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Design and Simulation of a Simple Educational Mechanical Ventilator Using Arduino Control

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Abstract

We will prepare a basic educational mechanical ventilator based on the Arduino Uno microcontroller and simulate the process. The system simulates the inhalation and exhalation cycles by adjusting the speed of the 12-V DC fan with pulse-width modulation (PWM). Two potentiometers were placed to independently adjust the breathing rate (BPM) and airflow intensity, giving students practice on ventilator control.

Experimental testing took place at approximately 10, 18, and 28 BPM, where qualitative airflow observations yielded stable and repeatable cyclic patterns under all the conditions. These results confirm that the prototype model can be used to simulate the basic mechanism of mechanical ventilation more cost-effectively and with simpler application, so that it can be of interest to biomedical engineering and medical physics education. It serves as an accessible platform for studying ventilator timing, modulation control, and basic respiratory simulation.

Keywords: educational ventilator model; Arduino control; PWM; airflow regulation; respiratory simulation; biomedical training system

Introduction

Open-source microcontroller systems [1] have been used to develop inexpensive biomedical teaching equipment for school laboratories. Their programmability, availability, and suitability with a wide range of sensors and actuators allow mimicking the control of biomedical control schemes in medical systems to be performed [2]. Within respiratory education, biomedical science students and medical physics students need to be able to understand the mechanics of airflow, timing, and duty cycle of mechanical ventilators. But commercial devices for ventilator use are expensive, with little insight into internal control mechanisms.

Thus, it is essential to build instructional prototypes that demonstrate key concepts around PWM modulation, flow production, and timing control so an idea can be demonstrated to an understanding user. Mechanical ventilation is one of the important methods for those who have difficulty breathing naturally. It is often prescribed for acute respiratory distress syndrome (ARDS), hypoxemia, chronic bronchitis, and so forth, some notable lung disorders. Mechanical ventilation is designed to compensate for the body's failure to satisfy the demand for appropriate oxygen supply or natural carbon dioxide elimination [3]. [4] revealed that an Arduino-based ventilator is able to replicate simple breathing cycles with programmable timing. Similarly, [5] showed that simple configurations of airflow using PWM control fans might produce a consistent, reproducible pattern of ventilation. A further study [6] emphasizes the importance of low-cost prototype systems for the training process. The present work also offers a novel dual-potentiometer system compared to previous approaches so that BPM and airflow intensity can be adjusted concurrent with each other, and a clearer visualization of respiratory mechanics for teaching purposes is achieved.

Problem Statement

Commercial ventilators are costly and their internal operation is not easily observable by students, limiting hands-on understanding of breathing cycles, airflow regulation, and control timing. Commercial ventilators are costly and their internal operation is not easily observable by students, limiting hands-on understanding of breathing cycles, airflow regulation, and control timing. Moreover, most clinical ventilators are designed as closed, proprietary systems, making it difficult for learners to explore hardware components, sensor integration, or control algorithms. This lack of transparency reduces opportunities for practical training, especially in resource-limited educational settings where access to real medical devices is restricted. Therefore, there is a need for a simple, low-cost, and open-architecture educational ventilator that allows students to visualize, simulate, and control fundamental ventilation parameters using accessible technologies such as Arduino [7].

Methodology

This study followed an experimental–simulation methodology consisting of system design, algorithm implementation, and testing.

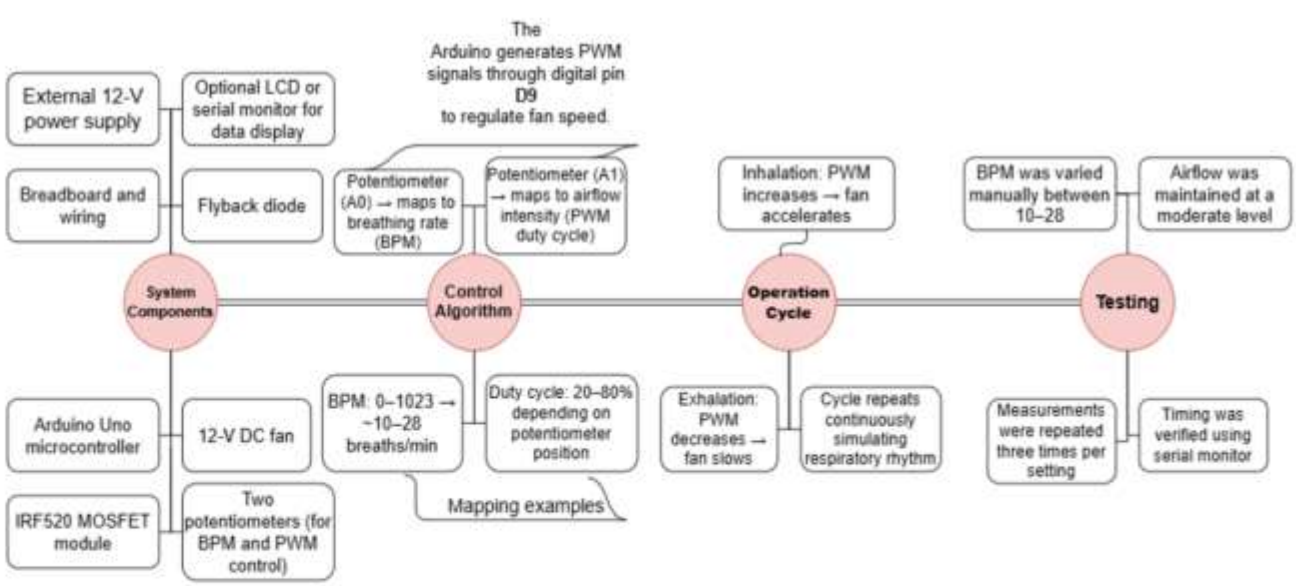
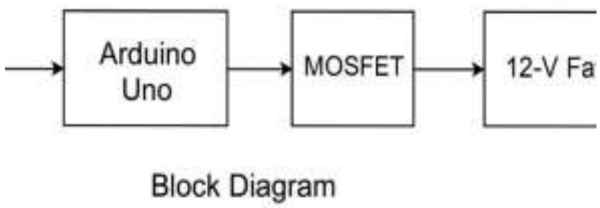
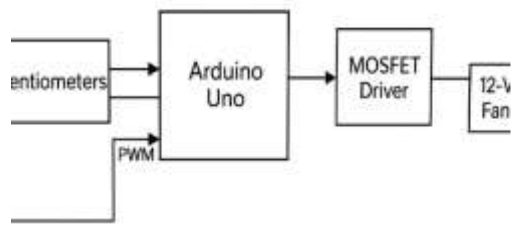


Image 1: Flow Chart of Methodology
Methodology validated through experimental measurements presented in Section 4 (Testing).

4. Design of Mechanical Ventilator

Image 2: Block diagram for the design of a mechanical ventilator





Circuit Diagram Description

The electronic control circuit system for the educational ventilator prototype was constructed ensuring stable PWM control of the 12-V DC fan in a safe and secure electrical environment with proper signal isolation. The DC fan was linked to the drain terminal of an N-channel MOSFET, which was used as the main switching device. With the source terminal of the MOSFET being directly attached to ground, the transistor could influence current flow through the fan according to PWM signals [8]
The gate terminal of the MOSFET was connected to the Arduino Uno using digital pin D9, and the microcontroller would generate PWM pulses in order to control speed of the fan in real time. In order to prevent any kind of inductive spikes from the fan switching, a flyback diode was positioned across the fan terminals to allow the back EMF to dissipate safely in order to avoid any damage to MOSFET or microcontroller. Two potentiometers were included in the design and connected to the Arduino's analog input pins A0 and A1[9]. They provide control capability for manual adjustment of the breathing rate (BPM) and airflow intensity via modulation of analog voltage levels that the control algorithm interprets. A 12-V DC fan was powered by an external source through the MOSFET switching stage. The Arduino was operated safely at its 5-V logic level while the fan was given enough current to simulate ventilation properly.

Results and Discussion

6.1 Results

Test No.	BPM Setting	Airflow (Qualitative)	Notes
1	~10	Moderate	Stable low-frequency airflow
2	~18	Moderate	Smooth cyclic transitions
3	~28	Moderate	Fast cycles, stable waveform

Table 1: Results of the experiment

6.2 Discussion

The simple educational ventilator with Arduino microcontroller can provide a similar airflow configuration at different ventilation speeds. The device provided stable airflow output at the lowest limit (~10 BPM), demonstrating its mechanical and control capability at relatively low frequency. The stability of this is important in simulating slow and controlled ventilation modes, which will be used for early training scenarios [10] The airflow was moderate at the medium setting (~18 BPM), and the inhaling and exhaling cycles are smooth. This proved that the timing techniques implemented by the Arduino code were capable of quickly dealing with intermediate cycle frequencies without misalignments.

It is critical for normal adult respiratory rates in schools. Even at the top speeds (~28 BPM), the ventilator still provided moderate and stable airflow at the high cycle frequency [11]. Maintaining stable waveforms at fast speeds suggests that the motor/fan and PWM-based control mechanisms were adaptive for fast modulating changes. It is another great insight that indicates that the system is capable of mimicking the tachypneic breathing seen in clinical conditions providing more educational output [12].

Conclusion and Recommendation

Conclusion

In this project, it was set out to build a basic low-cost educational mechanical ventilator simulator made with Arduino control. The prototype demonstrated a reliable modulation of airflow variability and reproducible breathing cycles for the duration of 10–28 BPM and also demonstrated the functionality and reliability of the PWM-based control algorithm. Its dual-potentiometer system could effortlessly adjust airflow intensity and breathing rate, making it a useful tool for anyone studying components of mechanical ventilation.

Overall, the device presents a practical and intuitive entry point for ventilator performance, timing adjustment, and respiratory simulation under laboratory conditions. Examples of future improvements may include: using quantitative airflow or pressure sensors, closed-loop feedback control, an LCD interface to track the function, 3D-printed housing design for more usable and realistic device. These enhancements would enhance the educational benefits and fidelity of this prototype even more.

Recommendation

Integrating pressure or flow sensors, implementing closed-loop control (PID), Adding LCD for real-time BPM/airflow display, 3D-printing a ventilator-style housing, recording airflow using quantitative sensors (m/s values).

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