungs results from the restriction of flow in the lungs and its subsequent inflation during the inspiration cycle. Hence it is important to estimate the pressure rise with respect to tidal volume based on lung compliance. This is achieved through a test lung bladder with added external stiffness based on tidal volume. However, the final characterization with human lungs equivalent setup is necessary. It is to be noted that, due to the configuration of the AMBU bag, not all combinations of tidal volume and positive inspiratory pressure requirements would be achievable. Though, the extent of this limitation will be known through the testing of human-equivalent lungs.
III. Pressure drop and compressibility effect in the ventilator circuits is another important factor. This is characterized through external measurement at the lungs and electronically compensated based on the readings from ventilator sensors. The goal of the testing and the characterization is to establish an exact correlation between the parameters set through the ventilator electronics, the same parameters measured by the sensors of the ventilator and the parameters measured through the external sensors in the test lung setup. This would ensure that the patient is getting the same ventilation as set by the doctor and the ventilator display also shows it correctly.

To provide the clinician a holistic view of the lung performance, the following parameters are plotted in real time.

- Lung pressure.
- Flow rate.
- Tidal volume.
- Breath per minute.

[6] This pandemic has led to the realization that when a hospital has used up all ventilators, it becomes imperative to patient survival to manually bag the patient or look for alternatives. Thus, automated AMBU bags may serve as a bridge device during ventilator shortages and help physicians triage patients, as most modern automated versions are able to detect excessive pressure and prevent overinflation of the lungs. Because automated AMBU bags are cheap, simple, light weight, portable, battery powered or plug in, have single or few knobs to control variables, and are easily assembled, they may be particularly useful during this pandemic crisis. When settling for low cost, we must acknowledge the extent to which it sacrifices the safety of patients. When we are heading towards technological advancements in the form of adaptive neural mechanisms, automatic tube compensation, and proportional assist ventilation modes, should we still rely on basic mechanical ventilation in the form of fixed tidal volume and respiratory rate? This poses a major question on safety of widespread use of automated AMBU resuscitators. The material used is

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another challenge as we have not determined the durability of these low-cost ventilators, the repercussions of wear and tear, the effectiveness of the cleaning methods employed to disinfect these devices and their effects on viral spread, as well as other parameters.

These devices could prove to be a fire hazard as oxygen can corrode materials. The pandemic may not last long but procuring a huge amount of these makeshift devices may not be a great option for long term. Also, in COVID-19 cases, these automated ventilators may not be able to provide lung protective ventilation; some newer versions of these devices can closely control tidal volume, respiratory rate inspiratory pressure, inspiratory: expiratory ratio, and positive end expiratory pressure, but additional monitoring of peak inspiratory pressure, plateau pressure, compliance, filtration, and adaptation is grossly lacking. They do not detect spontaneous breathing triggers and may lead to disuse weakening of respiratory muscles as a consequence. They are not standardized and employ crude mechanics. Ventilation is not just simply blowing air into a patient’s lungs. This automated self-inflating resuscitation bag must also be subject to appropriate scrutiny to evaluate its performance before approval for widespread clinical use. A number of variables should be used to judge the performance of a ventilator device. There is enough evidence to prove that unmonitored ventilation causes more harm than good.

Limitation of resources is a critical issue in this COVID-19 pandemic, which can lead to worse morbidity and mortality. It is important to respect the limitations of this device, and not favour the lower costs and ready availability of these devices over their potentially fatal risks and the lack scientific evidence “for” and “against” the same. Modern critical care is complex and artificial ventilation is only one component. In a pandemic crisis, all resources are scarce including human resources, hospital beds, and monitoring devices; therefore, the use of artificial mechanical ventilation support devices should have highest level of scientific evidence, in order to prevent any catastrophic clinical situations that may worsen an already precarious situation. Automated AMBU resuscitators should be strongly discouraged and not considered a valid substitute to mechanical ventilators. If they are used at all, it must be for a limited period of time, or as a last resort until a standard mechanical ventilator becomes available. Such use should only take place after safety checks and standardization, in line with the scientific evidence available, to prevent any iatrogenic complications

III.METHODOLOGY

All In this paper we would like to write about a prototype mechanical ventilator with respect to the survey done. Our project works on the principle of wiper motor, as we require a two synchronously moving arms for the proper working as well as increase in the accuracy of our project. For this, we use the concept of wiper motor where two arms of the wiper are controlled by a single motor to attain synchronous action. An emergency motor is connected to a single arm in case of malfunction. The action of both primary motor and emergency motor is controlled by a microcontroller. The input of the system is given manually by the healthcare worker. For the IoT we are using NODEMCU/ESP8266.This part of the project deals with the transferring if data collected from the sensors and transmit them to the end device such as phone or tablet, thereby helping in remote monitoring. The illustration of the methodology is as shown in the below diagram.

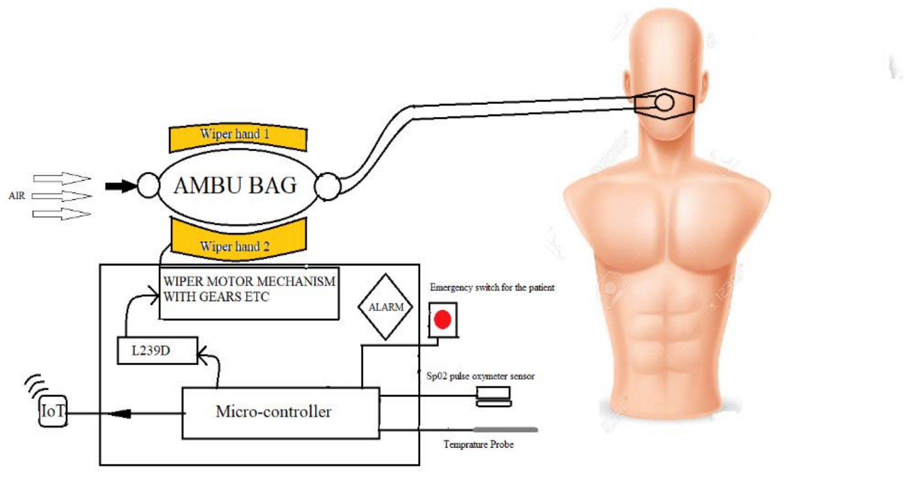

Fig. 1 Block diagram of the proposed system

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IV. CONCLUSION

Based on the above study, the following conclusions were made:

- With the proposed study, a simple Ambulatory bag can be made into an efficient IoT device to help healthcare workers.
- The contacts between medical staff and patients can be minimized by remote monitoring and care.
- Helps in proper management of workforce, skilled healthcare workers can prioritize as per need.
- It is therefore very promising for combating pandemics such as COVID-19.

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