LOW-COST SMART VENTILATOR FOR CRITICAL CARE

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Introduction:

The COVID-19 pandemic exposed major gaps in global healthcare infrastructure, especially in the availability of affordable and accessible ventilators. High costs, complex maintenance, and dependence on imported equipment have made it difficult for under-resourced areas, particularly rural and remote regions, to meet the demand for life-saving respiratory support. These challenges underline the urgent need for innovative, low-cost medical solutions that can be quickly deployed during emergencies.

This project focuses on creating a low-cost, portable ventilator system that can provide effective respiratory assistance using simple, accessible components. The system is built around the automation of an Ambu bag using a DC motor and motor driver, offering controlled, repeatable airflow for patients in need of ventilation.

To enhance functionality and patient safety, the system includes:

- A motor-controlled mechanism to compress the Ambu bag at adjustable speeds, simulating natural breathing.

- Integration of key health sensors, including the MAX30100 for monitoring SpO_2 and heart rate, and the DHT11 for measuring temperature and humidity.

- IoT-based monitoring via Blynk, enabling real-time display of sensor data on a smartphone or dashboard for remote observation.

This ventilator prototype is designed to be simple, affordable, and reliable, making it a practical solution for emergency use in low-resource healthcare settings. It bridges the gap between cost and functionality, aiming to support patients when advanced medical systems are not available.

Objectives:

Main objectives of this project are to:

- **To design and implement an automatic ventilator system** that adjusts motor operation based on predefined settings, includes a toggle switch for sensor calibration, and monitors vital signs such as heart rate, SpO_2, and temperature.
- **To integrate IoT technology for remote monitoring and control** of the ventilator through the Blynk platform, allowing healthcare providers to track patient vitals and adjust ventilator settings remotely, improving efficiency and accessibility in resource-limited settings.

Methodology:

The IoT based technology is organized by hardware and software.

The hardware components of the IoT-based automatic ventilator system include the NodeMCU ESP8266 microcontroller, DC motors, motor driver modules, toggle switches, I2C LCD display, and Heartbeat sensor (MAX30100), SpO2 sensor (MAX30102), Temperature sensor (DHT11) to monitor vital parameters.

The software used for the system includes the Arduino IDE, where the programming is done in C/C++. The Blynk IoT platform is utilized for remote monitoring and control.

The system functions by collecting data from the sensors, processing it with the NodeMCU, and displaying real-time vitals on the local LCD. The ventilator is controlled based on the settings selected through the toggle switches, with data also sent to the Blynk platform for remote monitoring.

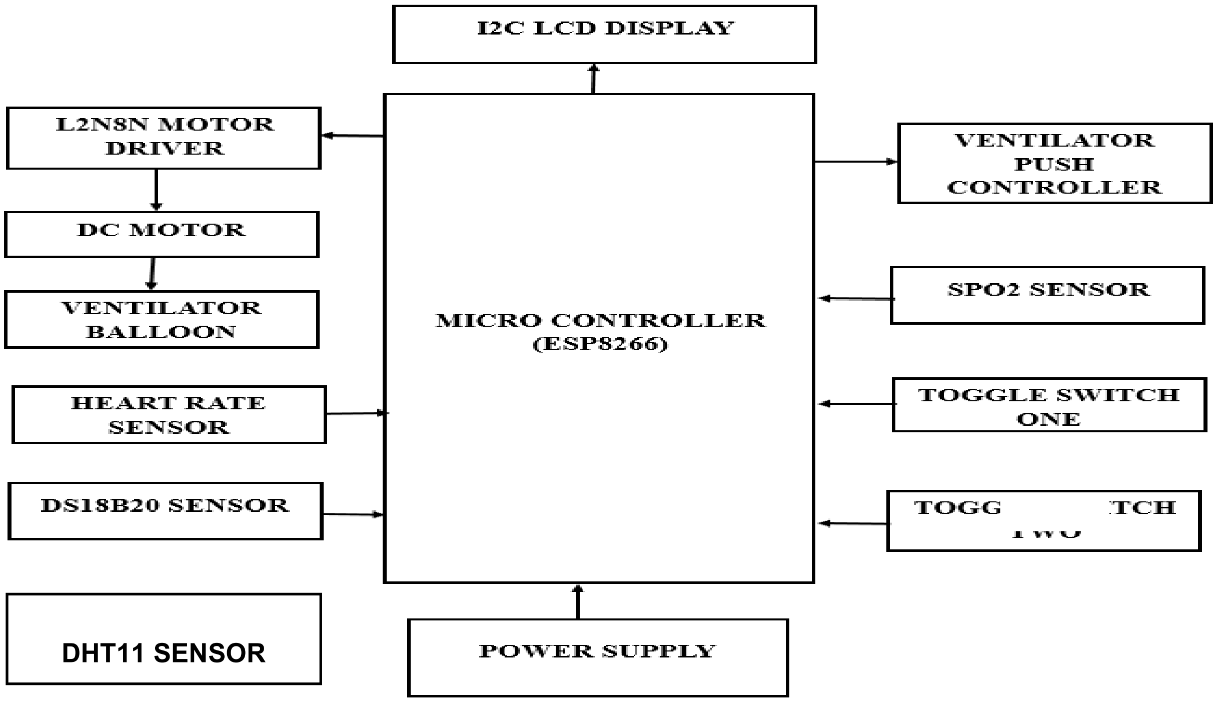

Figure 1: Block Diagram

The system's ventilator mechanism operates through a DC motor that is controlled by a motor driver module. This motor is responsible for adjusting the pressure on an Ambu bag (ventilator balloon), which is crucial for providing mechanical ventilation to the patient. The motor driver module allows precise control of the motor's speed and direction, enabling the inflation and deflation of the Ambu bag in a controlled manner. This action mimics the process of natural breathing, delivering consistent breaths to the patient. The settings adjust the ventilator's parameters, such as the pressure and volume of air delivered, ensuring that the system provides appropriate support based on the patient's needs.

The system also includes sensors that monitor the patient's vital signs. A heartbeat and SpO2 sensor (MAX30100) track the heart rate, providing crucial data on the patient's cardiovascular health and measures the oxygen saturation levels in the blood, which is critical for assessing respiratory function. The temperature and humidity sensor (DHT11) monitors the patient's body temperature and humidity, helping detect any signs of fever or infection. These sensors are connected to the NodeMCU ESP8266 microcontroller, which processes the data and displays it on an I2C LCD for immediate feedback to caregivers. Additionally, the data is transmitted to the Blynk IoT platform for remote monitoring by healthcare providers, enabling timely intervention when necessary. The integration of the ventilator control and vital sign monitoring ensures a comprehensive and responsive healthcare solution.

To ensure the ventilator functions effectively, multiple validation steps will be carried out. First, the motor-driven mechanism will be tested for consistent and repeatable compression of the Ambu bag to maintain controlled airflow. Sensor outputs from the MAX30100 (for SpO_2 and heart rate) and DHT11 (for temperature and humidity) will be compared with readings from standard medical devices to ensure accuracy.

The system will also be checked for real-time responsiveness, ensuring that vital signs are updated promptly for immediate feedback to caregivers. Additionally, the data is transmitted to the Blynk IoT platform for remote monitoring by healthcare providers, enabling timely intervention when necessary. The integration of the ventilator control and vital sign monitoring ensures a comprehensive and responsive healthcare solution.

Result and Conclusion:

Results

Component	**Function**	**Outcome**
Ventilation Mechanism	Utilizes a DC motor to operate an Ambu bag for mechanical ventilation.	Successfully delivers controlled mechanical ventilation.
MAX30100 Sensor	Monitors heart rate and SpO_2 levels.	Provides accurate readings of vital parameters.

DHT11 Sensor	Measures ambient temperature.	Offers reliable temperature monitoring.
I2C LCD Display	Displays real-time patient data.	Enables immediate feedback to caregivers.
Blynk IoT Platform	Facilitates remote monitoring via smartphone or PC.	Allows seamless access to patient vitals remotely.
Toggle Switch	Initiates sensor calibration before ventilation.	Ensures sensors are properly calibrated prior to operation.
Sensor Validation	Compares sensor readings with standard medical devices.	Confirms reasonable accuracy of sensor measurements.

Conclusion

The proposed system successfully demonstrates a low-cost, automated ventilator with integrated IoT-based health monitoring. It provides reliable mechanical ventilation and real-time tracking of vital signs, making it suitable for use in emergency situations and resource-limited environments. The combination of automation, sensor integration, and remote access ensures a responsive and accessible healthcare solution.

Project Outcome & Industry Relevance:

This project resulted in a functional prototype of an automatic ventilator system integrated with real-time health monitoring using IoT. It demonstrated the feasibility of delivering cost-effective respiratory support using readily available components like the NodeMCU, DC motor, and biomedical sensors. The system reliably monitored vital signs such as heart rate, SpO_2, and temperature, with real-time display and remote access via the Blynk platform.

From an industry perspective, this solution addresses the urgent need for affordable and scalable healthcare technology, especially in underserved and rural areas. It can serve as a base model for developing low-cost emergency ventilators in hospitals, mobile clinics, or during disaster relief. With further refinement and certification, this technology can be adapted by medical device manufacturers, NGOs, and government health programs to expand access to life-saving equipment. The project contributes to the growing field of biomedical IoT by merging automation, patient monitoring, and remote accessibility into one compact and efficient solution.

Working Model vs. Simulation/Study:

This project involved the development of a physical working model. The system was built using actual hardware components, including the NodeMCU ESP8266, DC motor, motor driver, Ambu bag, and biomedical sensors (MAX30100 and DHT11). The ventilator mechanism and sensor integration were physically implemented, tested, and validated. Real-time data was displayed on an LCD and transmitted to the Blynk IoT platform for remote monitoring, demonstrating a fully functional prototype rather than a simulation or theoretical study.

Project Outcomes and Learnings:

Project Outcomes:

- Developed a fully functional, low-cost automatic ventilator with real-time vital sign monitoring.
- Achieved successful integration of IoT for remote patient monitoring via the Blynk platform.
- Demonstrated accurate sensor readings and effective mechanical ventilation using a motor-controlled Ambu bag.
- Ensured system calibration and stability with the help of a toggle switch and reliable sensor performance.

Key Learnings:

- Gained practical experience in embedded systems, IoT integration, and biomedical instrumentation.
- Learned how to interface multiple sensors and control hardware components using a microcontroller.
- Understood the importance of accurate data collection, real-time feedback, and system calibration in healthcare applications.
- Developed problem-solving skills while troubleshooting hardware-software issues and optimizing performance for real-time use.

Future Scope:

The future scope of this project includes**:**

1. Add real-time alerts for abnormal vital signs to enhance patient safety.
2. Upgrade to medical-grade sensors for improved accuracy and reliability.
3. Implement cloud-based data storage for long-term patient monitoring.
4. Integrate battery backup or solar power for use in remote areas.
5. Improve the user interface on the Blynk platform for better remote access.
6. Miniaturize the hardware for better portability and compact design.
7. Include respiratory pressure and airflow sensors for advanced monitoring.
8. Enable automatic ventilation adjustments using smart algorithms.
9. Enhance the enclosure design to meet clinical safety standards.
10. Explore collaboration with healthcare providers for real-world testing and feedback.