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| RESEARCH ARTICLE

An Innovative Embedded Ventilator for Accessible and Intelligent Respiratory Support

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| ABSTRACT
Breathing issues affect people of all ages and worsen during emergencies like pandemics, making them a serious worldwide health concern. In order to provide effective, timely, and economical respiratory assistance, mechanical ventilators are essential. Even though industry leaders are developing smart ventilator technologies, there is still a pressing need for accessible, reasonably priced, and easy-to-use solutions, especially in environments with limited resources. In this study, a simulated model for an affordable smart innovative ventilator with internet of things (IoT) capabilities is presented. The gadget, which was made with affordability and ease of use in mind, can save important data, assess patient health characteristics, and allow real-time monitoring. It's IoT connectivity enables smooth communication with mobile platforms and web apps, giving family members and caregivers immediate access to patient data. Improved results, quicker medical answers, and remote patient monitoring are all made possible by this connectivity. Advanced features including real-time anomaly notifications, automated airflow modifications based on patient demands, and secure data encryption to protect patient privacy are all included in the suggested ventilator. Furthermore, its ability to work with telemedicine systems increases its usefulness for remote consultations and lessens the strain on medical institutions. By prioritizing low-cost, intelligent design, this research aims to democratize smart ventilator technology for underserved regions. The proposed model has the potential to significantly improve healthcare capacity, especially during respiratory emergencies in pandemics, natural disasters, or other crises. This work underscores the transformative role of IoT and biomedical engineering in addressing global health challenges and enhancing respiratory care.

| KEYWORDS

Smart Ventilator, IoT-Enabled Ventilator, Respiratory Support, Remote Patient Monitoring, Biomedical Engineering.

| ARTICLE INFORMATION

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1. Introduction

The virus's contagious nature can cause respiratory difficulties, extremely low oxygen levels, and even lethal effects [1][2]. According to a World Health Organization research, one in five virus-infected people will require medical care for breathing issues, and one in twenty will wind up in the critical care unit, or ICU, because they have trouble breathing and require ventilation [3]. The demand for medical treatment, specialized equipment, and trained care workers can greatly exceed the nation's capacity to supply it when there is a highly contagious and hazardous virus, such as corona virus and HMPV [4]. Pneumonia is the medical term for inflammation and fluid accumulation caused by an invasion of the lungs by a bacterium, virus or fungus [5][6]. Breathing becomes challenging, and a fever and cough can occur, producing yellow, green, or red mucus. Pneumonia is frequently brought on by bacteria like pneumococcus or viruses like influenza [7]. In essence, a breathing machine is the best solution to provide respiratoryly challenged individuals with a supplemental supply of oxygen gas through their nostrils or throat [8] [9]. In 1952, high-pressure ventilation was first implemented in a hospital [10]. In order to assist breathing, a number of one-way valves with complex features were invented in the middle of the 20th century [11]. Mouth and nose models are among the manual ventilation approaches that have been discussed and used [12]. There are several different kinds of breathing machines on the market right now. Two of the most popular types of ventilators are noninvasive and intrusive, and each has a different way of working [13]. Depending on their physical construction, ventilators can be classified as exhaust ventilators, motorized ventilators, natural ventilators, and other types [14][15]. Researchers sought to create a respirator that could continuously deliver oxygen, because of the rapid changes in patients health and the potential for extremely harmful bacteria. The ventilator was designed to have as few parts as possible so that it could be manufactured rapidly and in large quantities. It was shown that a low-cost, portable mechanical breathing equipment might be used in disaster areas and other places with few medical services. In addition to an air bag valve and rotating cam arms, the breathing machine delivers breaths by compressing a standard mask. Thus, there is no longer a need for a healthcare operator [16] [17]. A novel concept for an oxygen respirator that is compact, affordable, and simple to operate has been developed and successfully tested. The test subject's airways may be sufficiently ventilated by the ventilator apparatus. Additionally, the integrated lung pressure monitor could detect leaks and obstructions in breathing. Because of its low power consumption, it can be operated remotely with batteries [18]. Another technique creates a low-cost breathing machine by using an AMBU bag without a continuous blower. According to Mukaram Shahid's calculations, the AMBU setup may complete all of a commercial ventilator's functions for less than $100 USD (without manpower). The item includes a closed-loop system, electrical design, and images. Additionally, it can be used as a starting point, but not enough information is exchanged for this to be regarded as "active hardware'' [19]. The specialists examined a motorized blower with a microprocessor that employs an arm device to push an Ambu-Bag. The camshaft (CAM) is used to plan the movement of mechanical elements. The output data illustrates how the tide's magnitude varies over time [20]. Several attempts are currently being made to construct pressure-controlling venting devices, given that the original concept with a pair of paddles is powered by a power source [21]. That has been stated that a great option is for utilizing electrical motors that pressing the Ambu Bag with electrical motors is a great option. Tidal volume may continuously increase regardless of the compressed air supply [22]. The innovative design for the proposed ventilator includes a plastic air reservoir, polymer loops, flexible wires, two control valves, a direct current (DC) motor, and a support box. Its concept is currently being worked out. Future iterations will be modified in light of the lessons learnt by researchers from testing the prototype [23]. Researchers have suggested that the use of medical gases and the flow interruption technique can enhance the high efficiency and cheap cost of ventilation technology. The problem is different in the developed world, where everyone has access to well-equipped medical facilities. Although there are enough ventilators for regular use, they are not prepared for events like virus pandemics, natural disasters, and large-scale hazardous chemical releases where many people will be killed. In wealthy countries, it is not viable to store and deploy state-of-the-art mechanical ventilators during mass casualty situations due to the huge costs involved [24]. Analyzing the most recent research, it is evident that a low-income nation requires a respirator that is inexpensive, reasonably effective, and portable in order to assist those with asthma and COPD. Between 2019 and 2021, the COVID-19 pandemic, due to the SARS-CoV-2 virus, triggered a global health crisis characterized by severe respiratory problems such as pneumonia and acute respiratory distress syndrome (ARDS), resulting in high mortality rates. The critical need for accessible, effective, and reasonably priced ventilators to help patients experiencing respiratory distress was brought to light by this exceptional catastrophe. The current study suggests creating a low-cost, Internet of Things (IoT)-enabled smart ventilator in answer to this pressing need. This device would allow for real-time patient monitoring and enhance accessibility for healthcare systems across the globe. The suggested ventilator offers a scalable and reasonably priced respiratory support option, which would increase the capacity of healthcare facilities, especially in settings with limited resources. Furthermore, this research emphasizes the possible role of such technologies in reducing the impact of future world health crises, ensuring a swift and effective response in the case of pandemics or other large-scale disasters comparable to COVID-19 [25].

2. Methedology of the Embedded Ventilator

This study focuses on simulating a bio-enabled emergency device—more precisely, a ventilator or respiratory machine—that is made to adhere to exacting standards for critical care. Key aspects like automated changes, real-time monitoring, and system stability can be tested and improved using the simulation approach without the requirement for actual prototypes right away. This research attempts to optimize design for ease of use, affordability, and compatibility with current healthcare systems while simultaneously ensuring the device's operation, safety, and effectiveness in emergency situations through the simulation of multiple-scenarios.

2.1 Medical device requirements

There are few essential points to think about prior to creating this medical device. These are-

- ✓ Minimal Cost : The cost should be as minimal as possible in relation to the market pricing.
- ✓ A user interface that is simple enough for patients and doctors to utilize is essential.
- ✓ Reusability : Reusable facilities are essential for lowering initial investment.
- ✓ Strong Mechanical and Medical Outcome : The device needs to have enough output capacity to meet its real goals.

2.2 Design Equipment

Here are the components that will be used in the simulation to design the device-

- ✓ Arduino Nano;
- ✓ ESP8266 Module;

- ✓ Servo Motor (MG995);
- ✓ Ambu Bag;
- ✓ LM35 Sensor;
- ✓ Heart Rate Sensor;
- ✓ 12V Buzzer.

3. Functional Block Diagram of the Embedded Ventilator

There are many different levels of complexity and sophistication associated with mechanical respirators. The most sophisticated hospital breathing equipment, sensors, and electronics all use software data to regulate the airflow volume and breathing rate [26]. It is unclear if there will be enough hospital-grade breathing equipment available to meet demand in the upcoming weeks and months given the exponential increase in the number of sick people. When a hospital-grade respirator is unavailable, alternative breathing devices are researched. For controlling air flow during ventilation, this mechanical low-function respirator is a less costly, more complicated, and less efficient alternative to a hospital-grade ventilator [27].

A low-cost, reliable ventilator was developed by researchers to aid in unpredictable pandemic situations. The ventilator was developed and constructed using Arduino fulfills all the qualities to serve patients requiring ventilation facilities. Researchers use a two-sided pushing mechanism on a silicon-based respiratory bag that is attached to a direct current servo motor. Researchers use a variable pot and toggle switch to change and modify the patient's tidal volume and BPM. Using a blood oxygen sensor and a sensitive pressure sensor, the researcher's system tracks the patient's vitals and shows them on a little screen. Additionally, the gadget has an emergency buzzer alert that sounds a warning when an irregularity is detected. IoT is also incorporated into this ventilation system. Remote patient monitoring technologies are increasingly affordable, practical, and available for taking and recording patient parameters in a comfortable setting. Instead of going to the hospital every day, patients may receive help from system components at home, including microcontrollers, sensors, actuators, and cloud-enabled systems. To finish the project, researchers must employ a different approach. Researchers conducted the study and developed standards for successfully finishing the task. This proposed system is intended to measure all pertinent information associated with a respiratory disease and identify a patient's oxygen levels.

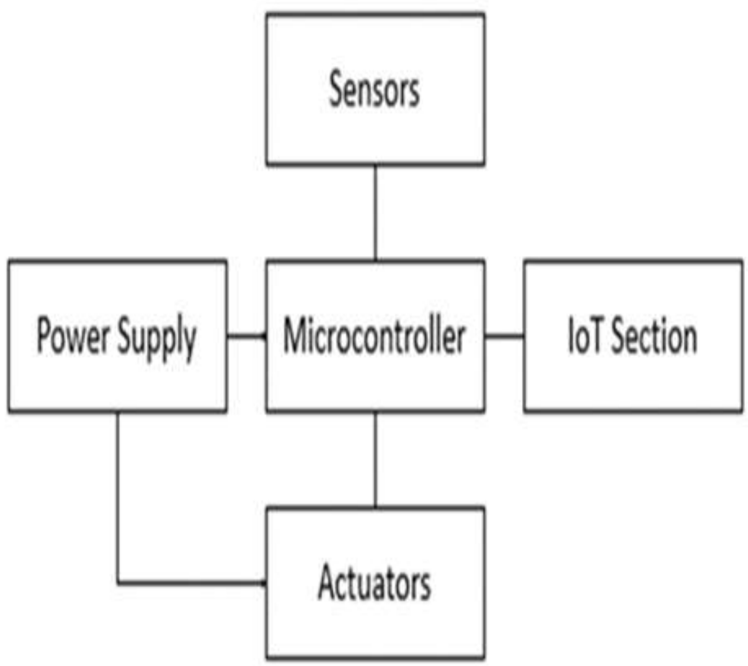

Fig.1. A Simple Block Diagram of the Innovative Embedded Ventilator

The comprehensive block diagram shows the four main sensors that are incorporated into the system. Vital indicators including body temperature, oxygen saturation, cardiac activity, and the requirement for quick action are all crucially monitored by these sensors. These sensors allow the system to evaluate the patient's status and decide on the best course of action by continuously supplying real-time data. An AC-to-DC converter is also necessary to provide the system with the necessary power, guaranteeing steady and dependable performance. The block diagram showing the design of the system for this research is presented below-

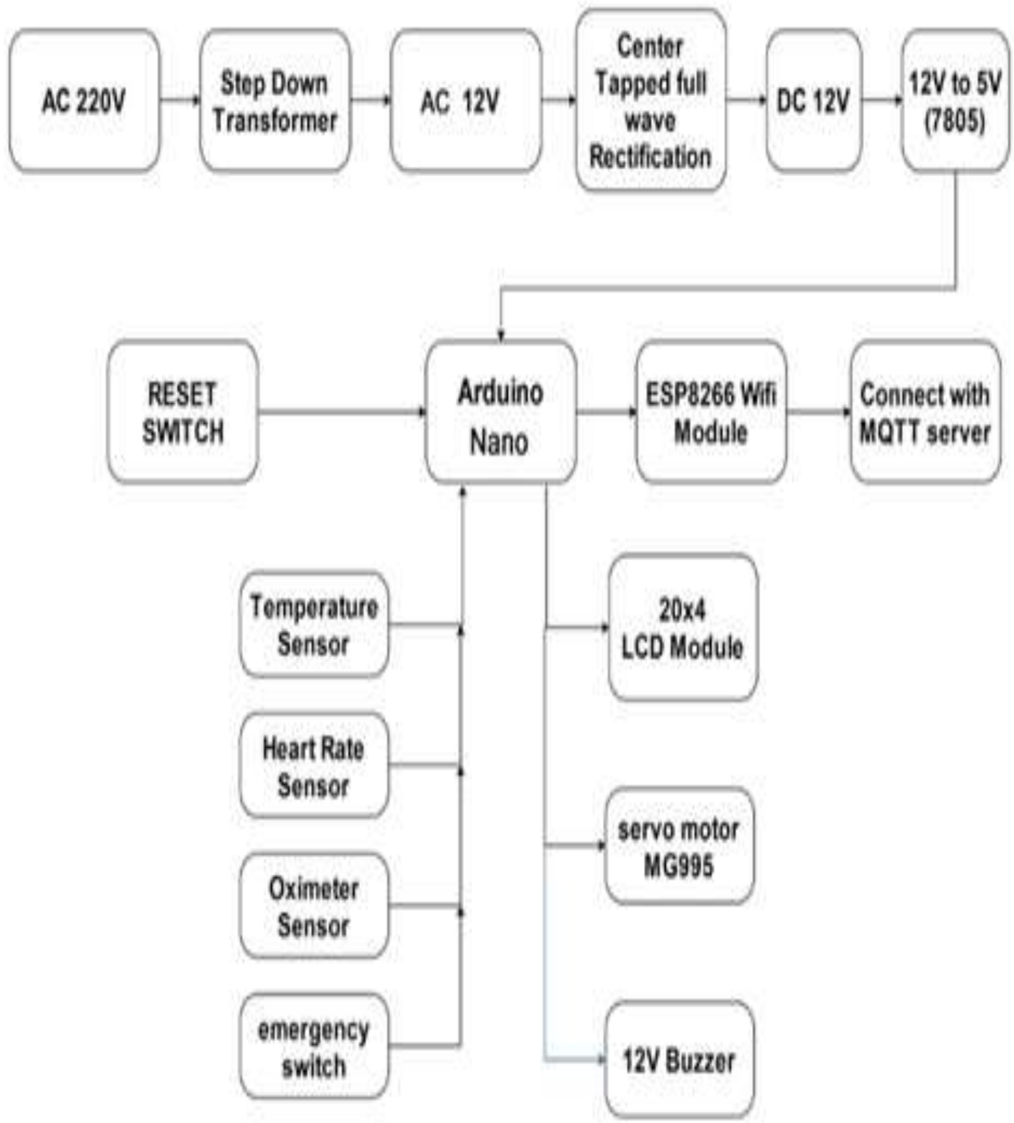

Fig.2. A Detailed Block Diagram of a smart low-cost innovative ventilator

The following diagrams show the connections between each component and the micro-controller. This system can additionally be powered directly by a 12-volt source. An Internet of Things-based intelligent power supply system will increase the system's efficacy and patient-friendliness. The WIFI module is also connected to the E-health system for data storage, as shown in Figure 2.

4. System Design

In Figure 3, this schematic diagram serves as a representation of the entire project. The following diagrams show the connections between each component and the micro-controller.

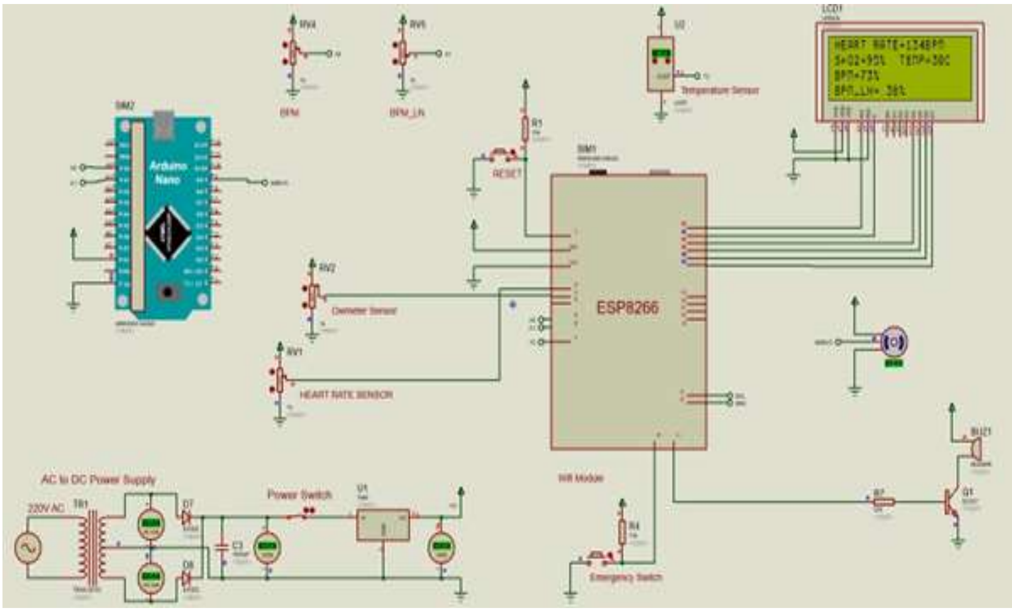

Fig.3. System design of IoT based Innovative Embedded Ventilator In proteus 8

5. Simulation and Result Analysis

In the simulation of this research, the researchers utilized the professional version of the Proteus software. Although the software's default library could be used to run the simulation, a custom library was assembled to include all required elements. The simulation's main objective was to assess the system's performance and functioning. As shown in Figure 4, a number of difficulties were discovered during this process, and attempts were made to address them in order to fulfill the goals of the study.

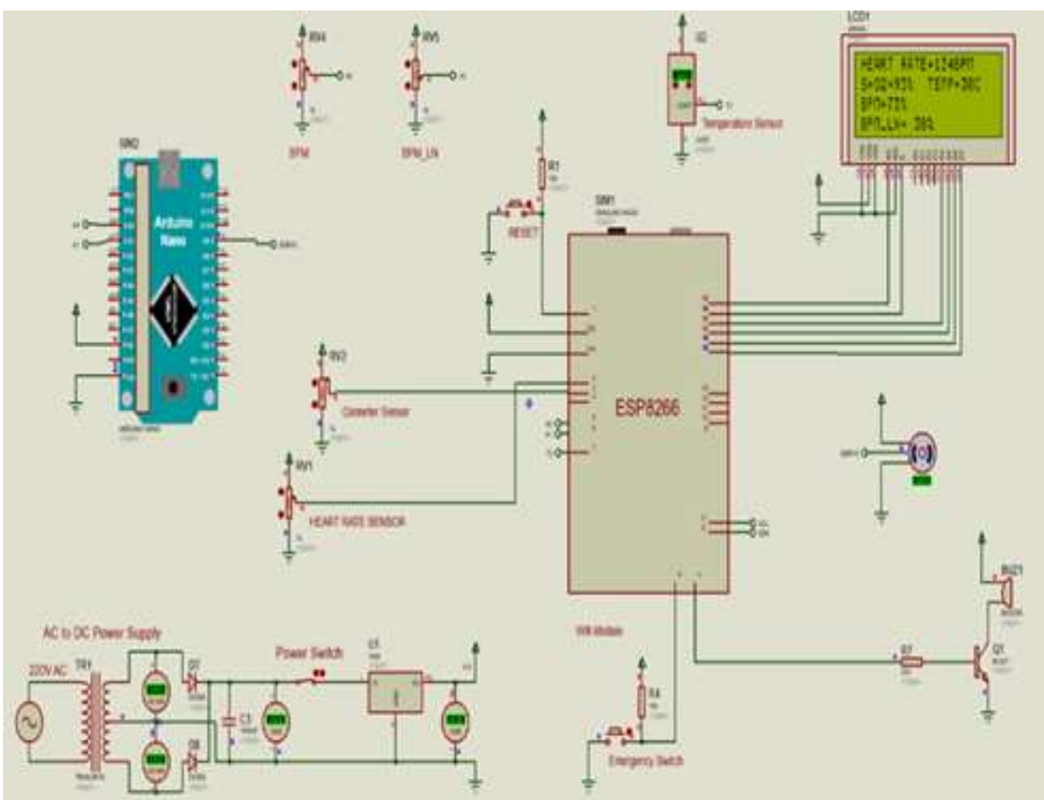

Fig.4. Simulation of of IoT based Innovative Embedded Ventilator

As seen in Figure 5, the LCD display displays the simulation's outcomes and includes important metrics including temperature, oxygen saturation, heart rate, and pump speed. The integration of sensors, devices, and modules into the embedded system is depicted in Figure 4. This circuit architecture, which is based on the Internet of Things (IoT), makes it possible to generate vast amounts of data in real time with accuracy and speed. Sensor-equipped IoT devices collect data and send it across a wireless network to systems and applications that are linked.

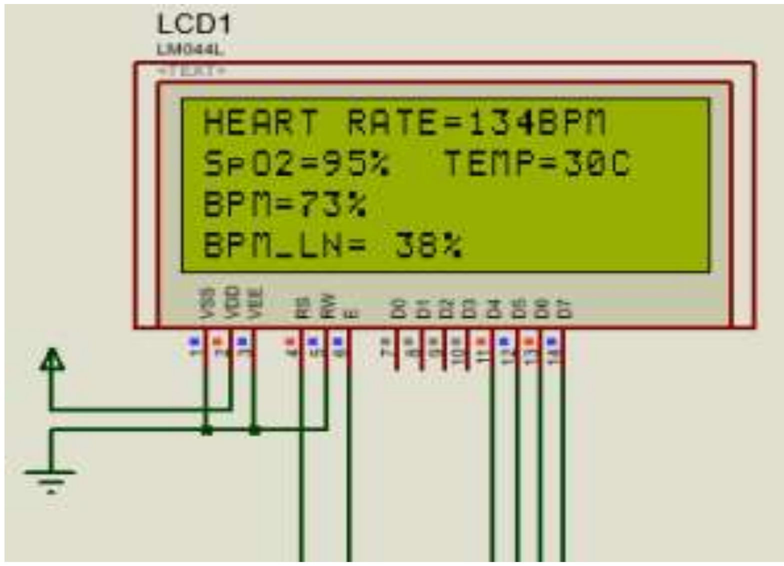

Fig 5. LCD display that Presents the gathered information from sensors

The IoT framework is designed particularly to allow connection among internet-connected devices, creating a seamless exchange of data. The simulation output of the entire system is displayed in Figure 4, and the result parameters measurements based on the patient's condition are shown in Figure 5. Healthcare practitioners can continuously monitor patient status by using the web output curve to assess these metrics in real time.

To enhance the system’s accessibility, the Internet of Things (IoT) design is linked to both mobile and web applications, enabling doctors and family members to monitor the patient's health remotely. The app interface is shown in Figures 6, 7, 8, 9, and 10, which offer an easy-to-use view of the system's data.

Fig 6. Temperature Curve in web model

This method provides a straightforward yet efficient respiratory support solution. When local healthcare facilities are unavailable, the suggested affordable mechanical breathing machine with temperature, pressure, and blood oxygen sensors can offer vital respiratory support. This is in contrast to hospital-grade ventilators, which are more complicated, costly, and less effective at controlling airflow.

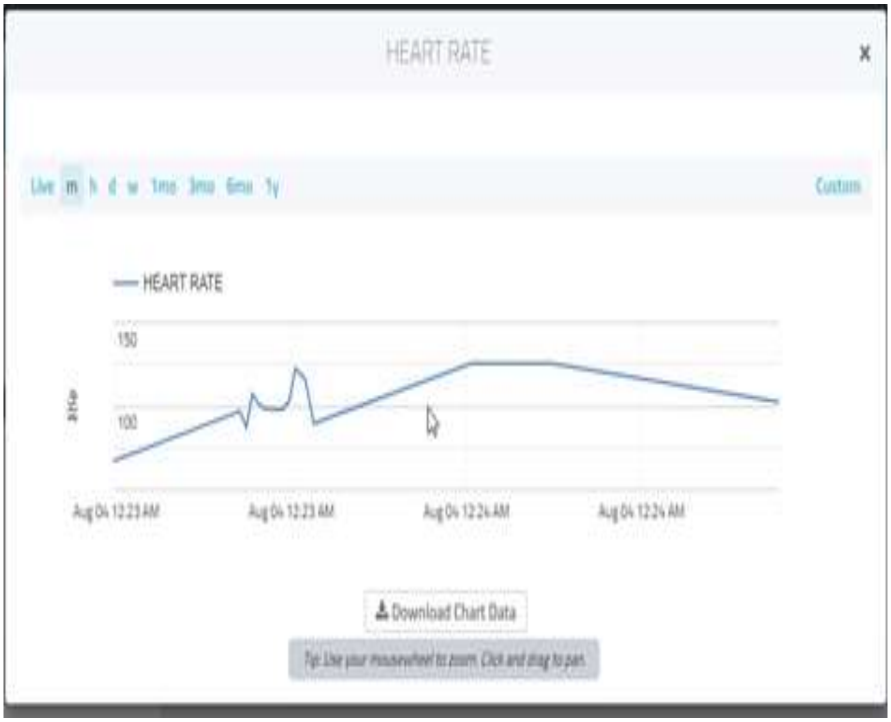

Fig 7. Heat rate in web version web view

Fig 8. Oxygen level curve in web

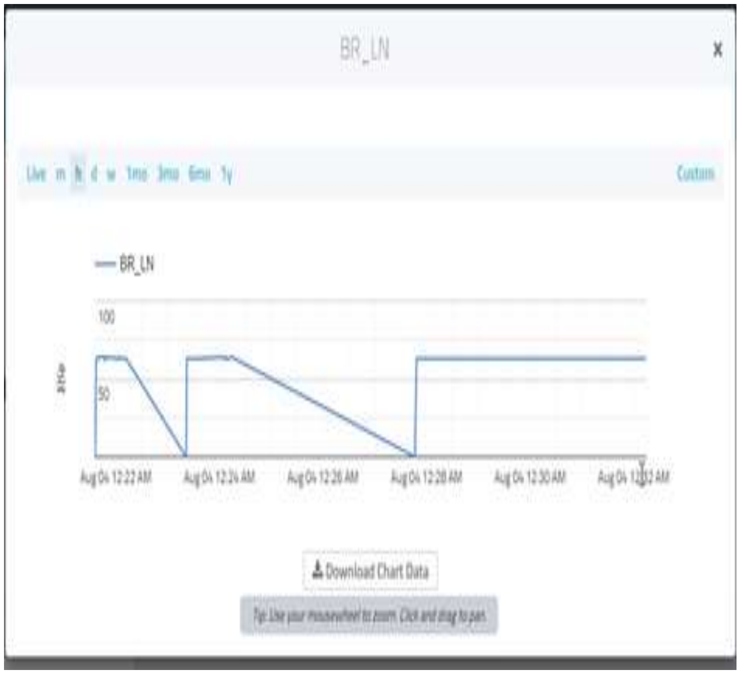

Fig 9. Breath rate curve web view

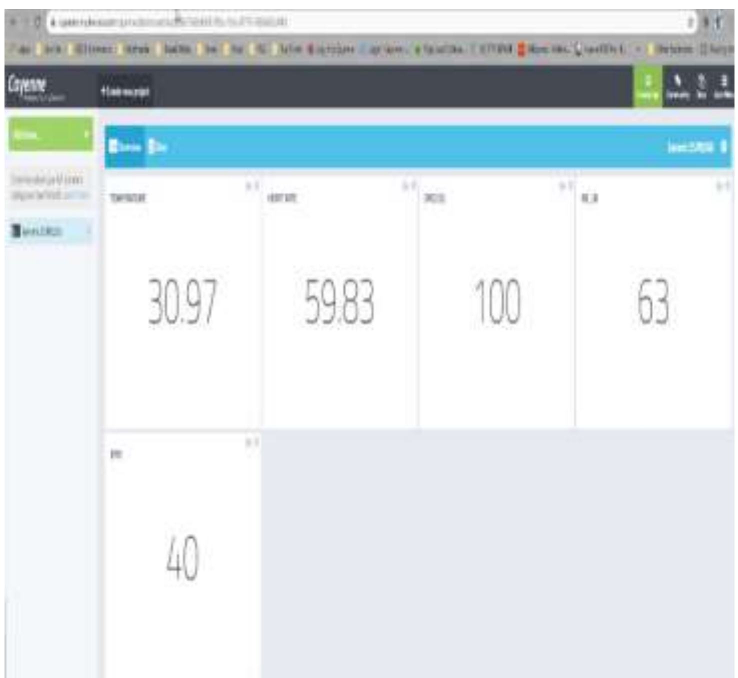

Fig 10. Web-based Simulation

Low-function breathing machines can be useful when cost, usability, and accessibility are important factors, even if they are all less powerful than a typical hospital-style breathing machine. Because of its intended use in an emergency and because researchers show how a human using the gadget would breathe, they call it a Low-Cost Mechanical Ventilatory Support with a Pressure, Temperature & Sensing of Blood Oxygen unit. This is because it is classified as an emergency ventilator because of both of these features. IoT is also used by researchers to monitor events remotely. The enormous demand for ventilators at the moment can be met by our project.

6. Future Work

Every system, including this smart ventilator, has its limitations. Although the model has been created and effectively simulated, real-world testing has not yet been done on it. The automated ventilator is almost finished, and researchers intend to improve its performance by using artificial intelligence (AI) to increase its output and speed. In order to enhance its functioning, a fully integrated physical prototype with extra oxygen modules, sensors, and features must be created in the following step. Human experiments will be carried out to improve the system and guarantee its dependability and acceptability in clinical applications after receiving approval from the health ministry and gathering real-time feedback. The ultimate goal is to create an affordable, effective, and flexible respiratory support system, especially in settings with limited resources. This ventilator will improve patient outcomes in critical care circumstances and solve global health concerns, particularly in locations with limited access to advanced medical equipment, by utilizing IoT and AI technologies to provide real-time patient monitoring and data exchange.

7. Conclusion

This cost-effective mechanical ventilator, designed to assist patients with respiratory conditions such as COPD, integrates pressure, temperature, and oxygen in the blood sensors, making it an essential tool in critical care situations. Researchers have created a dependable and reasonably priced alternative that uses an Ambu breathing bag that is operated by a motor-powered side-push mechanism. The apparatus has a changeable potentiometer to modify the patient's breath length and breaths per minute (BPM) and a toggle switch for power control. Using sensitive blood oxygen and pressure sensors, it continuously tracks the patient's health information and shows important parameters on a single screen. A warning LED or buzzer is triggered to notify caretakers in the event of aberrant readings. The entire system is driven by an Arduino processor, ensuring efficient operation and precise outcomes. By offering a dependable, accessible, and reasonably priced respiratory support system, this invention has the potential to completely transform contemporary healthcare, especially in settings with limited resources. This ventilator has the potential to greatly enhance patient care with its real-time monitoring and emergency alarm features, particularly in dire circumstances where cutting-edge medical equipment might not be available.

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