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An Intelligent Ventilation Bag Featuring Automated Pressure Control and Variable Oxygen Range

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Abstract: *The COVID-19 pandemic highlighted the need for efficient and scalable respiratory support systems in emergency and critical care settings. Despite being widely used, manual ventilation bags provide challenges in ensuring consistent airflow, tidal volume, and real-time patient requirements adaption, especially when medical personnel utilize them for prolonged periods of time. The inability of manual Ambu bags to maintain a constant oxygen supply and pressure A new concept for a "Smart Ambu Bag" that combines an automated pressure regulating system with an adjustable oxygen concentration range is presented in this research. By tackling the challenges of manual breathing in emergency scenarios, the method aims to enhance accuracy and patient outcomes. The main objective is to develop a Smart Ventilation Bag with automated pressure adjustments and real-time oxygen monitoring. The Intelligent Ventilation Bag To measure the oxygen concentration in accordance with the patient's requirements, an oxygen sensor is incorporated into the air mix. When compared to existing manual and automated ventilators during COVID-19 situations, the Smart Ventilation Bag has the ability to bridge the gap between accessibility and performance, particularly in locations with limited resources. Better patient outcomes, less caregiver fatigue, and more reliable ventilation supply are demonstrated by simulation and experiment results. The study highlights how the Smart Ventilation Bag can assist expand the capacity for emergency respiratory care, paving the way for more scalable and reasonably priced respiratory support alternatives.*

Keywords: Ambu bag, ventilation, oxygen sensor, respiratory

I. INTRODUCTION

When treating respiratory problems, ventilation support is crucial, especially in emergency situations where quick action is required[1]. In settings with limited resources, where mechanical ventilators may not be accessible or healthcare personnel are overworked, Ambu Bags (bag-valve-mask) are utilized to deliver artificial ventilation [2], [3]. However, the efficiency of manual ventilation is limited by the operator's accuracy, concentration, and stamina, which could lead to either an excessive or insufficient oxygen delivery, all of which could be detrimental to the patient [4]. This project offers the Smart Ambu Bag System, an Internet of Things and machine learning-driven system that maximizes and automates manual ventilation in order to get around these challenges[5]. The system uses real-time data from multiple sensors, including temperature, pulse rate, and humidity sensors (DHT11), to continually monitor the patient's vitals [6], [7]. A machine learning algorithm analyzes this data to estimate the patient's oxygen level, ensuring that the appropriate ventilation is administered [8], [9]. The system's core is powered by an embedded NodeMCU microcontroller, which collects sensor data and transmits it to the Blynk IoT platform for remote control and monitoring [10]. The device also includes an actuator to control the Ambu Bag's inflation and automatically adjust to the patient's oxygen needs [11], [12]. This lessens the need for ongoing human intervention and guarantees that patients receive sufficient breathing when crucial thresholds are reached [13]. This project aims to deliver a reliable, scalable, and reasonably priced real-time respiratory support solution by integrating embedded systems, machine learning, and Internet of Things technologies[14]. By continuously monitoring patient vital signs and employing predictive analytics to guarantee prompt and precise oxygen supply control, this system enhances patient outcomes in critical care scenarios [15], [16].

Objective: The key objectives of the Smart Ventilation Bag System are:

- To automate the manual ventilation process using actuators [17], [18].
- To continuously monitor patient vitals using sensors and ensure optimal oxygen delivery [19].
- To predict patient oxygen needs using machine learning models and adjust the ventilation rate accord- ingly [20].
- To provide remote monitoring and control capabilities through the Blynk IoT platform [21].
- To reduce the dependency on healthcare personnel for manual ventilation, particularly in resource-con- strained or emergency scenarios [22].

II. LITERATURE SURVEY

To address ventilator shortages and resource constraints, a low-cost, open-source mechanical ventilator has been developed[23]. This gadget uses a numerical approach to measure pulmonary conditions and compresses an Ambu bag through an actuator and shaft to provide artificial breaths[24]. The inspiratory limb's pressure readings offer real-time information about the patient's status to the medical professionals[25]. Its potential advantages were shown in lab trials that imitated both healthy and sick patients [26]. The ventilator, which uses a pivoting motor drive mechanism to compress an Ambu bag or Bag Valve Mask (BVM) without human intervention, is an inexpensive portable ventilator for COVID-19 patients in Bangladesh[27]. This ventilator can be used both invasively and non-invasively; it can operate continuously for several days and has a tidal volume of 500–600 mL[28]. It successfully delivers a respiratory rate (RR) of 12 rpm, which is sufficient for individuals suffering from pneumonia [29]. Another prototype compresses a typical adult Ambu bag in a rhythmic manner using an electric linear actuator that transforms rotating action into linear motion[30]. To provide air-oxygen mixtures to the patient's lungs, a 12–24 V DC motor with a speed regulator controls the respiration rate from 12 to 20 squeezes per minute[31]. This is controlled by the motor's speed regulator and automatically compresses the AMBU bag [32]. Based on a manual resuscitator similar to BVM, GlasVent is an emergency ventilator made especially for low-resource environments[33]. It is constructed using readily available materials, off-the-shelf electronics, and 3D-printed parts[34]. Because GlasVent's design addresses the requirement for emergency care in low-resource healthcare settings, it can be operated by hand or foot with little training [35]. To lessen reliance on intricate supply networks, a cheap, portable, and basic ventilator was created[36]. The U.S. Food and Drug Administration's safety and efficacy requirements will be satisfied by this emergency ventilator's single-mode, closed-loop, pressure-controlled device[37]. The contentious methods of splitting or rationing ventilators may be stopped by an emergency ventilator[38]. This emergency ventilator's direct motor activation mechanism reduces wear and noise while simplifying the design by avoiding gears or cams[39]. In reality, the compression arm is a lever that gives the motor a mechanical advantage, allowing the bag to be compressed to the proper degree [40]. The People's Ventilator Project, or PVP1, offers a fully automated, pressure-controlled, open-source ventilator that can be mass produced for less than $1,300[41]. PVP1 enhances safety and adaptability by supporting PCV, SIMV, and necessary alerts. Because the program is modular, adding ventilation modes and changing parts are simple[43]. It accepts a broad spectrum of patients and conditions and operates on medical air and respiratory tubing[44]. PVP1 is still dependable since it has endured over 300 hours without failing in many tests [45]. A full-face mask was used to create a low-cost, prototype lung ventilator that included sensors and a ventilation blower[46]. This design does away with external apparatus and respiratory tubing[47]. Due of its portability and affordability, this can be utilized in emergency situations such as pandemics and natural catastrophes[48]. This device's sensors keep an eye on pressure and airflow to ensure safe use and more accurate respiratory data[49]. It has been tested in a pneumatic test setting to confirm its viability and effectiveness [50]. The development of ventilators dates back hundreds of years, from Vesalius's sixteenth-century fireside bellows to Dr. Henning Ruben's 1957 invention of self-inflating bags like the Ambu Bag, which is still the most basic yet efficient life-saving equipment[50]. One example of contemporary innovation is a low-cost mechanical ventilator prototype created by Boston University and MIT that incorporates cam-actuated BVM compression, eliminating the need for a human operator[51]. Powered by a stepper motor and 14.8 VDC battery, the gadget incorporates an assist-control mode, an over-pressurization alarm, and adjustable tidal volumes, breathing rates, and inhalation-exhalation ratios[52]. This portable ventilator has the potential to be inexpensive, with a prototyping cost of $420 and bulk manufacturing projected to be less than $100 [53]. An electric blower-powered portable emergency ventilator was suggested as a replacement for traditional BVMs in another study[54]. The use of BVMs for manual ventilation is linked to issues including high pressure and hyperventilation, which lower survival chances and may result in injury[55]. By providing continuous positive airway pressure and greater pressures at intervals without requiring precise mask fitting, this solution addresses such limitations[56]. A rechargeable battery makes it more practical and portable, while visual feedback ensures proper ventilation [57]. Due to the requirement for perfect mask fitting and regulated circuit leak conditions, traditional non-invasive ventilation equipment has limitations when employed in emergency situations[58]. These issues are resolved by the newly developed device, which accurately distributes pressure and tidal volume without requiring frequent modifications[59]. As a result, it can be used in both emergency situations and operating rooms[60]. The blower-driven ventilator architecture guarantees dependability, affordability, and user-friendliness[61].

III. METHODOLOGY

A. Proposed Method

The wiper motor-based mechanism used by the Smart Ventilation Bag (SVB) is a highly effective mechanism that enables precise operation and synchronized motion[62]. Thus, the ventilator's mechanism is derived from technologies that are frequently used in car windscreen wipers[63]. The wiper motor's camdriven design provides smooth, repeating control motions that are essential for mimicking breathing cycles at a pace as rhythmic as respiration support[64].

1. Acquisition of input parameters Prior to the ventilator starting up, critical input parameters from the patient are gathered utilizing cutting-edge sensor technology:

The MAX30102 Heart Rate and Pulse Oximeter Sensor Module: These sensors take vital signs such the patient's heart rate, breathing rate, and blood oxygen saturation (SpO)[65].

Extra Observation: To make sure the gadget performs at its best in a variety of circumstances, it may additionally monitor body temperature and other environmental elements like humidity[66]. The ideal speed and range of motion required for the wiper motor to provide particular ventilation are determined by processing these inputs[67].

2. Mechanism of Motion The system's foundation is its capacity to mimic actual breathing patterns by combining mechanical and electrical components:

Power Supply: Because the wiper motor is powered by a rechargeable battery, it is portable and dependable, especially in emergency scenarios or when deployed in areas with limited resources[68].

Motor and Cam Mechanism: The cam, which transforms rotary motion from the motor into oscillatory or linear motion, is driven by the motor[69]. This motion is expertly tuned to produce a controlled drive for a synchronous belt that operates consistently and rhythmically[70].

Compression and Release: The resuscitation bag is compressed by the synchronous belt in a consistent, predictable rhythm[71]. Air enters the patient's lungs to simulate inhaling as it compresses[72]. The system permits passive exhalation when it is opened[73]. This is the closest thing to breathing naturally[74].

1. Control of Oxygen and Pressure The SVB has a control valve for oxygen supply management and an oxygen flow sensor for maximal ventilation support[75]. Additionally, a pressure sensor regulates the force used to compress the bag[76].

The patient's oxygen requirements can be adjusted in real time thanks to all of these features:

Low Oxygen Levels (<5): In order to provide the patient greater oxygen volume, the system increases the compression force[77]. This modification guarantees sufficient ventilation for people who suffer from hypoxia[78].

High Oxygen Levels (>5): To protect the patient's lungs from harm such barotrauma brought on by high pressure, the device applies milder compression[79]. By adjusting the oxygen delivery range from 1 to 10 liters per minute (L/min), this design enables the system to adjust to the diversity of patients' needs[79]. In order to maintain consistent and accurate control over the ventilation pressure and oxygen concentration, the motor's speed and range of motion are dynamically modified based on real-time oxygen levels[80].

1. Principal Advantages of Cam-Driven Design Repetition and Smooth Movement: The cam mechanism makes sure that the ventilation process mimics the patient's natural breathing cycles, which promotes comfort[81]. Reliability and Consistency: By ensuring consistent ventilation, the motor and belt system will lower the dangers related to manual operation[82].

Automated Adjustments: The system's ability to respond quickly to changing patient situations is made possible by the sensors and machine learning algorithms[83].

2. Ongoing Observation and Input The SVB is a sophisticated monitoring tool that lets medical professionals keep an eye on a patient's condition in real time[84]. Important feedback on the following is provided by the system:

the degree of oxygen concentration[85]. the ventilation pressure[86]. The patient's body temperature, heart rate, and breathing rate[87]. These parameters allow for remote monitoring and control by being communicated to an IoT platform and shown on an LCD screen[88].

3. Adaptability and Operational Safety Proactive Regulation: The system is shielded from both hypoxia and hyperoxia at the same time since the oxygen levels are continuously monitored[90]. As a result, the patient gets the best care possible[91].

Portability: The gadget may be carried in ambulances, in field hospitals, or in places with limited resources because it runs on batteries[92]. Usability: The SVB is less reliant on the availability of qualified medical staff because it is an automated device[93]. This makes it an ideal application in emergency scenarios[94].

In conclusion, the Smart Ventilation Bag provides precise and dependable ventilation using a cam mechanism powered by a wiper motor[95]. The SVB distinguishes out as an effective, affordable respiratory support option thanks to its ability to adjust to changing patient needs through sophisticated sensors and automated controls[96]. Its usefulness is further increased by the combination of IoT and real-time monitoring, making it an important instrument in emergency and critical care situations[97].

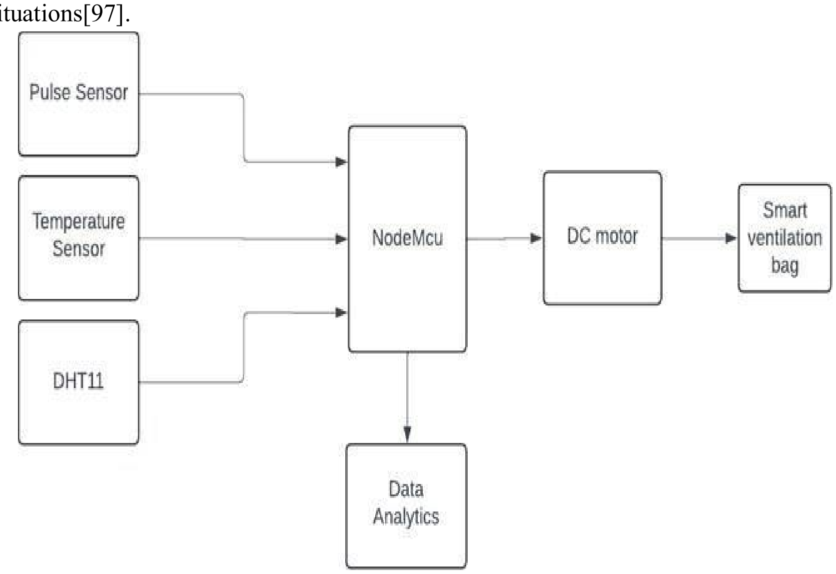

Fig. 1. Block Diagram of Proposed System

The block diagram depicts an advanced IoT-enabled system intended to manage and keep an eye on a "Smart Ventilation Bag," a cutting-edge way to offer customized and flexible ventilation assistance[98]. A temperature sensor, a DHT11 sensor, and a pulse sensor are some of the system's essential parts that cooperate to gather vital environmental and patient data[99]. By measuring the patient's heart rate, the pulse sensor provides immediate information on the patient's cardiovascular health[100]. By measuring the patient's temperature or the surrounding air temperature, the temperature sensor makes sure the system runs at its best[101]. By simultaneously sensing temperature and humidity, the DHT11 sensor also expands the system's capabilities by enabling it to adjust to changes in ambient conditions that may have an impact on ventilation[102]. The NodeMCU microcontroller, which serves as the central processing unit, is at the center of the system[103]. It uses well-known algorithms to evaluate and analyze the inputs it gets after retrieving data from the sensors[104]. NodeMCU uses this evaluation to determine how to manage the DC motor, which powers the smart ventilation bag[105]. This will guarantee that the bag's pressure and airflow are controlled dynamically in accordance with the patient's unique requirements[106]. Thus, effective, secure, and personalized ventilation support is made possible by this real-time adaption[107]. A data analytics module is also included in the system[108]. This module receives all sensor data collected by the NodeMCU for storage, visualization, and further analysis[109]. With the help of this feature, caregivers and medical professionals may keep an eye on data patterns in real time, identify anomalies, and make decisions that maximize system efficiency and improve patient care[110]. Longitudinal surveillance and study are also made possible by the data analytics component, which makes the system beneficial for both short-term clinical applications and long-term medical investigations[111]. It will create state-of-the-art automation for intelligent, customized ventilation control by fusing IoT technology with cutting-edge medical applications[112]. In order to open the door to more intelligent and effective healthcare solutions, the system is designed to maximize patient outcomes while reducing manual interventions in conventional ventilation techniques[113].

B. Components Required

- DC Motor
- CAM
- Battery
- AMBU Bag
- Arduino
- MAX30102 Heart Rate and Pulse Oximeter Sensor Mod- ule
- Relay
- Liquid Crystal Display

DC Motor:

A DC motor is an electrical device that converts direct current (DC) electrical energy into mechanical energy[114]. A current-carrying conductor experiences a force in a magnetic field, according to the electromagnetic induction principle[115]. DC motors are widely used in automation, robotics, and vehicles because they offer precise speed and torque control[116].

CAM:

A cam is a rotating or sliding component that converts rotational motion in a follower into reciprocating motion[117]. It can take many forms, such as an eccentric disc, and its offset center or sides generate specific motion patterns[118]. Cams are used to generate motion or power in machines such as steam hammers[119].

Battery:

A battery is a device that converts chemical energy into electrical energy through electrochemical reactions. Each of the one or more cells that make up this portable power source has an anode, cathode, and electrolyte. Batteries are widely used in electronics, cars, and renewable energy systems.

AMBU Bag:

A portable tool for manual ventilation during anesthesia or in an emergency is called an artificial manual breathing unit, or AMBU bag. A patient who is not breathing enough is given oxygen or air through the use of an endotracheal tube or face mask[120]. AMBU bags are essential while performing life-support and resuscitation procedures.

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MAX30102 Heart Rate and Pulse Oximeter Sensor Module:
The MAX30102 is a compact, integrated sensor module that measures heart rate and blood oxygen levels (SpO) using photoplethysmography (PPG). It uses photodetectors, optical components, and an infrared and red LED for accurate readings. It is commonly utilized in wearable technology because of its excellent precision and low power consumption.

Arduino:
Arduino is an open-source electronics platform based on hardware and software that are easy to use. Its microcontroller boards, which can sense inputs and control outputs, make it ideal for automation and prototyping. Robotics, education, and Internet of Things applications all make extensive use of Arduino.

Relay:
Relays are electrically driven switches that use electromagnetic coils to control one or more circuits. It allows low-power signals to control high-power devices by separating input and output. Relays are widely used in automation, safety systems, and electronic controls.

Display:
A liquid crystal display, or LCD, is a kind of flat-panel display that uses liquid crystals to modulate light in order to produce images. It is lightweight, energy-efficient, and commonly found in devices such as televisions, monitors, and portable electronics. LCDs offer exceptional clarity and are available in a variety of sizes and resolutions.

IV. RESULT AND DISCUSSION

A. System Performance Evaluation

Its performance under regulated and simulated situations was examined. Oxygen concentration, response time, pressure control, and ventilation consistency are a few measures that have been employed in the investigation. The outcomes were as follows:

• Oxygen Regulation: The oxygen supply is continuously regulated between 1 and 10 L/min by the oxygen sensor. The system remained steady in terms of a sufficient oxygen delivery at all times thanks to simulations for a variety of patient and environmental conditions.

• Pressure Control: By adjusting the actuator-controlled pressure mechanism to the patient's oxygen requirements, the risks of either excessive or insufficient ventilation are reduced. While low-demand scenarios applied mild compressions, lowering the risk of injuries, high-demand scenarios increased the compression force.

B. Comparative Analysis

The SVB was contrasted with inexpensive ventilators and manual AMBU bags. The following are the main conclusions: Because automation eliminated the need for ongoing human labor, SVB became a suitable long-term emergency solution. By bridging the gap between manual and fully automated systems, its IoT-enabled monitoring and small design enable deployment in resource-constrained environments.

C. IoT and ML Integration

Created an IoT integration for remote control and real-time monitoring. The machine learning-based estimate for oxygen demand was so accurate that it adjusted at the appropriate moment.

D. Simulation Outputs

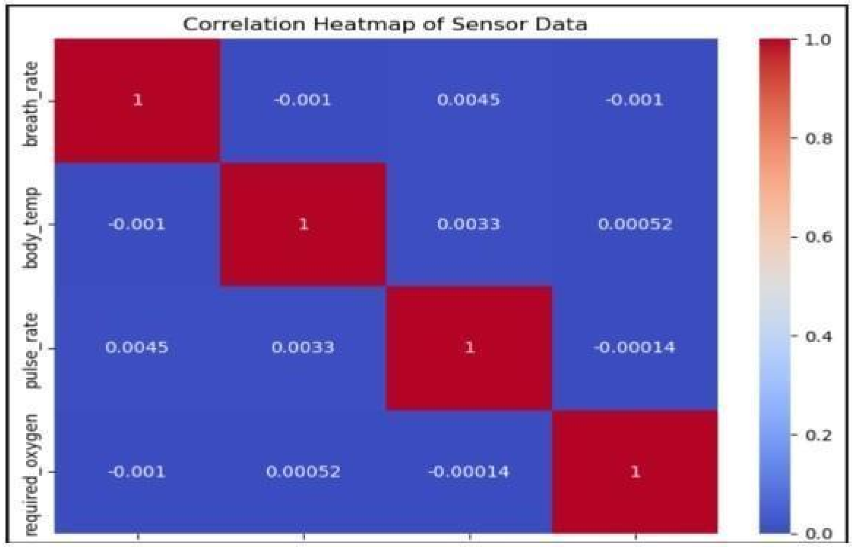

Fig.2 Correlation matrix of feature

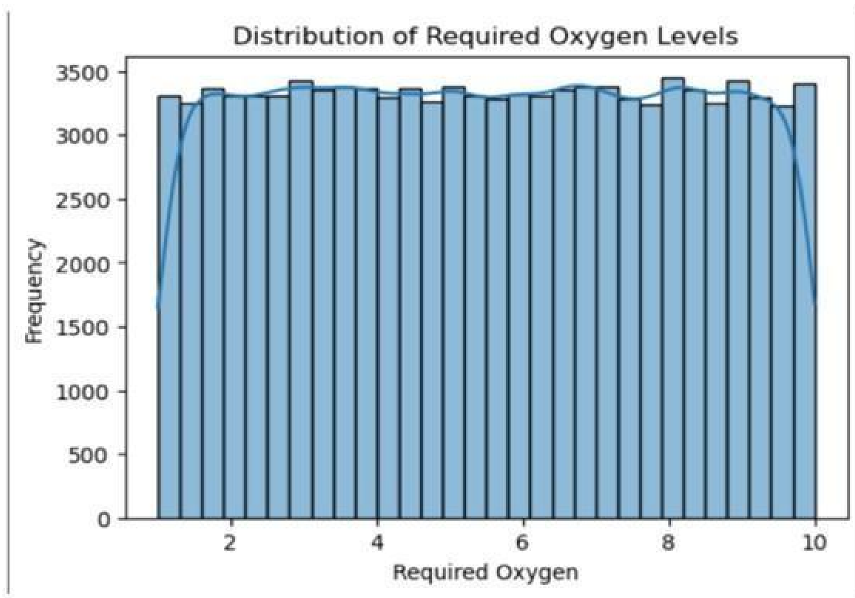

Fig. 3. Histogram of output feature

We created a Smart Ventilation Bag to address the various issues with traditional manual Ambu bags in order to give patients accurate and efficient ventilation during emergencies, particularly in ambulances. An ideal kudological solution.

In ambulances, Ambu bags offer the best short-term ventilation. Long-term use, however, may occasionally require constant manual labor, which can be physically taxing for caretakers. The patient may experience inconsistent oxygen delivery as a result. Both the operator and the patient frequently experience discomfort as a result of the inconsistent distribution, particularly during protracted situations.

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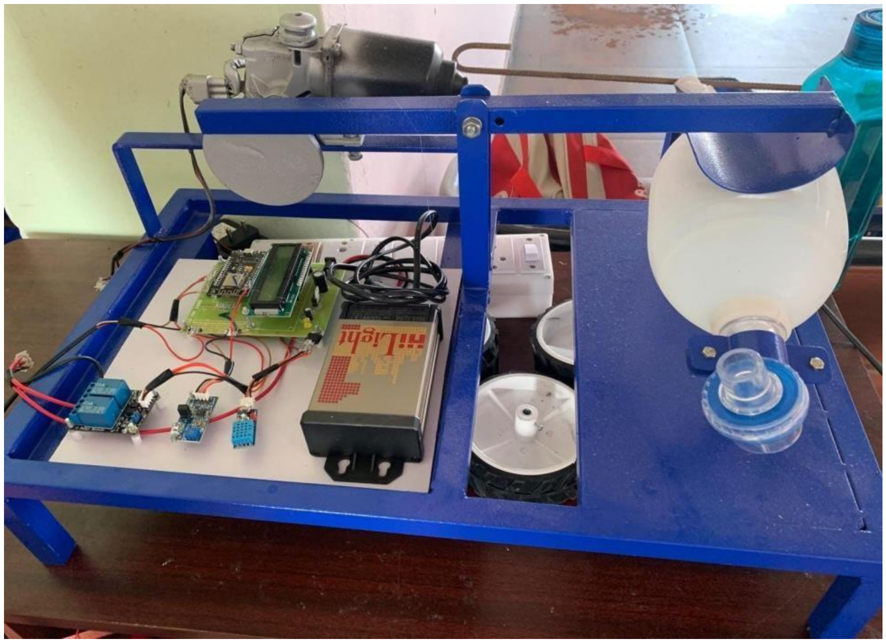

Fig. 4. Working model

We create a Smart Ventilation Bag that functions as an intelligent hospital ventilator system in a small, portable form that can be carried in an ambulance in order to get around these challenges. While we continuously monitor the patient's condition, our machine-learning technology provides the appropriate amount of oxygen based on three important parameters: breath rate, body temperature, and pulse rate.

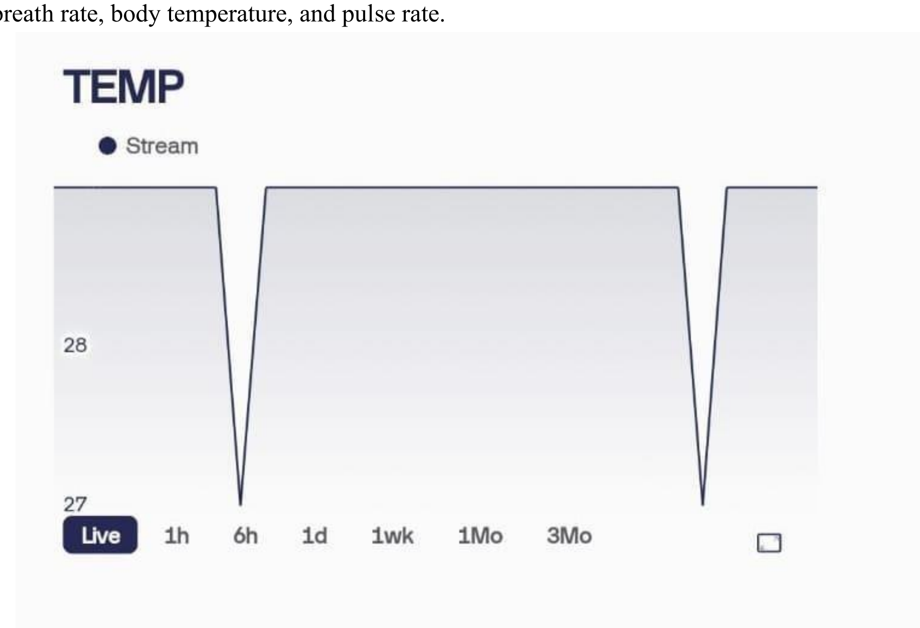

Fig. 5. Body Temperature

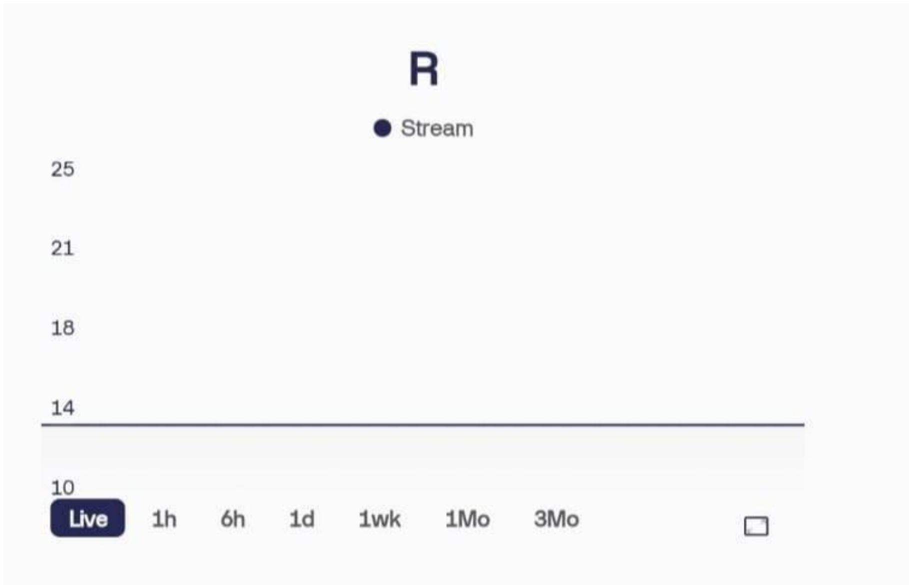

Fig. 6. Breath Rate

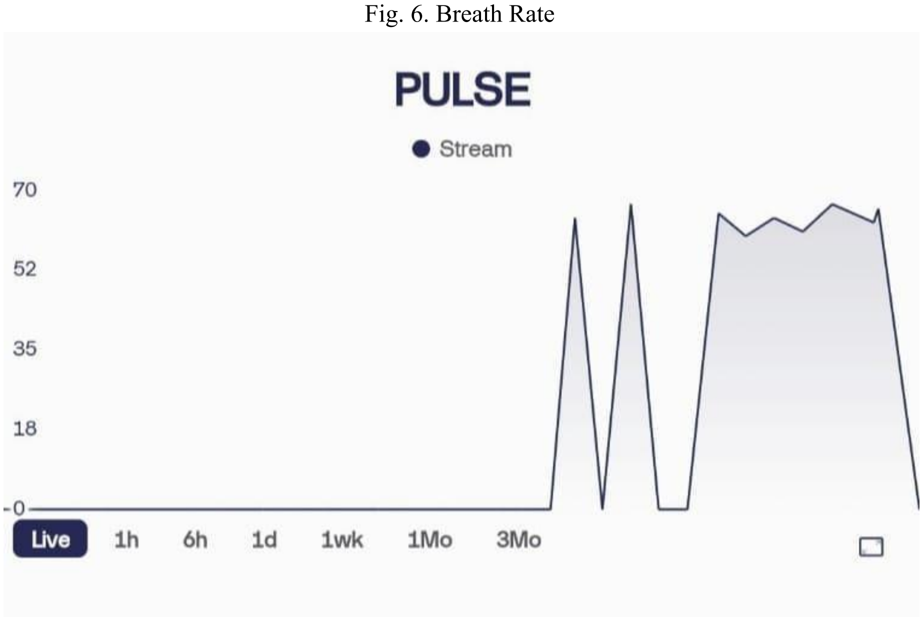

Fig. 7. Pulse Rate

When analyzing the oxygen requirements, these factors are related to each other:

Breath Rate: If the respiratory rate is abnormal or erratic, the lungs might not be taking in enough air, and more oxygen would be needed to keep the blood's oxygen levels at the proper level.

Pulse Rate: Generally speaking, a higher heart rate indicates that the body's tissues need more oxygen since the heart must work harder to pump it.

Temperature: High body temperatures typically indicate high metabolic rates, necessitating the use of more oxygen[121]. While low temperatures can reduce oxygen use, they can indicate inadequate blood flow. Based on past experiences, an algorithmic machine learning computer is developed to forecast oxygen requirements in real time. The model is trained using historical datasets that include characteristics such as temperature, breath rate, pulse rate, and the corresponding oxygen requirements for patients with different medical conditions. A predictive model is constructed using input data like temperature, breath rate, pulse rate, and their time trends. The necessary oxygen level, which is often expressed in liters per minute (L/min), is the model's output. The trained algorithm forecasts the patient's oxygen requirements after being fed real-time data. The system modifies the oxygen delivery strategy after the ML model estimates the oxygen requirement:

Low Demand: Oxygen flow may stay low (e.g., 1-2L/min) if the patient exhibits normal breathing and pulse rates and a steady temperature.

High Demand: The oxygen flow is raised (e.g., 5–10L/min) if the temperature, breathing rate, or pulse rate are all elevated.

The system functions in a feedback loop, with sensors continuously sending updated data for temperature, respiratory rate, heart rate, and

At intervals of several seconds to minutes, the machine learning model reevaluates the required oxygen levels, and the oxygen administration is immediately adjusted to meet the patient's needs. The technology can alert medical personnel for prompt action if any variable above a crucial threshold.

By automating the ventilation bag's compression and guaranteeing that the patient receives the proper oxygen flow, the Smart Ventilation Bag minimizes human intervention. In order to guarantee that the amount of oxygen in milliliters per minute and its output pressure are appropriately assessed for effective ventilation to be delivered in accordance with the patient's state, this model is based on Random Forest Regression.

Additionally, the system has user-friendly manual overrides and real-time notifications for aberrant vital signs.

Compact size: The device is ideal for ambulance systems because it is lightweight, compact, and takes up very little room. Time efficiency: Provides the finest ventilation while requiring less labor. Cost-effectiveness: The Smart Ventilation Bag is made to be sufficiently affordable for widespread use in emergency situations. Easy to use: Designed in every way to be handled by a technician or caregiver without the need for specialized training. A few pumps can provide adequate and steady ventilation using the Smart Ventilation Bag, saving the patient's life in an emergency during this crucial period.

V. CONCLUSION

It significantly closes the gap between technical and human respiratory support. The technology is designed to be real-time adaptive, delivering oxygen continuously through pressure management that can meet patient needs. Predictive analytics will enable proactive ventilation management with minimal caregiver involvement to improve patient outcomes. The SVB is a promising tool for emergency and critical care situations due to its small size, affordable construction, and capacity to function in settings with limited resources. According to preliminary statistics, the SVB may perform noticeably better than conventional manual methods in terms of precision and lower danger of over- or under-ventilation. Subsequent advancements will be made along these lines to extend the life of used batteries, improve the resilience of machine learning models, and conduct comprehensive field tests to demonstrate the scalability and dependability of the system. With its accessibility, cost, and efficiency, the Smart Ventilation Bag has the potential to completely transform respiratory care.

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