International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 12 | Dec - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

A Cost Effective IOT Based Smart Ventilator

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Abstract -This project presents the design and development of a cost-effective IoT-based smart ventilator system that provides real-time monitoring of respiratory parameters such as airflow, oxygen saturation, humidity, and temperature. The system uses an ESP32 microcontroller, medical sensors, and cloud connectivity to continuously measure patient health data and display it on a mobile app or web dashboard.
The ventilator also includes safety mechanisms such as automatic alerts during abnormal breathing patterns, low oxygen levels, or system failure. The main aim of this project is to support patients who require assisted breathing by ensuring reliability, portability, and real-time remote monitoring.
This prototype offers a low-cost alternative suitable for rural healthcare centers and emergency situations.

Key Words: IoT, ESP32, Smart Ventilator, Oxygen Monitoring, Cloud, Alert System.

1. INTRODUCTION

Ventilators play an important role in supporting patients who have difficulty breathing due to medical conditions, emergency situations, or post-operative care. Traditional ventilators are expensive and lack remote monitoring capabilities, making them difficult to use in rural hospitals or home-care situations.

To address this issue, this project proposes an IoT-based smart ventilator using an ESP32 microcontroller. The system measures and monitors real-time parameters such as:

1.**Airflow rate: The** ventilator regulates airflow using a variable-speed blower or proportional solenoid valve to deliver precise tidal volumes according to patient needs. Typical airflow ranges from 6–10 L/min for adults, with real-time monitoring to detect obstructions or leakage in the breathing circuit. IoT-enabled flow sensors continuously transmit data to the cloud or control dashboard for predictive adjustments. Proper airflow control ensures stable minute ventilation and supports both assist-control and pressure-controlled ventilation modes.

2.**Oxygen level(SpO2)**: The system uses an electrochemical or optical oxygen sensor to measure the fraction of inspired oxygen (SpO_2) in the range of **21–100%**, allowing clinicians to fine-tune oxygen delivery. IoT integration enables alarms when oxygen levels deviate from the safe therapeutic range. Real-time SpO_2 regulation helps avoid hypoxia and oxygen toxicity, especially in critical care scenarios. The ventilator uses mixing algorithms to maintain stable and accurate oxygen concentration even under varying airflow conditions.

3.**Humidity and temperature**: To mimic natural airway conditions, the ventilator maintains humidity between **40–60%** and temperature between **32–34°C** in the breathing circuit. Sensors measure humidity and temperature continuously, and a heating-humidification unit adjusts these values dynamically. Maintaining optimal humidification prevents mucosal dryness and reduces the risk of secretion buildup. IoT monitoring ensures that deviations trigger alerts, improving patient comfort and airway safety.

4.**Pressure inside the ventilation tube**: Pressure sensors measure peak inspiratory pressure (PIP), positive end-expiratory pressure (PEEP), and mean airway pressure in real time. The ventilator maintains safe values—typically **PIP: 20–30 cmH$_2$O** and **PEEP: 5–10 cmH$_2$O**—to prevent volutrauma and barotrauma. Continuous pressure waveform analysis allows early detection of patient–ventilator asynchrony or tube blockage. IoT connectivity logs pressure trends for clinical analysis and automated corrective actions.

2. Related work

1. Gund, Ankush Madhukar, Sajja Suneel, and M. Amina Begum. " An Efficient and Cost-Effective Systematic Ventilator Design Using Internet of Things with Smart Sensors Association." In 2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC), pp. 333-340. IEEE, 2024.

The authors proposed a systematic ventilator design based on IoT architecture. Integrated smart sensors such as SpO2 sensors, airflow sensors, and heart-rate monitors for continuous patient monitoring. Data transmission achieved through wireless IoT connectivity, enabling remote supervision of patient vitals. Focused on cost-effectiveness while maintaining real-time accuracy by using Aruino Nano microcontroller and system reliability. Demonstrated potential application in emergency care, rural healthcare setups, and resource-limited environments.

2. Gowda, CP Mallikarjuna, B. M. Bellishree, V. Janhavi, M. C. Prakruthi, and Riya Pawar." Venti-Smart: Crafting Smart Ventilators with IoT Technology." In 2024 International Conference on Knowledge Engineering and Communication Systems (ICKECS), vol. 1, pp. 1-6. IEEE, 2024.

The authors presented a portable ventilator prototype using low-power microcontroller ESP32 to optimize energy efficiency. Incorporated pressure sensors and flow sensors for accurate measurement of tidal volume and airflow regulation. Implemented PWM-based motor control for precise actuation of the Ambu bag compression mechanism.

Focused on compact PCB design and lightweight hardware integration to enhance portability. Validated the system through real-time testing of ventilation cycles, ensuring stable respiratory rate control under varying load conditions.

3. Ravishankar, Vihaan, Mohammad Ibrahim, Anjali Jain, and Neelam Verma." Design and Implementation of an IoT-Based Patient Monitoring System for Comprehensive Vital Tracking and Secure Data Access." (2024).

This report presents the design and implementation of an IoT-based Patient Monitoring System (PMS) that offers comprehensive vital tracking and ensures secure data access for healthcare providers and Patients. The IoT-based PMS comprises a network of wearable and non-invasive sensors that continuously collect real-time data on patients' vital signs, including heart rate, blood pressure, body temperature, and oxygen saturation. This data is transmitted securely to a centralized cloud platform via a robust and encrypted communication protocol.

The cloud platform acts as the central hub for data storage and processing.

4. Hussain, Tassadaq, Amna Haider, Wasim Akram, Mujeeb Ur Rehman, Azam Khan, and Muhammad Abbas." Synchronized intermittent mandatory ventilation mode control using pulse oximeter." In 2018 International Conference on Computing, Mathematics and Engineering Technologies (iCoMET), pp. 1-5. IEEE, 2018.

Mechanical ventilators are the machines which are commonly used in hospitals, Intensive Care Unit (ICU) and prolonged treatment centers for assistive or complete breathing. Mechanical ventilators work in four modes, Control Volume Cycled Ventilation, Assisted Pressure Controlled Ventilation, Pressure Support Ventilation and Synchronized Intermittent Mandatory Ventilation. Out of which, Synchronized Intermittent Mandatory Ventilation (SIMV) is an important and frequently used mode. By designing Pulse Oximeter based SIMV of ventilator the existing ventilator units in hospitals can be updated from manual to automatic state in a reasonable budget improving health facilities

5. Abdullah Haider Ali, Syed Murtaza Hassan Kazmi, and Madiha Akbar."Rapid design of an ICU ventilator: An approach based on smart switching of compressed air-oxygen." IEEE Transactions on Biomedical Circuits(2023)

COVID-19 highlighted the need for affordable alternatives.

The proposed NED-Vent design offers a comprehensive low-cost solution covering hardware, electronics, user interface, and control system. It uses compressed air-oxygen switching with proportional valves to support multiple ventilation modes, along with an interactive single-knob interface. The control system applies machine learning for lung modeling and is tuned using Jury's Test and Ziegler-Nichols methods, meeting international standards.

3.Materials and methods

The proposed smart ventilator was developed using an ESP32 microcontroller, a centrifugal blower, and solenoid valves for controlling inspiratory and expiratory airflow. Pressure, flow, temperature–humidity, and optional oxygen sensors were integrated to continuously monitor airway parameters. A TFT/LCD display and Wi-Fi module were used for local interface and IoT connectivity. The breathing circuit consisted of medical-grade tubing, a PEEP valve, and a test lung for validation.

Sensor signals were calibrated against standard manometers and spirometers to ensure accuracy. The ESP32 executed a PID-based control algorithm to regulate tidal volume, pressure limits, and respiratory rate. Real-time data were transmitted to an MQTT cloud dashboard for remote monitoring. Bench testing was performed using a calibrated test lung across different compliances and resistances to evaluate stability and accuracy. System performance was assessed by comparing set values with delivered values for pressure and tidal volume, and alarms were tested for high pressure, low volume, and power failure conditions.

Block Diagram

The IoT-based smart ventilator controlled by the ESP32 microcontroller. At the input side, START and STOP buttons allow the user or operator to manually control the ventilator operation. Patient vital parameters are captured through the MAX30102 pulse oximeter sensor, which measures SpO_2 and pulse rate, and the DHT11 sensor, which monitors temperature and humidity around the patient. These sensor readings are transmitted wirelessly to an Android phone using the ESP32's built-in Wi-Fi capability, enabling remote observation.

The ESP32 receives all inputs, processes the sensor data, and then controls the DC motor, which acts as the main actuator responsible for regulating airflow inside the ventilator. On the output interface, a 16×2 LCD display provides live information such as breathing cycles, sensor values, and system status. Two indicator lights, LED 1 and LED 2, help in giving quick visual alerts for normal operation or fault conditions. Additional control settings such as varying pressure and adjusting age-based ventilation parameters are included to customize airflow delivery according to patient needs.

All these modules work together through the ESP32, ensuring synchronized sensing, actuation, display, and communication. The diagram thus clearly shows how the ventilator collects physiological data, processes it, and produces controlled mechanical ventilation while allowing both local and remote monitoring.

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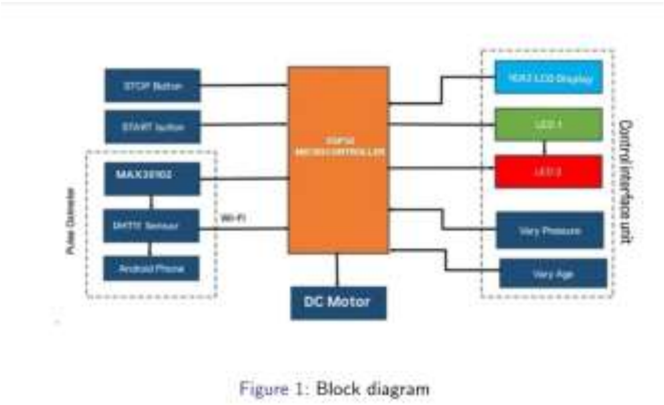

Figure 3.1: Block diagram of the project.

Circuit Diagram

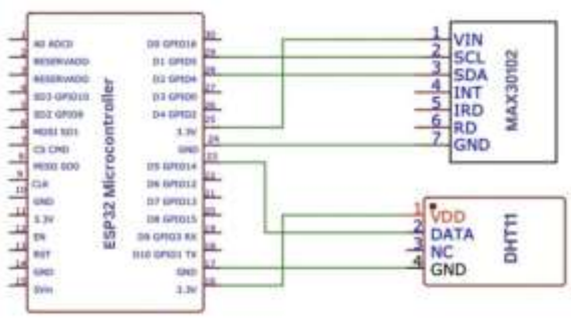

Figure 3.2: Circuit connections of the project

Here the connections are shown as to how ESP32 microcontroller is connected to MAX30102, which in turn is connected with DHT11 Sensor which runs the DC motors

Working of the model

The MAX30102 sensor measures the patient's SpO_2 level and heart rate using optical sensing. Its power pin (VIN) is connected to the 3.3V supply of the ESP32, while SCL and SDA are connected to the ESP32's I2C pins for communication. The INT pin allows the sensor to interrupt the ESP32 whenever new data is available, enabling efficient real-time monitoring. The ground connections ensure stable sensor operation.

The DHT11 sensor provides temperature and humidity readings. Its VDD pin receives 3.3V power from the ESP32, while the DATA pin is connected to a digital GPIO pin for one-wire communication. The ground pin is tied to the ESP32's GND. The ESP32 periodically reads temperature and humidity values to adjust ventilator airflow and environmental comfort.

Once both sensors send data to the ESP32, the microcontroller processes the readings using embedded algorithms. The processed information can then be displayed on an LCD, used to control ventilator parameters, or transmitted wirelessly to an Android phone via Wi-Fi. This enables remote monitoring of oxygen level, pulse rate, and breathing environment in real time.

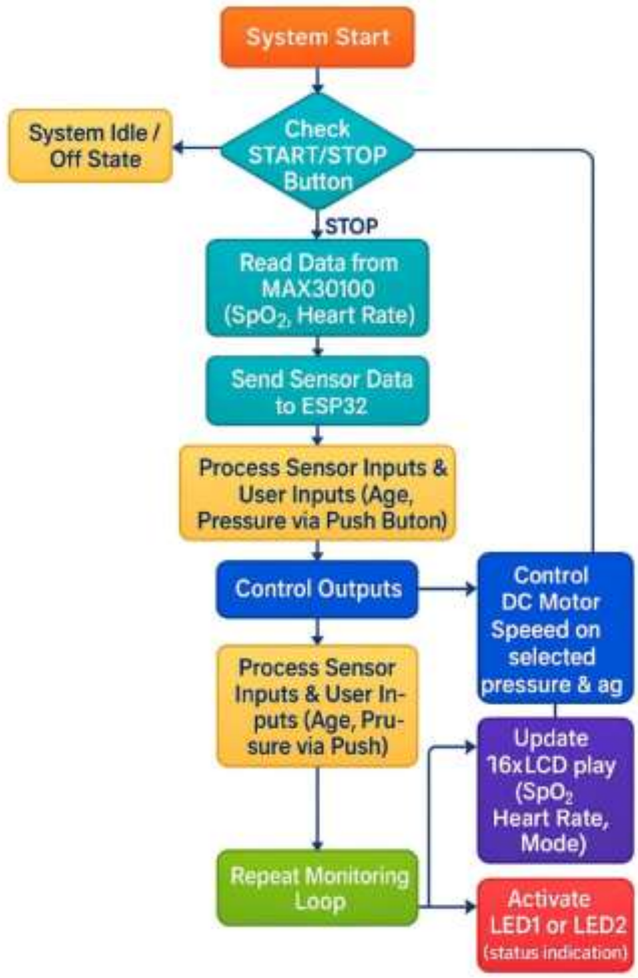

Figure 3.3: Flow of the model

6.Results and discussion

Here the results of AIRFLOW, OXYGEN LEVEL and HUMIDITY AND TEMPERATURE has been presented.

Figure 4.1: Humidity and temperature

Figure 4.2: fig showing blood pressure

Age Group (Years)	Motor Cycles
5 – 10	2 cycles
10 – 30	5 cycles
30 – 60	10 cycles
Above 60	15 cycles

Figure 4.3: fig showing the motor cycles based on the age of a person

Figure 4.4: fig showing the heartbeat graph of a person

Figure 4.5: fig showing the oxygen level of a person

Figure 4.6: fig showing the temperature of a person

Figure 4.7: A 16X12 LCD display showing the results of temperature,heartbeat,oxygen and ECG.

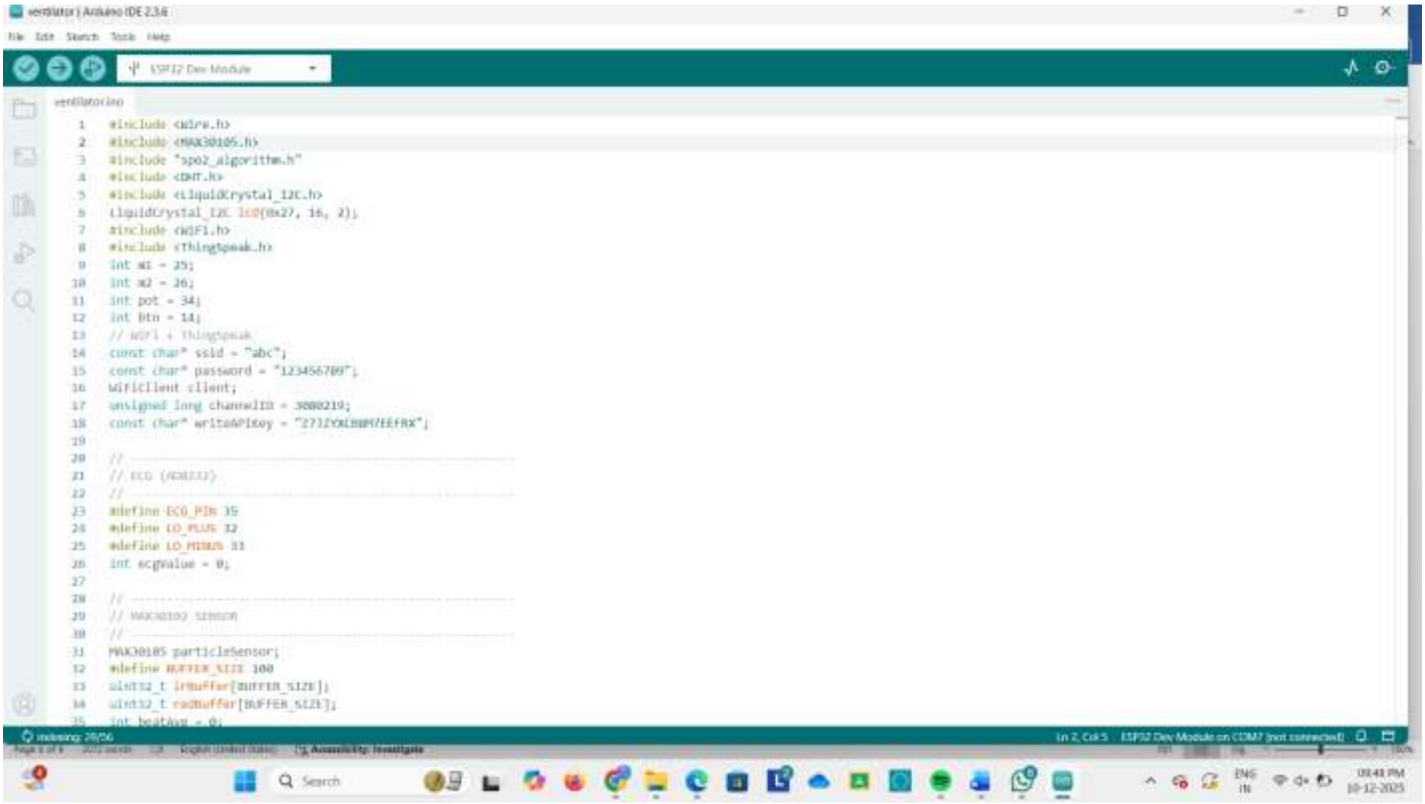

Figure 4.8: Window showing the code

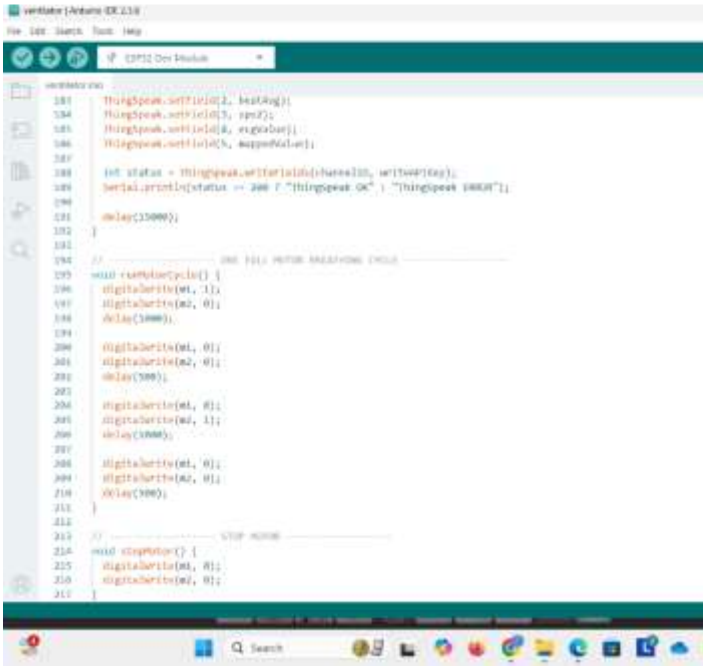

Figure 4.9: Window showing code continuation

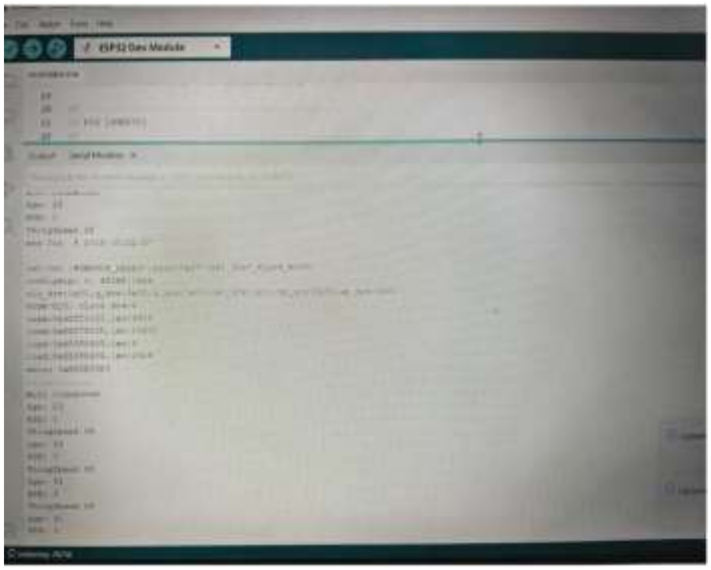

Figure 4.10: Window showing AGE detection

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Figure 4.11. Circuit implementation

Figure 4.13: Overall model

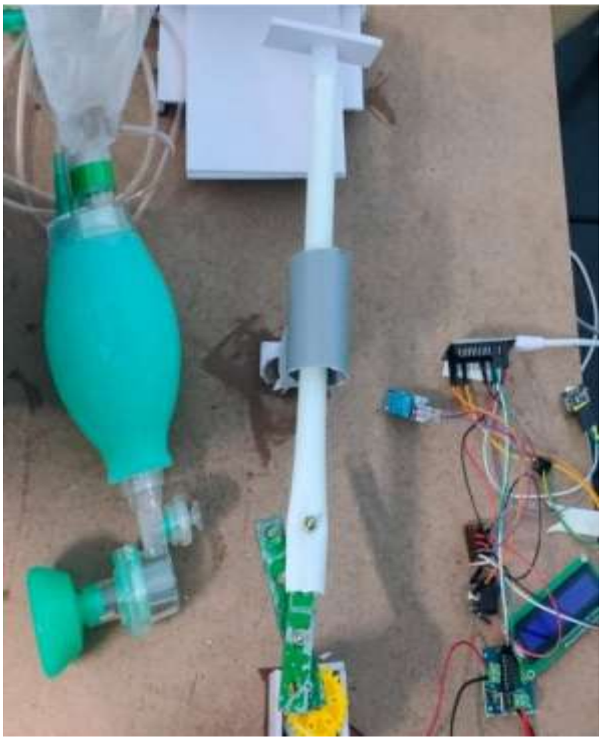

Figure 4.12: Model view

4.CONCLUSION

The developed cost-effective IoT-based smart ventilator provides an innovative solution to the increasing demand for affordable and intelligent respiratory support systems. Through the integration of sensors, microcontrollers, feedback mechanisms, and IoT platforms, the ventilator ensures accurate control of airflow, oxygen concentration, humidity, temperature, and tube pressure. The inclusion of IoT features enables continuous remote monitoring, data logging, and early alert generation, significantly improving patient safety.

The project demonstrates that high-performance medical technology can be achieved at a low cost without compromising functionality. It offers scalability for future enhancements such as AI-based predictive monitoring, advanced alarms, and hospital-network integration. Overall, the system has the potential to support healthcare facilities—especially in rural and resource-limited settings—by providing reliable, efficient, and smart ventilatory assistance

5.REFERENCES

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[5] "A Low-Cost Portable Ventilator Using IoT" by P. L. Prabha et al. (2022). This study presents the development of an inexpensive, portable, and easily deployable emergency ventilator prototype that uses an automated manual resuscitation device (Ambu-bag). The design integrates an Arduino board with an ESP8266 Wi-Fi module to provide real-time patient monitoring (SpO2 and BPM levels) and data transfer to a cloud server, making it a reliable and cost-effective option for resource-limited settings. The full paper can be accessed through IOP Science.