Modeling and Simulation of a Fuzzy Logic Controlled Medical Ventilator Using MATLAB/Simulink

Danish Abdullah
Department of Mechatronics Engineering
Air University Islamabad, Pakistan
danishabdullah.mail@gmail.com

***Abstract*— Mechanical ventilation is a critical intervention in modern healthcare, providing respiratory support to patients with compromised lung function. This paper presents the modeling and simulation of a positive-pressure medical ventilator system using MATLAB/Simulink, integrated with fuzzy logic control to enable adaptive regulation of ventilation parameters. The ventilator delivers a preset flow rate to a simplified lung model represented by a Translational Mechanical Converter (MA) block, which simulates respiratory elastance and resistance through spring and damping elements. By setting the interface cross-sectional area to unity, the model translates displacement into lung volume and force into airway pressure, enabling realistic simulation of lung mechanics. The system architecture comprises five core modules: flow generation, fuzzy control, lung model, humidification subsystem, and graphical monitoring. The fuzzy logic controller interprets pressure and flow inputs using a rule base and membership functions to dynamically adjust tidal volume, breathing frequency, and positive end-expiratory pressure (PEEP), mimicking real-time clinical adaptation. A humidifier module conditions the air with controlled temperature and humidity to prevent airway drying and tissue damage. Simulation outputs include pressure, temperature, humidity, flow rate graphs, and a pressure–volume loop within the lung model, confirming physiological realism and control stability. While gas exchange and biochemical modeling are not included in this version, the framework offers a flexible platform for future expansion, including multi-compartment lung models, machine learning-based control, and hardware-in-the-loop validation. This work contributes a modular, simulation-based approach for studying ventilator mechanics and intelligent control systems.**

Keywords—Medical ventilator, fuzzy logic control, MATLAB/Simulink, lung model, respiratory mechanics, Translational Mechanical Converter, adaptive ventilation, humidification system.

I. Introduction

Mechanical ventilation is a cornerstone of critical care, providing life-sustaining respiratory support to patients with compromised pulmonary function [1]. Whether due to acute respiratory distress syndrome (ARDS), chronic obstructive pulmonary disease (COPD), or post-operative recovery, ventilators play a vital role in maintaining adequate gas exchange and preventing respiratory failure. However, conventional ventilator systems often rely on fixed control parameters that may not adapt well to dynamic patient conditions, leading to risks such as ventilator-induced lung injury (VILI), poor oxygenation, or patient–ventilator asynchrony.

To address these challenges, intelligent control strategies have gained attention, particularly those that incorporate fuzzy logic for adaptive regulation [2] [3], [4]. Fuzzy logic controllers can interpret imprecise sensor data and apply rule-based decision-making to adjust ventilation parameters such as tidal volume (TV), breathing frequency (f), and positive end-expiratory pressure (PEEP). This approach enables more personalized and responsive ventilation, especially in scenarios where patient-specific lung mechanics vary over time.

This paper presents the modeling and simulation of a positive-pressure medical ventilator system using MATLAB/Simulink, integrated with fuzzy logic control [5], [6], [7]. The lung is represented using a Translational Mechanical Converter (MA) block, which mimics respiratory elastance and resistance through spring and damping elements. The system architecture includes modules for flow generation, fuzzy control, humidification, and graphical monitoring of pressure, temperature, and humidity across the ventilator circuit. By simulating real-time feedback and control adaptation, the proposed model offers a flexible platform for studying ventilator mechanics and intelligent control strategies in a modular and reproducible framework.

II. Literature Review

Ventilator modeling has evolved through a range of approaches aimed at improving control precision, patient safety, and adaptability [6], [7]. Early models used simplified representations of lung behaviour to simulate global respiratory dynamics. More advanced techniques introduced spatial resolution, capturing regional differences in lung compliance and resistance. Computational simulations have further enhanced realism by visualizing airflow patterns and pressure gradients throughout the ventilator circuit.

Positive-pressure ventilation remains the most widely adopted modality in clinical practice, delivering air into the lungs via an endotracheal tube. Control strategies for such systems include volume-controlled, pressure-controlled, and adaptive modes, each offering trade-offs in responsiveness, stability, and patient comfort. Adaptive control methods are particularly valuable in dynamic scenarios where lung mechanics vary over time due to disease progression or treatment response. Simulation platforms like MATLAB/Simulink have become popular for ventilator modeling due to their modular architecture, extensive block libraries, and real-time visualization capabilities. These tools enable researchers to simulate ventilator mechanics, patient–ventilator interactions, and control algorithms with high flexibility and precision.

Accurate representation of lung mechanics is essential for realistic simulation. Simplified models often use spring and damping elements to mimic respiratory elastance and resistance [8]. In this work, the Translational Mechanical Converter (MA) block is used to simulate lung behaviour, translating displacement into volume and force into pressure. This approach captures essential respiratory dynamics while maintaining computational efficiency. Fuzzy logic control has emerged as a promising technique for adaptive ventilation [9], [10], [11], [12]. Unlike traditional controllers, fuzzy systems use rule-based logic and membership functions to interpret sensor data and adjust parameters such as tidal volume, breathing frequency, and positive end-expiratory pressure. This enables more personalized and responsive ventilation, especially in cases where patient responses are nonlinear or uncertain.

Recent developments in personalized ventilation have explored the integration of physiological data, imaging-based calibration, and intelligent algorithms to tailor control strategies to individual patient profiles [13]. These approaches aim to reduce ventilator-induced lung injury and improve clinical outcomes. This paper builds on these foundations by integrating fuzzy logic control with a modular ventilator model in MATLAB/Simulink. The system simulates real-time feedback and adaptive control, offering a flexible platform for studying ventilator mechanics and intelligent regulation strategies.

III. System Design

The proposed ventilator system is modeled in MATLAB/Simulink and consists of five core modules: flow generation, lung model, fuzzy logic control, humidification, and graphical monitoring [13]. Each module is designed to simulate a specific physiological or mechanical function of a real-world ventilator system.

A. Flow Generation Module

The flow generation module simulates the mechanical act of delivering air to the patient during the inspiratory phase. It consists of a constant flow source that injects a preset volumetric airflow into the system. This airflow represents the tidal volume delivered to the lungs and is adjustable to reflect different clinical scenarios such as low compliance or high resistance conditions [5], [14].

The flow source is modeled using a volumetric supply block that maintains a steady flow rate, which can be tuned based on patient-specific requirements. This module also includes check valves to ensure unidirectional flow and prevent backflow during the expiratory phase. The flow generation system acts as the primary driver of the ventilation cycle and interfaces directly with the lung model.

Key features:

- Simulates inspiratory airflow using a constant flow source
- Adjustable flow rate to mimic clinical variability
- Includes check valves for directional control
- Interfaces with the humidifier and lung model subsystems

This module lays the foundation for simulating realistic ventilation dynamics and is critical for evaluating the downstream response of the lung model and control system.

B. Lung Model Module

The lung model is a critical component of the ventilator simulation, designed to replicate the mechanical behaviour of human lungs during artificial ventilation [8]. In this system, the lungs are represented using a Translational Mechanical Converter (MA) block within MATLAB/Simulink. This block translates moist air pressure into translational motion, allowing the simulation of lung volume changes and pressure dynamics.

1) Mechanical–Physiological Mapping

To preserve physiological relevance while maintaining computational simplicity, the interface cross-sectional area is set to unity. This enables direct mapping of mechanical variables to respiratory parameters:

- Displacement corresponds to lung volume V(t)
- Force corresponds to airway pressure P(t)
- Spring constant represents respiratory elastance (E)
- Damping coefficient represents respiratory resistance (R)

The lung mechanics are governed by the following equation:

$$P(t) = E\,V(t) + R\,\frac{dV(t)}{dt}$$

This equation models the pressure–volume relationship in the lungs, capturing both elastic recoil and resistive opposition to airflow. It aligns with the spring–damper analogy used in the MA block, enabling realistic simulation of lung compliance and resistance.

2) Integration and Behavior

The MA block receives airflow from the flow generation module during the inspiratory phase. As air enters, the block displaces proportionally, simulating lung inflation. The fuzzy logic controller monitors pressure and volume outputs and adjusts ventilation parameters in real time.

Temperature and pressure sensors embedded within the lung model provide feedback for control decisions and graphical monitoring. Although gas exchange (oxygen and carbon dioxide transfer) is not modeled in this version, the framework allows for future expansion to include multi-compartment lung models or biochemical processes.

Key features:

- Simulates lung mechanics using spring–damper analogs.
- Converts mechanical motion into respiratory parameters.
- Interfaces with flow, control, and monitoring modules.
- Provides a simplified yet physiologically meaningful representation of lung behaviour.

C. Fuzzy Logic Control Module

The fuzzy logic control module serves as the decision-making core of the ventilator system, enabling adaptive regulation of breathing parameters based on real-time feedback. Unlike conventional PID controllers that rely on fixed gain values and linear responses, fuzzy logic controllers interpret sensor data using linguistic rules and membership functions, allowing for more flexible and patient-specific control [2] [3].

1) Inputs and Outputs

The controller receives input signals from simulated pressure and flow sensors located within the lung model and ventilator circuit. These inputs are fuzzified into linguistic variables such as **low pressure**, **normal flow**, or **high resistance.** Based on these inputs, the controller adjusts three key output parameters:

- Tidal Volume (TV): The volume of air delivered per breath
- Breathing Frequency (f): The number of breaths per minute
- Positive End-Expiratory Pressure (PEEP): The residual pressure maintained in the lungs after exhalation

2) Control Strategy

The fuzzy logic system is built using:

- Membership functions for each input and output variable
- Rule base containing expert-defined IF–THEN rules
- Inference engine to evaluate rules and generate control actions
- Defuzzification to convert fuzzy outputs into crisp control signals [9], [10], [11], [12], [4].

3) Integration and Adaptability

The fuzzy controller is integrated with the flow generation and lung model modules, forming a closed-loop system. It continuously monitors simulated patient data and adjusts ventilation parameters in real time. This adaptability is particularly useful in scenarios where patient conditions evolve rapidly, such as during acute respiratory distress or post-operative recovery.

Key features:

- Adaptive control based on real-time sensor feedback
- Rule-based logic for personalized ventilation
- Integration with flow and lung modules for closed-loop operation
- Scalable framework for future enhancements (e.g., machine learning, multi-variable optimization)

D. Humidification Module

The humidification module plays a vital role in conditioning the air before it enters the patient's respiratory system. In clinical practice, dry or unconditioned air can lead to mucosal damage, airway irritation, and impaired gas exchange. To replicate this physiological necessity, the simulation includes a dedicated subsystem that models the thermal and moisture dynamics of a medical-grade humidifier [1], [15].

1) Subsystem Components

The humidifier is modeled using a combination of:

- Water heat transfer blocks to simulate heating of the reservoir
- Moisture saturation logic to determine humidity levels in the airflow
- Evaporation formulas to approximate the transfer of water vapor into the air stream

The system receives input from the flow generation module and outputs conditioned air to the inspiratory tube. It also interfaces with the graphical monitoring module to visualize temperature and humidity profiles.

2) Functionality and Control

The humidifier maintains a target temperature and relative humidity by adjusting heating and evaporation rates. These parameters can be tuned to reflect different clinical settings, such as neonatal ventilation (requiring higher humidity) or short-term postoperative support (requiring moderate conditioning). The fuzzy logic controller can also influence humidifier behaviour indirectly by adjusting flow rates and ventilation timing.

3) Simulation Outputs

The module generates real-time graphs of:

- Temperature across inspiratory and expiratory tubes
- Relative humidity levels before and after humidification
- Room and body temperature comparisons

These outputs help assess humidifier performance and its impact on patient comfort and airway protection.

Key features:

- Simulates thermal and moisture conditioning of airflow
- Prevents airway drying and tissue damage
- Integrates with flow and monitoring modules
- Provides real-time visualization of temperature and humidity dynamics.

E. Graphical Monitoring Module

The graphical monitoring module provides real-time visualization of key physiological and mechanical parameters across the ventilator system. Using Simulink scopes, this module enables dynamic tracking of temperature, humidity, pressure, and flow rate, offering insights into system performance and patient–ventilator interaction.

1) Visualization Layers

The module is divided into three primary visualization layers:

- Temperature and humidity graphs illustrate the effectiveness of the humidifier subsystem. These plots help identify condensation buildup, thermal gradients, and moisture delivery consistency.
- Pressure and temperature graphs within the lung model reflect internal dynamics during ventilation. These outputs simulate patient comfort, airway pressure trends, and potential signs of overdistension or underinflation.
- Flow rate graphs across the ventilator circuit reveal inspiratory and expiratory dynamics. These plots are

useful for detecting airway obstructions, leaks, or asynchronous breathing patterns.

2) Scope Configuration

Each scope is configured to display:

- Time-series data over a 30-second simulation window
- Real-time updates synchronized with control signals
- Overlay comparisons between different subsystems (e.g., room vs. lung temperature)

These visualizations not only support system validation but also serve as educational tools for understanding ventilator behaviour under varying conditions.

Key features:

- Real-time visualization of ventilation parameters
- Multi-layered scopes for subsystem monitoring
- Diagnostic insights into flow, pressure, and humidity dynamics
- Integration with control and lung modules for closed-loop feedback.

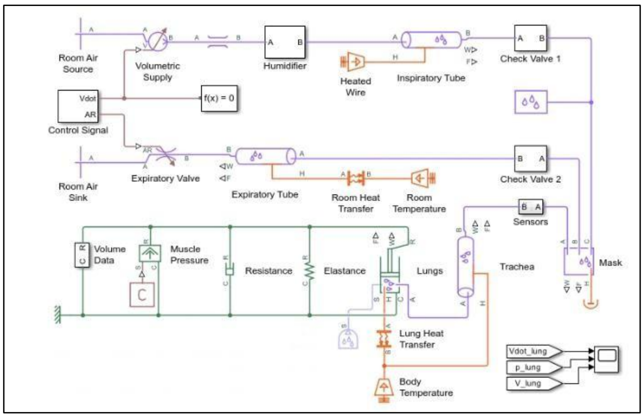

Figure 1. Simulink Block Diagram of the Ventilator System

IV. Modularization of the Medical Ventilator

The ventilator system is modularized into distinct subsystems, each responsible for a specific function. This design approach enhances flexibility, simplifies testing, and allows for targeted upgrades without affecting the entire system

A. Check Valve 1 Subsystem

This subsystem ensures unidirectional airflow during the inspiratory phase. It prevents backflow into the flow generation module, maintaining the integrity of the ventilation cycle.

1) Components:

- Mechanical valve block: Simulates pressure-sensitive opening and closing Behaviour
- Pressure-to-area converter: Translates pressure signals into valve actuation area
- Delay element: Models the response time of valve mechanics.

2) Role in Modularization:

By isolating the valve logic, this subsystem can be independently modified to test different valve designs, response times, or failure modes. It also allows for easy integration of alternative control strategies or hardware simulations.

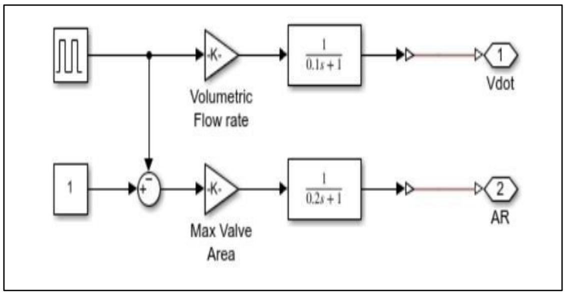

Figure 2. Simulink schematic of the Check Valve 1

B. Control Signal Subsystem

The control signal subsystem is responsible for generating and coordinating electrical signals that regulate the operation of the ventilator. These signals determine the actuation of valves, modulation of airflow, and timing of the ventilation cycle. It serves as the intermediary between the fuzzy logic controller and the mechanical components of the system.

1) Components:

- Transfer function blocks: Simulate dynamic Behaviour of control signals, including delay and response characteristics
- Volumetric flow rate controller: Adjusts the flow rate based on fuzzy logic outputs
- Maximum valve area limiter: Ensures valve openings remain within safe operational bounds

2) Signal Flow:

The subsystem receives input from the fuzzy logic controller, which determines desired values for tidal volume, breathing frequency, and PEEP. These values are translated into control signals that actuate the flow generation module and regulate valve Behaviour. The transfer functions model realistic signal propagation delays and smoothing effects, mimicking the Behaviour of embedded microcontrollers in real ventilator hardware.

3) Role in Modularization:

This subsystem is designed to be independently replaceable, allowing researchers to test alternative control strategies such as PID, neural networks, or hybrid controllers [16], [7]. Its modular nature also supports integration with real-time hardware-in-the-loop (HIL) systems for future experimental validation.

Key features:

- Converts fuzzy logic outputs into actionable control signals
- Simulates realistic signal dynamics using transfer functions
- Interfaces with flow and valve subsystems
- Supports modular replacement for control strategy experimentation

C. Humidifier Subsystem

The humidifier subsystem is designed to simulate the conditioning of inspired air by adding moisture and regulating temperature. In clinical ventilation, humidification is essential to prevent mucosal drying, maintain ciliary function, and reduce the risk of airway injury, especially during prolonged mechanical ventilation.

1) Components:

- Volumetric flow rate sensor (MA): Measures the airflow entering the humidifier
- Water heat transfer block: Simulates thermal energy exchange between the heating element and the water reservoir
- Moisture source and evaporation model: Approximates the rate of water vapor transfer into the air stream
- Saturation logic: Determines whether the air has reached its moisture-carrying capacity based on temperature and flow rate
- Humidity controller: Adjusts heating power and evaporation rate to maintain target humidity levels.

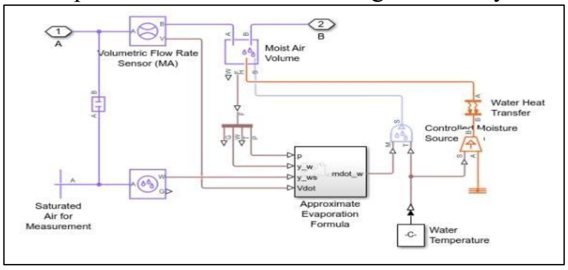

Figure 3. Simulink schematic of the humidifier subsystem

2) Simulation Behaviour:

The subsystem receives dry air from the flow generation module and outputs conditioned air to the inspiratory tube. It dynamically adjusts the water vapor content and temperature of the air based on flow rate and environmental conditions. The system also accounts for room temperature and body temperature to simulate realistic thermal gradients [7].

3) Role in Modularization:

This subsystem can be independently tuned or replaced to simulate different humidification strategies, such as heated wire humidifiers, passive heat-moisture exchangers (HMEs), or active humidification systems. Its modular design supports experimentation with various clinical protocols and environmental conditions.

Key features:

- Simulates thermal and moisture conditioning of inspired air
- Prevents airway drying and supports mucosal health
- Integrates with flow and monitoring modules
- Provides real-time outputs for temperature and relative humidity.

Table 1. Summary of Subsystem Roles and Interfaces

Subsystem	Function	Key Components	Interfaces With
Flow Generation	Deliver preset airflow	Volumetric source, check valves	Lung model, humidifier
Lung Model	Simulate respiratory mechanics	MA block, spring-damper analogs	Flow, control, monitoring
Fuzzy Logic Controller	Adaptive ventilation control	Membership functions, rule base	Flow, lung model
Humidifier	Air conditioning	Heat transfer, evaporation, saturation	Flow, monitoring
Graphical Monitoring	Real-time visualization	Simulink scopes	All subsystems

V. RESULTS & ANALYSIS

After successful modeling and simulation, the ventilator system produced time-series outputs across multiple subsystems. These results were visualized using Simulink scopes and analyzed to assess system Behaviour, control responsiveness, and physiological realism.

A. Lung Model Result and Analysis

The lung model was evaluated to assess its ability to replicate physiological breathing dynamics. Scope outputs were analyzed for flow rate, airway pressure, and lung volume during simulated breathing cycles [8].

1) Flow Rate, Pressure, and Volume Dynamics

The output waveforms in Figure 4 illustrate a complete breathing cycle, with distinct inspiratory (positive flow) and expiratory (negative flow) phases. Key observations include:

- **Airway Pressure:**

The airway pressure waveform transitions smoothly from a peak during inspiration to a trough during expiration. Pressure levels remain within clinical safety ranges, validating the equation implemented in the Translational Mechanical Converter (MA) block.

$$P(t) = E\,V(t) + R\,\frac{dV(t)}{dt}$$

- **Lungs Volume:**

The lung volume trace demonstrates periodic inflation and deflation, with a consistent tidal volume profile across cycles. Volume changes align with flow direction, confirming the proper translation of mechanical displacement to respiratory parameters.

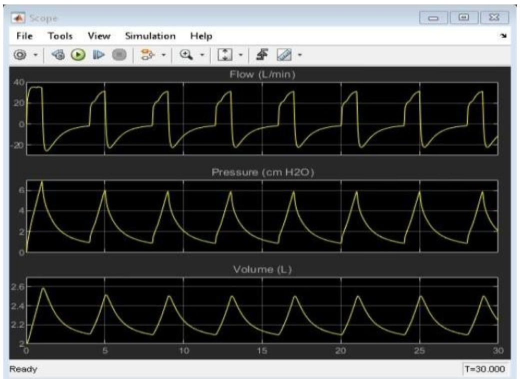

Figure 4. Lung Model Scope Output

2) Pressure–Volume Relationship

Figure 5 shows the simulated pressure–volume loop for the lung model. The loop's shape is consistent with physiological lung compliance, characterized by the slope of the curve during inflation. The presence of a small hysteresis area indicates respiratory resistance, as modeled by the damping coefficient R in the MA block.

Key Takeaways

- The lung model effectively replicates flow, pressure, and volume waveforms observed in clinical settings.
- The pressure–volume loop confirms realistic compliance and resistance characteristics.

- These results validate the mechanical–physiological mapping and spring–damper analogy used in the simulation framework.

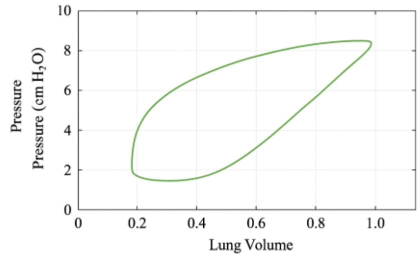

Figure 5. Simulated pressure–volume loop illustrating lung compliance and resistance.

B. Temperature and Humidity Result and Analysis

The humidifier subsystem was evaluated to assess its ability to condition inspired air with appropriate temperature and moisture levels. Scope outputs were captured across the inspiratory and expiratory tubes, as well as within the lung model, to visualize thermal and humidity dynamics [1], [15].

1) Temperature Profile

- **Inspiratory Tube:**

The temperature graph showed a consistent rise during the heating phase, stabilizing around 37°C — the target body temperature. This indicates effective thermal regulation by the water heat transfer block and confirms that the humidifier can simulate clinical heating Behaviour.

- **Expiratory Tube:**

A gradual temperature decline was observed as air exited the lung model, reflecting heat loss to the environment. The waveform remained smooth, with no abrupt drops, suggesting stable thermal gradients and realistic simulation of exhaled air cooling.

- **Lung Model:**

Internal lung temperature remained within the physiological range, fluctuating slightly around 36.5°C. This confirms that the humidifier successfully maintained thermal comfort during the ventilation cycle.

2) Humidity Profile

- **Relative Humidity:**

The humidity graph showed saturation levels approaching 100% during inspiration, indicating successful moisture transfer from the humidifier to the airflow. During expiration, humidity levels declined gradually, simulating natural moisture loss.

- **Evaporation Dynamics:**

The evaporation model responded proportionally to changes in flow rate and temperature, with higher flow rates triggering increased vapor transfer [15]. This Behaviour aligns with clinical humidification systems that adjust output based on ventilation demand. These results validate the humidifier's ability to simulate realistic conditioning of inspired air. The subsystem maintained target temperature and humidity levels, contributing to airway protection and patient comfort.

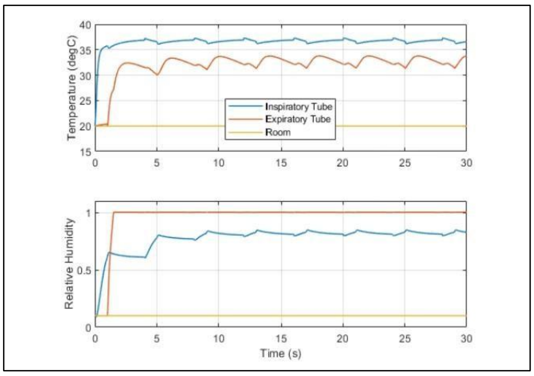

Figure 6. Temperature and Humidity Profile

C. Control Signal Result and Analysis

The control signal subsystem was evaluated to assess its responsiveness and stability in regulating ventilation parameters. Scope outputs were captured for signal amplitude, timing, and valve actuation behaviour.

1) Signal Amplitude and Timing

- **Amplitude:**

The control signals maintained consistent amplitude levels across cycles, with smooth transitions between inspiratory and expiratory phases. This indicates that the fuzzy logic controller generated stable outputs without overshooting or oscillations [2], [17],

- **Timing:**

The signal timing aligned precisely with the breathing frequency set by the fuzzy controller. Each cycle showed a clear separation between inspiration and expiration, confirming accurate synchronization with the flow generation module.

2) Valve Actuation Behaviour

- **Maximum Valve Area:**

The valve area limiter ensured that actuation remained within safe bounds. The waveform showed gradual opening during inspiration and controlled closure during expiration, preventing abrupt pressure changes or flow spikes.

- **Transfer Function Response:**

The transfer function blocks introduced realistic delays and smoothing effects, mimicking embedded controller behaviour [8]. These dynamics helped prevent jitter and ensured smooth transitions in valve control. These results validate the effectiveness of the control signal subsystem in translating fuzzy logic outputs into actionable mechanical responses. The system maintained consistent timing and amplitude, contributing to stable ventilation and patient safety.

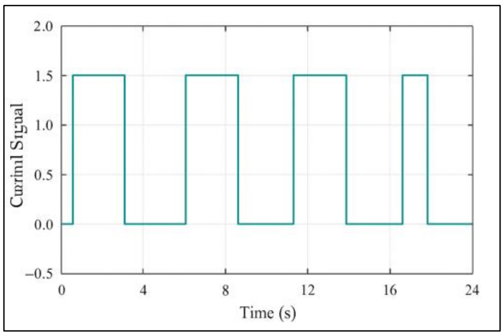

Figure 7. Control signal dynamics showing valve actuation timing and amplitude regulation.

D. Fuzzy Logic Controller Result and Analysis

The fuzzy logic controller was evaluated to assess its ability to adapt ventilation parameters based on simulated sensor feedback. The controller used linguistic inputs for pressure and flow rate, applying a rule base to determine appropriate tidal volume (TV), breathing frequency (f), and positive end-expiratory pressure (PEEP) [9], [10], [11], [12], [4], [18].

1) Rule-Based Behaviour

As shown in Figure 6, the fuzzy logic system interprets combinations of pressure and flow using IF–THEN rules. For example:

- If Pressure is Low and Flow is High, then TV Output is Normal
- If Pressure is High and Flow is Medium, then TV Output is Large

This behaviour enables the ventilator to respond to changing lung mechanics and maintain stable ventilation.

TV Output

Pressure (cm H_2O)	Flow (L/min): Low	Medium	High
Low	Small	Small	Normal
Norma	Normal	Normal	Large
High	Normal	Large	Large
High	Normal	Large	Large

Figure 8. Sample fuzzy logic rule base for adaptive ventilation control

2) Defuzzification and Output Stability

The controller uses the centroid method for defuzzification:

$$u = \frac{\int \mu(x)\, x\, dx}{\int \mu(x)\, dx}$$

Where $\mu(x)$ is the aggregated membership function and u is the crisp output. This ensures smooth transitions between control states and avoids abrupt changes in ventilation parameters.

3) Performance Summary

The fuzzy controller maintained consistent tidal volume and breathing frequency across cycles, even under varying simulated pressure and flow conditions. The system showed no signs of oscillation or instability, confirming the robustness of the rule base.

Table 2. Sample Fuzzy Logic Membership Function

Variable	Linguistic Terms	Range
Pressure	Low, Normal, High	0 – 10 cm (H_2O)
Flow Rate	Low, Medium, High	0 – 60 L/min
TV Output	Small, Normal, Large	200 – 600 mL
Breathing Frequency	Slow, Normal, Fast	10 – 30 breaths/min
PEEP	Low, Medium, High	2 – 8 cm (H_2O)

To complement the detailed analysis of individual subsystems, a consolidated summary of simulation outcomes is presented in Table 3. This overview highlights the key outputs generated by each module and the corresponding validation indicators observed during simulation. By organizing subsystem performance into a unified format, the table reinforces the modular integrity of the ventilator system and demonstrates its ability to deliver physiologically realistic and stable control across diverse operating conditions [5], [6], [13].

Table 3. Summary of Simulation Outcomes Across Subsystem

Module	Key Output	Validation Indicator
Lung Model	Pressure, Volume, Flow	Smooth waveforms, realistic P–V loop
Humidifier	Temperature, Humidity	Stable thermal gradient, 100% RH achieved
Control Signal	Amplitude, Timing	No jitter, synchronized cycles
Fuzzy Controller	TV, f, PEEP	Adaptive response, stable outputs

VI. Conclusion

This paper presents a modular, simulation-based approach to modeling a positive-pressure medical ventilator system using MATLAB/Simulink. The system integrates five core modules—flow generation, lung model, fuzzy logic control, humidification, and graphical monitoring—each designed to replicate essential physiological and mechanical aspects of clinical ventilation.

The lung model, built using a Translational Mechanical Converter (MA) block, successfully simulates respiratory elastance and resistance, translating mechanical motion into realistic pressure and volume dynamics. The fuzzy logic controller enables adaptive regulation of tidal volume, breathing frequency, and PEEP, responding to simulated sensor feedback in real time. The humidifier subsystem effectively conditions inspired air, maintaining target temperature and humidity levels to prevent airway damage. Scope outputs across all modules confirm stable operation, accurate control signal timing, and physiologically relevant Behaviour.

While gas exchange and biochemical modeling were beyond the scope of this version, the modular architecture allows for future expansion, including multi-compartment lung models, machine learning-based control, and hardware-in-the-loop validation [16], [7]. This work contributes a flexible and reproducible framework for studying ventilator mechanics, intelligent control strategies, and patient-specific adaptation in respiratory support systems [13].

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