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Development of a Portable Ventilator with Real-Time SpO_2 Monitoring and Automated Ventilation Control Using ESP8266

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Abstract

Respiratory conditions associated with reduced oxygen saturation require continuous monitoring and timely respiratory support. This study presents the development and experimental evaluation of a smart portable ventilator that integrates physiological monitoring, automated ventilation, and IoT-based remote monitoring. The proposed system uses an ESP8266 microcontroller, MAX30102 pulse oximeter sensor, OLED display, buzzer, and servo-driven mechanical arms to control an Ambu bag according to predefined blood oxygen saturation (SpO_2) conditions. When SpO_2 remained within the normal operating range (91–100%), the ventilation mechanism remained inactive, whereas it was activated when SpO_2 reached the predefined emergency range (80–90%). The system was experimentally evaluated using three participants, with three measurements recorded for each participant under normal and reduced- SpO_2 conditions. SpO_2 and pulse rate were displayed in real time on the OLED screen, while the Blynk platform enabled remote monitoring. The results demonstrated that the system responded to changes in SpO_2 according to the programmed conditions, with the ventilation mechanism remaining inactive under normal conditions and activating when the emergency range was reached. The findings demonstrate the feasibility of integrating physiological monitoring with automated ventilation and remote monitoring in a compact portable prototype, without the need for continuous manual compression of the Ambu bag.

Keywords: Mechanical Ventilation, ESP8266, Pulse Oximeter Sensor, Servo Motor, Ambu Bag.

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1. Introduction

Ventilators are critical medical devices that provide respiratory support to patients who experience difficulty breathing due to conditions such as chronic obstructive pulmonary disease, pneumonia, and acute respiratory distress syndrome [1]. Mechanical ventilation assists the respiratory process by delivering air to the lungs when spontaneous breathing is insufficient, thereby supporting adequate oxygenation and carbon dioxide removal [2,3]. These systems are widely used in intensive care units, emergency medicine, and anesthesia, where reliable respiratory support is essential [4]. The importance of ventilatory support became particularly evident during the COVID-19 pandemic, when the demand for ventilators increased substantially and exposed significant shortages, especially in low-resource healthcare settings [5, 6]. This situation emphasized the need for affordable, portable, and accessible respiratory support technologies that can be deployed in emergency and resource-constrained environments [7,8]. Recent advances in embedded systems and the Internet of Things (IoT) have created opportunities to develop low-cost medical devices capable of combining physiological monitoring, ventilator systems, and remote communication. In particular, microcontrollers with integrated wireless connectivity can facilitate real-time monitoring and enable healthcare providers to access patient data remotely [9,10,11]. In this study, a compact and low-cost smart ventilator system based on the ESP8266 microcontroller is developed. The proposed system integrates physiological monitoring using the MAX30102 pulse oximeter sensor to measure heart rate and blood oxygen saturation (SpO_2), together with an automated ventilation mechanism based on two servo motors and an Ambu bag. The system continuously monitors the patient's physiological parameters and activates assisted ventilation when predefined abnormal SpO_2 conditions are detected. In addition, an audible alarm provides local notification of abnormal conditions, while the measured data are transmitted through the Blynk IoT platform for remote monitoring. The proposed approach aims to provide an accessible and portable respiratory support system that combines physiological monitoring, automated response, and IoT-based connectivity in a low-cost platform.

2. Related Works

Several studies have explored low-cost and portable ventilator systems using microcontrollers, physiological sensors, mechanical compression, and IoT-based monitoring. Table 1 summarizes selected related studies, including their main components, monitoring parameters, control methods, and communication capabilities.

Table 1. Comparison of previous portable and low-cost ventilator systems.

Ref/ Year	Controller	Sensors Used	Actuator	Ventilation Mechanism	Cloud
[12]/2021	Arduino Uno	Oxygen sensor (SpO_2 & Heart rate), pressure sensor	MG995 Servo motor	Silicon Bag	No
[13]/2022	Arduino Uno	Max30100 sensor (SpO_2 & Heart rate), LM35 sensor (Temperature)	MG995 Servo motor	Ambu Bag	No
[14]/2022	Arduino	Max30102 (SpO_2), KY039 sensor (Heart rate), DS18B20 sensor (Temperature)	Stepper motor	Ambu Bag	Yes
[15]/2022	Two Arduino platforms + Raspberry Pi4	Max30100 sensor (SpO_2 & Heart rate)	Dual solenoid valves	Pneumatic ventilation	Yes
[16]/2023	Arduino ATmega 328	Blood pressure sensor, Heart rate sensor, LM35 sensor (temperature)	Servo motor	Ambu Bag	Yes
[17]/2024	Arduino Nano + Node MCUESP8266	Max30100 sensor (SpO_2 & Heart rate)	MG995 Servo motor	Ambu Bag	Yes
[18]/ 2025	Arduino Nano	Max30100 sensor (SpO_2 & Heart rate), DHT11 sensor (Temperature)	DC motor	Ambu Bag	Yes

[19]/2025	Arduino Uno + ESP8266	Max30105 sensor (SpO_2 & Heart rate), DHT11 sensor (Temperature)	Servo motor	Ambu Bag	Yes
[20]/2026	Arduino Mega 2560	Max30100 sensor (SpO_2 & Heart rate), MPX5010DP sensor (airway pressures)	Stepper motor	Ambu Bag	Yes
This work	ESP8266	MAX30102 sensor (SpO_2 & Heart rate)	GM996 servo motor	Ambu Bag	Yes

3. Materials and Methods

3.1. System Architecture

Figure 1 illustrates the block diagram of the proposed smart portable ventilator system. The system is centered on the ESP8266 microcontroller, which coordinates physiological monitoring, ventilation control, user interaction, alarm generation, and IoT connectivity.

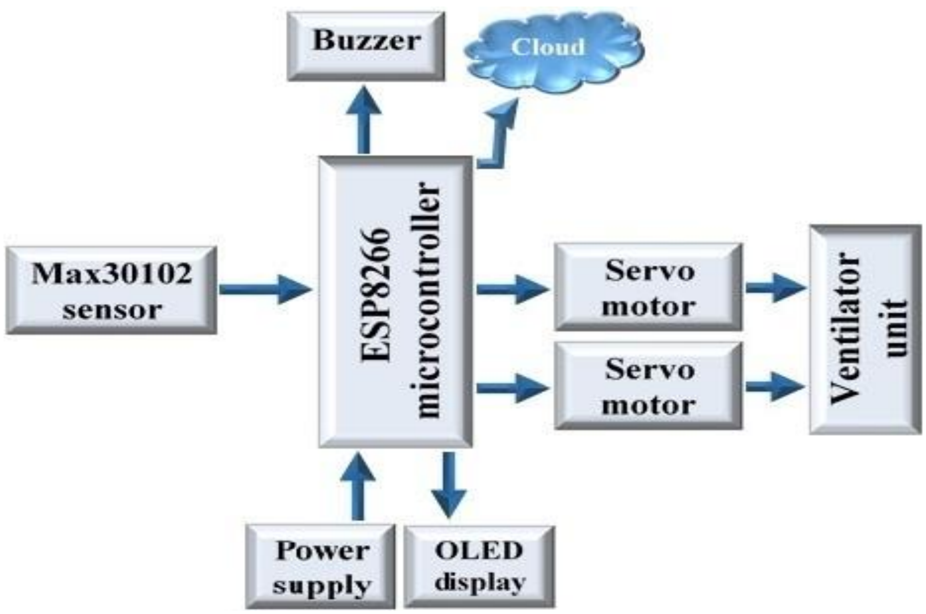

Figure 1. Block diagram of the proposed portable ventilator system.

3.2. Hardware components

The hardware components used in the proposed ventilator system are summarized in Table 2, while Figure 2 shows the main hardware components integrated into the prototype. The selected components were chosen based on their functionality, availability, reliability, and suitability for developing a low-cost portable ventilator.

Table 2. The hardware components used in the proposed ventilator system

Component	Model	Purpose	Quantity
Microcontroller	ESP8266 NodeMCU	Controls the ventilator operation and IoT communication	1
Servo Motor	GM996R	Drives the mechanical arms for Ambu bag compression.	2
Pulse Oximeter Sensor	MAX30102	Measures SpO_2 and heart rate	1
OLED Display	I2C OLED 0.96 (128×64)	Displays real-time patient vial sings	1
Ambu Bag	Manual Resuscitator	Delivers air to the patient	1
Mechanical Arm	Handmade PVC structure with Styrofoam reinforcement, 15×20 cm	Transfers the servo motor motion to the Ambu bag for compression	2
Battery	3.7V Rechargeable Li-ion	Supplies power the portable ventilator	4
Buzzer	Active Buzzer	Provides audible alarms for abnormal conditions	1
DC-DC Buck Converter	LM2596 (14.8V to 5V)	Regulates the supply voltage	1
Push buttons	Tactile Push Button	Adjust ventilation parameters	7
Breadboard	Standard Breadboard	Prototyping and circuit connections.	2
Green LED	5 mm LED	Indicates system power status	1
Jumper Wire	Connecting Wires	Electrical connections between the components	As needed

(a) (b) (c) (d) (e)

Figure 2. The main components of the proposed system: (a) ESP8266, (b) Servo motor, (c) Pulse oximeter sensor, (d) OLED display, (e) Mechanical arm.

After assembling and integrating the hardware components, the proposed ventilator was constructed as a compact portable prototype. The assembled system integrates the physiological monitoring unit, control unit, mechanical ventilation mechanism, display and alarm units, and power supply. Figure 3 presents the prototype of the proposed ventilator system.

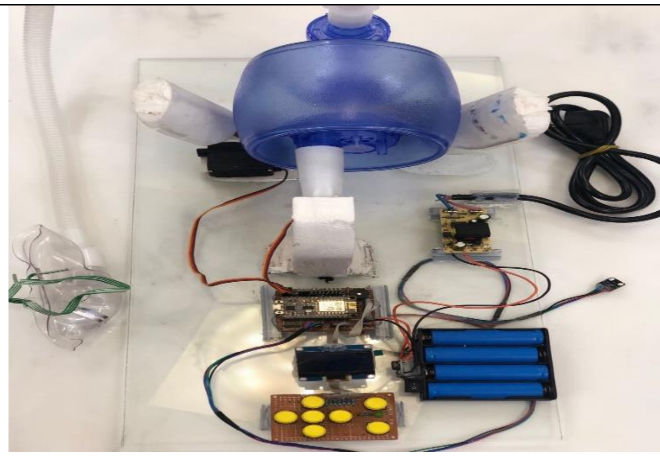

Figure 3. The prototype of the proposed ventilator system

3.3. Software Implementation

The ESP8266 microcontroller was programmed using the Arduino Integrated Development Environment (IDE), with C/C++ to integrate and control the system components: the MAX30102 was configured to continuously monitor SpO_2 and pulse rate, while the OLED display was programmed to visualize the measured parameters and system status, the buzzer was configured to generate a 2 Hz audible alarm under abnormal conditions. The servo motors were programmed to actuate the mechanical arms by oscillating between 45° and 135° at a rate of 12 cycles per minute (0.2 Hz), thereby compressing the ambu bag to provide a targeted tidal volume of approximately 500–600 ml. Figure 4 presents a sample of the code used in the Arduino IDE for the proposed system.

Figure 4. Sample IDE code for the proposed system

3.4. System Operation

Figure 5 illustrates the operational workflow of the proposed ventilator system. Following system initialization, the ESP8266 continuously acquires the patient's heart rate and SpO_2 from the Max30102 sensor. The measured values are compared with predefined threshold limits to assess the patient's physiological condition in real time. When the physiological parameters remain within the normal range, the system continues monitoring while activating the green status LED, updating the OLED display with the measured values, and periodically transmitting the data to the Blynk cloud platform for remote monitoring. This operating mode enables continuous supervision of the patient's condition without initiating mechanical ventilation. When an abnormal condition, particularly a reduction in SpO_2 to the predefined emergency range, is detected, the ESP8266 activates the audible buzzer and drives the two servo motors. The servo motors move the mechanical arms to compress the Ambu bag and provide assisted ventilation according to the programmed settings. During ventilation, the physiological parameters continue to be monitored. When SpO_2 returns to the acceptable range, the servo motors are deactivated and the system resumes normal monitoring.

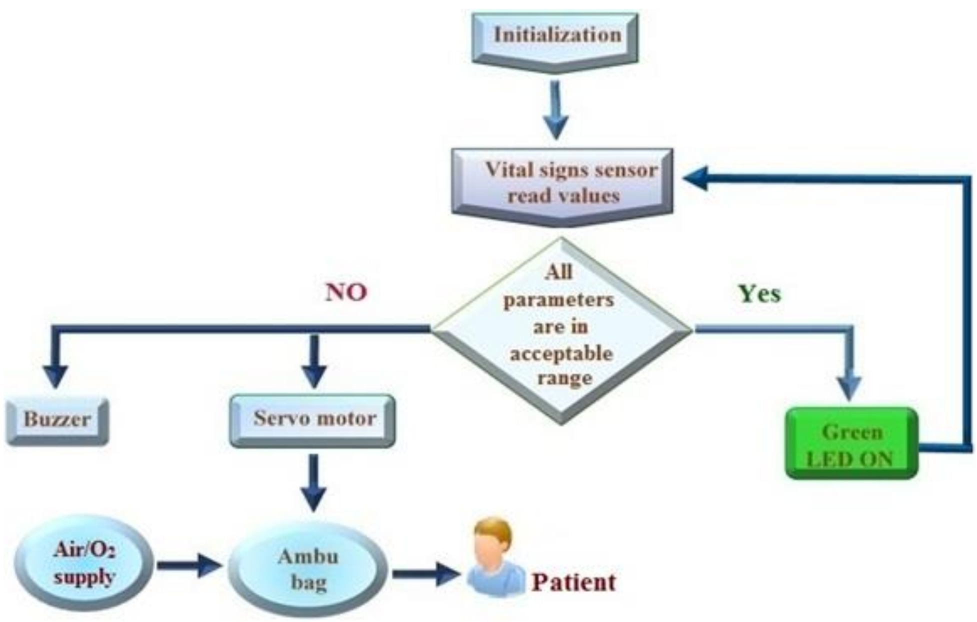

Figure 5. Operational flowchart of the proposed ventilator system

4. Experimental Setup

4.1. Study Sample

Three adult male volunteers, aged 22-24 years, with clinically documented asthma diagnoses participated in the evaluation. Exclusion criteria included the presence of cardiovascular disease, anemia, or an acute respiratory infection at the time of testing. The evaluation was performed under controlled conditions from February 2 to 26, 2026, to assess the functionality, reliability, and performance of the proposed smart ventilator system.

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4.2. Ethical Considerations

All participants provided written informed consent prior to participation. The study protocol was reviewed by the Ethics Committee of the Faculty of Medical Technology.

4.3. Experimental Procedure

The proposed ventilator was evaluated under predefined operating conditions based on SpO_2 thresholds. For each participant, three measurements were recorded: the first under normal physiological conditions and the second and third during a health-related condition associated with reduced SpO_2 (80–90%). The system operation was categorized into two states:

i. Normal state: When SpO_2 remained within the normal operating range (91–100%), the servo motors remained inactive and the system continued physiological monitoring.

ii. Emergency state: When SpO_2 reached the predefined emergency range (80–90%), the ESP8266 activated the two servo motors, which moved the mechanical arms to compress the Ambu bag and initiate assisted ventilation.

SpO_2 and pulse rate were monitored continuously and displayed in real time on the OLED screen, while the measured data were transmitted to the Blynk platform for remote monitoring. Figure 6 shows the practical experimental setup used to evaluate the proposed ventilator system.

Figure 6. Practical experimental setup of the proposed ventilator system during testing.

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5. Results

The experimental results obtained from the three participants are summarized in Table 3, including three measurements of SpO_2 and pulse rate for each participant, together with the corresponding servo activation status. The measured values were displayed in real time on the OLED screen, as shown in Figure 7.

Table 3. Experimental measurements and ventilator response

Participant	Trial	SpO_2 (%)	Pulse rate (bpm)	Ventilator State
Participant 1	1	98	80	Ventilation inactive
	2	90	85	Assisted ventilation activated
	3	80	80	Assisted ventilation activated
Participant 2	1	98	94	Ventilation inactive
	2	88	82	Assisted ventilation activated
	3	88	90	Assisted ventilation activated
Participant 3	1	93	75	Ventilation inactive
	2	90	81	Assisted ventilation activated
	3	89	82	Assisted ventilation activated

Figure 7. Real-time physiological measurements displayed on the OLED screen.

6. Discussion

The experimental results demonstrate that the proposed system responded to changes in SpO_2 according to the predefined operating conditions. When SpO_2 was within the normal range, the ventilation mechanism remained inactive, whereas it was activated when SpO_2 reached the predefined emergency range. Clinically, normal SpO_2 in healthy individuals is typically reported between 95% and 100%, while values below 90% are considered low and may require clinical attention [21,22]. Therefore, the predefined SpO_2 ranges provided a practical basis for evaluating the automated response of the prototype to reduced oxygen saturation. The results also demonstrate the ability of the proposed system to combine physiological monitoring and automated ventilation in a single portable device. The MAX30102 provided SpO_2 and heart rate measurements, while the ESP8266 controlled the ventilation mechanism according to the predefined conditions. The OLED and buzzer provided local feedback, while the Blynk platform enabled remote access to the monitored data.

These findings are consistent with previous studies of low-cos mechanical ventilators, including those of [12] and [13], which integrated physiological monitoring with automated ventilation. However, these systems did not include remote monitoring via the internet. The study [20] integrated SpO_2-based detection, Proportional–Integral–Derivative (PID) control, and IoT connectivity for automated ventilation and remote monitoring. Similarly, the proposed system combines physiological monitoring and automated ventilation with remote monitoring via Wi-Fi using the ESP8266 and Blynk platform. This combination provides a practical approach for integrating monitoring, automated response, and remote access within a portable ventilator prototype.

7. Conclusion

The proposed smart ventilator successfully integrated physiological monitoring, automated ventilation, local alerts, and IoT-based remote monitoring into a portable prototype. The experimental evaluation demonstrated that the system responded to predefined SpO_2 conditions as intended, activating the ventilation mechanism when the emergency range was reached while maintaining normal monitoring otherwise. The system therefore provides a practical approach to automating Ambu bag compression without the need for manual compression. Further evaluation with a larger sample and comprehensive ventilation measurements is required to assess its performance, safety, and potential for clinical application.

8. Limitations and future work

The main limitations of this study were the small sample size, resulting from the inability to conduct clinical testing in hospitals due to concerns about patient safety. As a result, the assessment was limited to a small number of participants, restricting the generalizability of the findings to a wider range of patient conditions. In addition, the evaluation focused primarily on the functional response of the prototype, while a comprehensive ventilation performance, including airway pressure, and positive end-expiratory pressure (PEEP) generation [23], was not conducted. Therefore, future work will focus on expanding the scope of the experimental evaluation using a larger and more diverse sample, incorporating additional respiratory monitoring such as carbon dioxide (CO_2) sensing, and assessing key ventilation parameters, including airway pressure, and PEEP. Further development of adaptive or AI-based control methods could also be explored to improve the system's response to changes in physiological conditions.

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Conflict of interest. No Conflict of interest

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