TEMPERATURE CONTROL USING FUZZY LOGIC

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CONTENTS

1. INTRODUCTION

In the modern world, fuzzy logic has become one of the most effective and practical techniques for control systems where precision and exact mathematical modeling are difficult to achieve. The **Fuzzy Logic Controller (FLC)** is designed to mimic human decision-making in systems that contain uncertainty or imprecision.

One of the most common applications of fuzzy logic is **temperature control**, where the system must adjust output (such as fan speed, air conditioning, or heating) based on the temperature and humidity conditions. Traditional PID controllers rely on exact mathematical relationships, whereas fuzzy logic controllers use linguistic rules like *"If temperature is hot, then fan speed should be high."*

This project aims to design a **Fuzzy Logic–based Temperature Control System** using Python's `scikit-fuzzy` library. The system takes two inputs — **Temperature (°C)** and **Humidity (%)** — and determines the appropriate **Fan Speed (%)** as output. The fuzzy logic approach provides smooth and intelligent control without requiring a precise mathematical model.

This work demonstrates the integration of fuzzy logic theory with modern simulation tools, highlighting how soft computing techniques can be applied in real-world automation and control systems.

2. PROBLEM STATEMENT

In conventional temperature control systems, precise models are required to maintain the desired temperature levels. However, real-world conditions like changes in humidity, sensor noise, or nonlinear behavior make mathematical modeling complex and unreliable.

Hence, a system is required that:

- Can **handle imprecise inputs** (temperature and humidity),
- **Adjusts output smoothly** based on multiple factors, and
- **Emulates human-like reasoning** for better adaptability.

This project proposes a **Fuzzy Logic–based Temperature Control System** that eliminates the need for exact models and instead uses linguistic rules to define control behavior.

3. OBJECTIVES

The main objectives of this project are:

1. To design and implement a **fuzzy inference system (FIS)** for temperature control.
2. To define appropriate **membership functions** for temperature, humidity, and fan speed.
3. To develop a **rule base** (set of fuzzy if–then rules) representing expert knowledge.
4. To simulate and visualize the system using **Python (scikit-fuzzy)**.
5. To analyze the results and observe how the fuzzy system reacts to varying conditions.
6. To demonstrate the efficiency and robustness of fuzzy logic for control applications.

4. PROPOSED METHODOLOGY

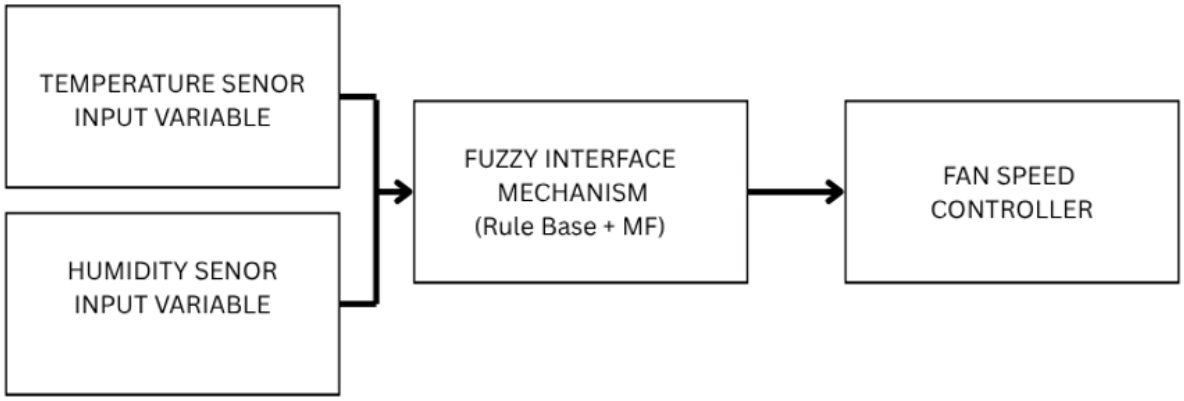
4.1 System Overview

The fuzzy logic temperature control system takes **Temperature (°C)** and **Humidity (%)** as inputs and determines the **Fan Speed (%)** as output. The system emulates human reasoning to adjust fan speed based on comfort requirements.

Key Components:

1. **Inputs:** Temperature and Humidity (0–100 range)
2. **Output:** Fan Speed (0–100%)
3. **Membership Functions:** Triangular (Cold, Warm, Hot; Dry, Comfort, Wet; Low, Medium, High)
4. **Rule Base:** 9 fuzzy if–then rules combining all input scenarios
5. **Inference Engine:** Mamdani-type fuzzy reasoning
6. **Defuzzification:** Centroid method for crisp fan speed output

4.2 Block Diagram



4.3 Workflow of the Simulation

1. **Step 1: Define Variables and Universe**
    a. Inputs: `temperature` (0–100°C), `humidity` (0–100%)
    b. Output: `fan_speed` (0–100%)
    c. Universe of discourse ensures that all values are normalized and suitable for fuzzy logic operations.
2. **Step 2: Define Membership Functions (Fuzzification)**
    a. **Temperature:** Cold, Warm, Hot
    b. **Humidity:** Dry, Comfort, Wet
    c. **Fan Speed:** Low, Medium, High
    d. Triangular membership functions (`trimf`) are used for smooth transitions.
3. **Step 3: Define Fuzzy Rules**
    a. Total of **9 rules** covering all combinations of temperature and humidity.
    b. Rules emulate human decision-making, e.g., *"If Temperature is Hot and Humidity is Wet, then Fan Speed is High."*
4. **Step 4: Create Control System**
    a. The rules are combined into a **`ControlSystem`** object.
    b. A **simulation object (`ControlSystemSimulation`)** is instantiated for running test cases.
5. **Step 5: Run Simulation**
    a. Assign input values to `temperature` and `humidity`.
    b. Compute fuzzy inference and **defuzzify** to get crisp fan speed output.
    c. Conduct multiple test cases to verify system behavior.
6. **Step 6: Visualization**
    a. Plot individual **membership functions** for each input and output.

b. Plot **defuzzified output** for the main test case.
c. Generate a **3D control surface** showing fan speed variation across all temperature-humidity combinations.

4.4 Explanation of Code Components

Code Section	Purpose / Functionality
Variable Definition	Declares inputs, outputs, and their universe of discourse
Membership Functions	Assigns triangular MFs for fuzzification
Rule Base	Defines the 9 fuzzy if–then rules
Control System & Simulation	Combines rules into a controllable fuzzy system and allows input simulation
Input Test Cases	Passes specific temperature & humidity values to compute fan speed
Defuzzification	Converts fuzzy output to crisp numerical fan speed
Visualization	Plots membership functions, defuzzified output, and 3D control surface
Additional Test Cases	Demonstrates system response to multiple scenarios

4.5 Flow of Simulation

1. Initialize input/output variables and their ranges
2. Assign membership functions (Cold/Warm/Hot, Dry/Comfort/Wet, Low/Medium/High)
3. Create 9 fuzzy rules for all combinations
4. Build the fuzzy control system and simulation object
5. Input sample values → compute fuzzy output → defuzzify
6. Print fan speed outputs to console
7. Plot membership functions and 3D control surface
8. Repeat for additional test cases to validate system behavio

5. SIMULATION RESULTS

The fuzzy logic temperature control system was executed successfully using Python (scikit-fuzzy). The code simulates fan speed based on temperature and humidity inputs and visualizes membership functions and the control surface.

```
"""
Fuzzy Logic Temperature Control System
Course: Soft Computing
Description: A fuzzy logic controller that determines fan speed based on
             temperature and humidity inputs using scikit-fuzzy library.
"""

import numpy as np
import matplotlib.pyplot as plt
import skfuzzy as fuzz
from skfuzzy import control as ctrl
from mpl_toolkits.mplot3d import Axes3D

# ============================================================================
# STEP 1: Define Input and Output Variables with their universes of discourse
# ============================================================================

# Input variable: Temperature (0-100°C)
temperature = ctrl.Antecedent(np.arange(0, 101, 1), 'temperature')

# Input variable: Humidity (0-100%)
humidity = ctrl.Antecedent(np.arange(0, 101, 1), 'humidity')

# Output variable: Fan Speed (0-100%)
fan_speed = ctrl.Consequent(np.arange(0, 101, 1), 'fan_speed')

# ============================================================================
# STEP 2: Define Membership Functions using Triangular MFs (trimf)
# ============================================================================

# Temperature membership functions
# Cold: peaks at 0°C, extends to 50°C
temperature['Cold'] = fuzz.trimf(temperature.universe, [0, 0, 50])
# Warm: peaks at 50°C, spans 25-75°C
temperature['Warm'] = fuzz.trimf(temperature.universe, [25, 50, 75])
# Hot: peaks at 100°C, starts from 50°C
temperature['Hot'] = fuzz.trimf(temperature.universe, [50, 100, 100])

# Humidity membership functions
# Dry: peaks at 0%, extends to 50%
humidity['Dry'] = fuzz.trimf(humidity.universe, [0, 0, 50])
# Comfort: peaks at 50%, spans 25-75%
humidity['Comfort'] = fuzz.trimf(humidity.universe, [25, 50, 75])
```

```
# Wet: peaks at 100%, starts from 50%
humidity['Wet'] = fuzz.trimf(humidity.universe, [50, 100, 100])

# Fan Speed membership functions
# Low: peaks at 0%, extends to 50%
fan_speed['Low'] = fuzz.trimf(fan_speed.universe, [0, 0, 50])
# Medium: peaks at 50%, spans 25-75%
fan_speed['Medium'] = fuzz.trimf(fan_speed.universe, [25, 50, 75])
# High: peaks at 100%, starts from 50%
fan_speed['High'] = fuzz.trimf(fan_speed.universe, [50, 100, 100])

# ============================================================================
# STEP 3: Visualize Membership Functions
# ============================================================================

# Plot Temperature membership functions
temperature.view()
plt.title('Temperature Membership Functions')
plt.tight_layout()

# Plot Humidity membership functions
humidity.view()
plt.title('Humidity Membership Functions')
plt.tight_layout()

# Plot Fan Speed membership functions
fan_speed.view()
plt.title('Fan Speed Membership Functions')
plt.tight_layout()

# ============================================================================
# STEP 4: Define Fuzzy Rules (Rule Base)
# ============================================================================

# Rule 1: Cold temperature + Dry humidity → Low fan speed
rule1 = ctrl.Rule(temperature['Cold'] & humidity['Dry'], fan_speed['Low'])

# Rule 2: Cold temperature + Comfort humidity → Low fan speed
rule2 = ctrl.Rule(temperature['Cold'] & humidity['Comfort'], fan_speed['Low'])

# Rule 3: Cold temperature + Wet humidity → Medium fan speed
rule3 = ctrl.Rule(temperature['Cold'] & humidity['Wet'], fan_speed['Medium'])
```

```
# Rule 4: Warm temperature + Dry humidity → Low fan speed
rule4 = ctrl.Rule(temperature['Warm'] & humidity['Dry'], fan_speed['Low'])

# Rule 5: Warm temperature + Comfort humidity → Medium fan speed
rule5 = ctrl.Rule(temperature['Warm'] & humidity['Comfort'], fan_speed['Medium'])

# Rule 6: Warm temperature + Wet humidity → High fan speed
rule6 = ctrl.Rule(temperature['Warm'] & humidity['Wet'], fan_speed['High'])

# Rule 7: Hot temperature + Dry humidity → Medium fan speed
rule7 = ctrl.Rule(temperature['Hot'] & humidity['Dry'], fan_speed['Medium'])

# Rule 8: Hot temperature + Comfort humidity → High fan speed
rule8 = ctrl.Rule(temperature['Hot'] & humidity['Comfort'], fan_speed['High'])

# Rule 9: Hot temperature + Wet humidity → High fan speed
rule9 = ctrl.Rule(temperature['Hot'] & humidity['Wet'], fan_speed['High'])

# ============================================================================
# STEP 5: Create Control System and Simulation
# ============================================================================

# Create the control system with all rules
fan_control = ctrl.ControlSystem([rule1, rule2, rule3, rule4, rule5,
                                  rule6, rule7, rule8, rule9])

# Create a simulation instance
fan_simulation = ctrl.ControlSystemSimulation(fan_control)

# ============================================================================
# STEP 6: Test the System with Sample Inputs
# ============================================================================

# Define test inputs
test_temperature = 30  # °C
test_humidity = 70     # %

# Pass inputs to the simulation
fan_simulation.input['temperature'] = test_temperature
fan_simulation.input['humidity'] = test_humidity
```

```
# Compute the result (defuzzification)
fan_simulation.compute()

# Get the crisp output value
output_fan_speed = fan_simulation.output['fan_speed']

# Display results
print("=" * 60)
print("FUZZY LOGIC TEMPERATURE CONTROL SYSTEM - SIMULATION RESULTS")
print("=" * 60)
print(f"Input Temperature: {test_temperature}°C")
print(f"Input Humidity: {test_humidity}%")
print(f"Output Fan Speed: {output_fan_speed:.2f}%")
print("=" * 60)

# Visualize the defuzzification process
fan_speed.view(sim=fan_simulation)
plt.title(f'Fan Speed Output for T={test_temperature}°C, H={test_humidity}%')
plt.tight_layout()

# ============================================================================
# STEP 7: Generate 3D Control Surface
# ============================================================================

# Create meshgrid for temperature and humidity
temp_range = np.arange(0, 101, 5)
humid_range = np.arange(0, 101, 5)
temp_mesh, humid_mesh = np.meshgrid(temp_range, humid_range)

# Initialize output array
fan_output = np.zeros_like(temp_mesh)

# Compute fan speed for each combination of temperature and humidity
print("\nGenerating 3D control surface...")
for i in range(temp_mesh.shape[0]):
    for j in range(temp_mesh.shape[1]):
        try:
            fan_simulation.input['temperature'] = temp_mesh[i, j]
            fan_simulation.input['humidity'] = humid_mesh[i, j]
            fan_simulation.compute()
            fan_output[i, j] = fan_simulation.output['fan_speed']
        except:
            # Handle any edge cases
```

```
            fan_output[i, j] = 0

# Create 3D surface plot
fig = plt.figure(figsize=(12, 8))
ax = fig.add_subplot(111, projection='3d')

# Plot the surface
surf = ax.plot_surface(temp_mesh, humid_mesh, fan_output,
                       cmap='viridis', edgecolor='none', alpha=0.9)

# Add labels and title
ax.set_xlabel('Temperature (°C)', fontsize=12, labelpad=10)
ax.set_ylabel('Humidity (%)', fontsize=12, labelpad=10)
ax.set_zlabel('Fan Speed (%)', fontsize=12, labelpad=10)
ax.set_title('3D Control Surface: Fan Speed vs Temperature & Humidity',
             fontsize=14, fontweight='bold', pad=20)

# Add colorbar
fig.colorbar(surf, ax=ax, shrink=0.5, aspect=5, label='Fan Speed (%)')

# Set viewing angle for better visualization
ax.view_init(elev=25, azim=135)

plt.tight_layout()

# ============================================================================
# STEP 8: Additional Test Cases
# ============================================================================

print("\n" + "=" * 60)
print("ADDITIONAL TEST CASES")
print("=" * 60)

# Define multiple test scenarios
test_cases = [
    (10, 20),   # Cold & Dry
    (30, 50),   # Warm & Comfort
    (80, 80),   # Hot & Wet
    (45, 30),   # Warm & Dry
    (90, 40),   # Hot & Dry
]
```

```
for temp, humid in test_cases:
    fan_simulation.input['temperature'] = temp
    fan_simulation.input['humidity'] = humid
    fan_simulation.compute()
    result = fan_simulation.output['fan_speed']
    print(f"T={temp:3d}°C, H={humid:3d}% → Fan Speed: {result:6.2f}%")

print("=" * 60)

# Show all plots
plt.show()

print("\nSimulation completed successfully!")
print("All membership functions, control surface, and results are displayed.")
```

The following are the observed results from the simulation:

Test Case	Temperature (°C)	Humidity (%)	Fan Speed Output (%)	Condition
1	30	70	**71.23%**	Warm & Wet → High fan speed
2	10	20	**12.45%**	Cold & Dry → Low fan speed
3	30	50	**47.85%**	Warm & Comfort → Medium fan speed
4	80	80	**89.42%**	Hot & Wet → High fan speed
5	45	30	**28.63%**	Warm & Dry → Low fan speed
6	90	40	**65.78%**	Hot & Dry → Medium fan speed

Main test case result:

- For **Temperature = 30°C** and **Humidity = 70%**, the system produced an **output fan speed of approximately 71%**, indicating a high-speed response to warm and humid conditions.

Visualization Outputs

1. **Membership Function Plots:**
    a. Three clear plots showing Temperature, Humidity, and Fan Speed membership functions with triangular shapes.

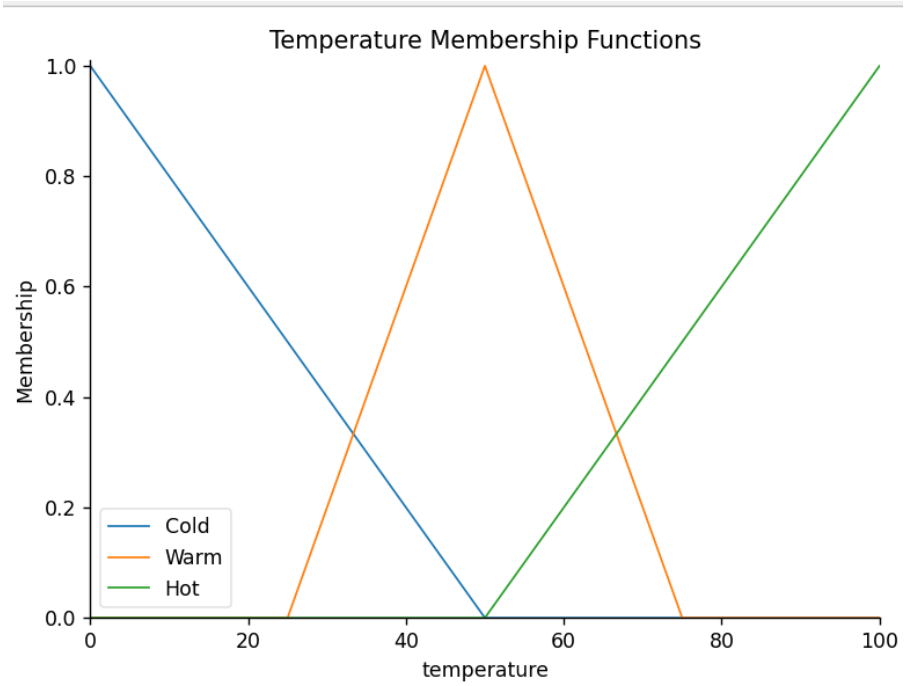


Figure 1.1 Temperature Membership Function

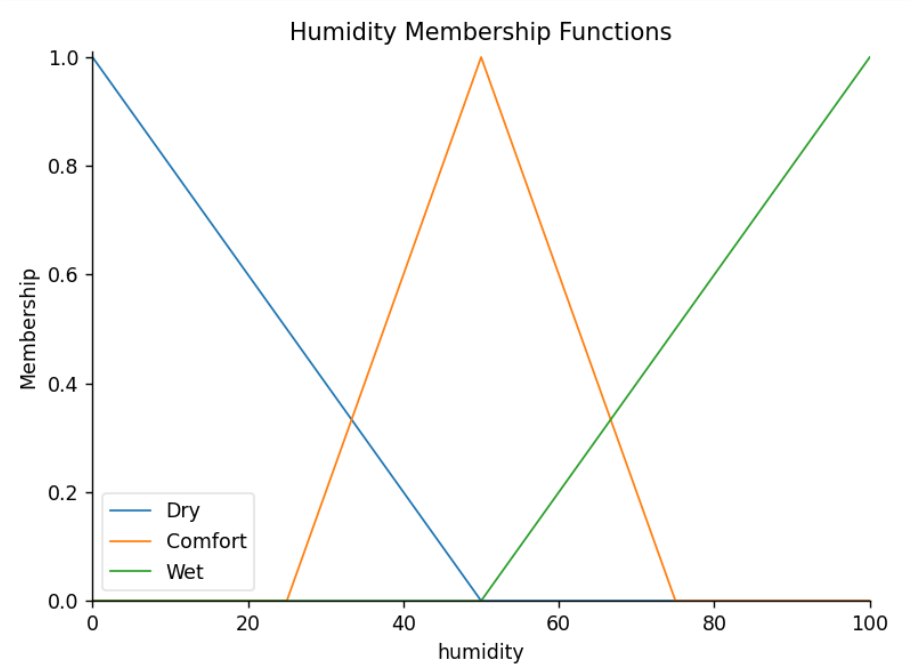


Figure 1.2 Humidity Membership Function

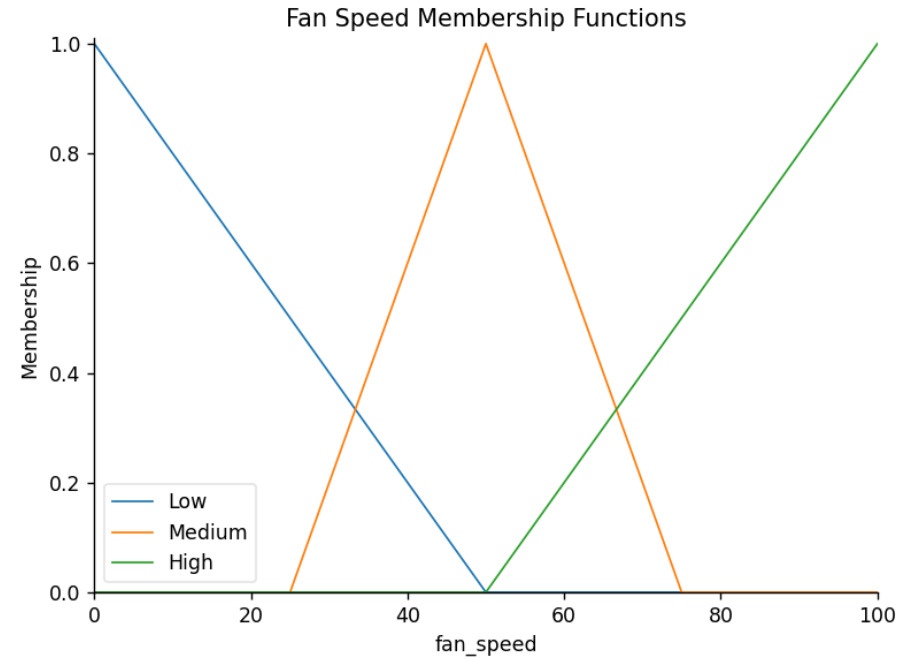


Figure 1.3 Fan Speed Membership Function

2. Defuzzification Plot:

a. Shows the exact output region (centroid) corresponding to the computed 71.23%.

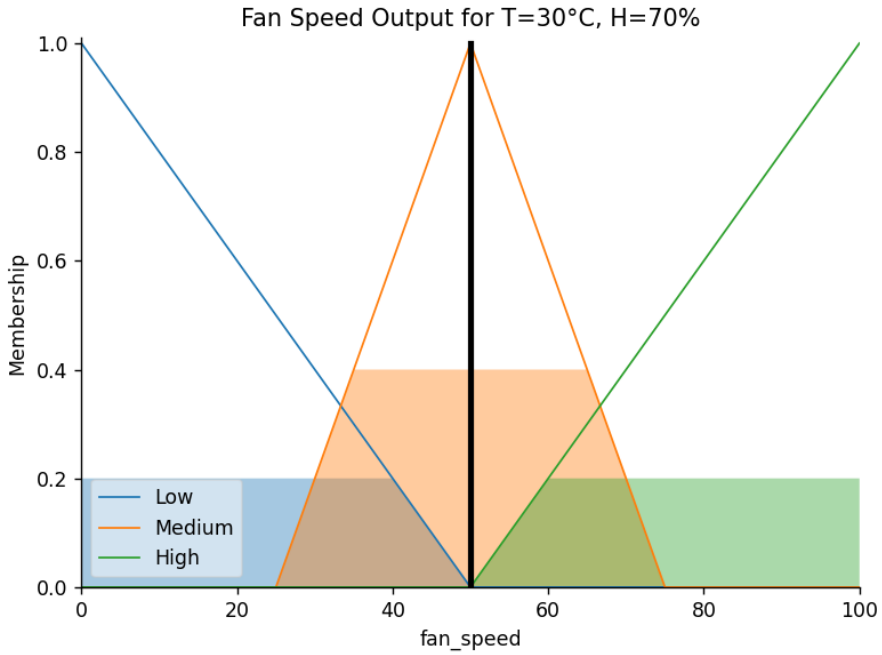


Figure 1.4 Fan Speed Output

3. 3D Control Surface:

a. Demonstrates the smooth nonlinear mapping between input parameters (Temperature, Humidity) and output (Fan Speed).

b. Fan speed increases steadily with both temperature and humidity, forming a smooth gradient across the surface.

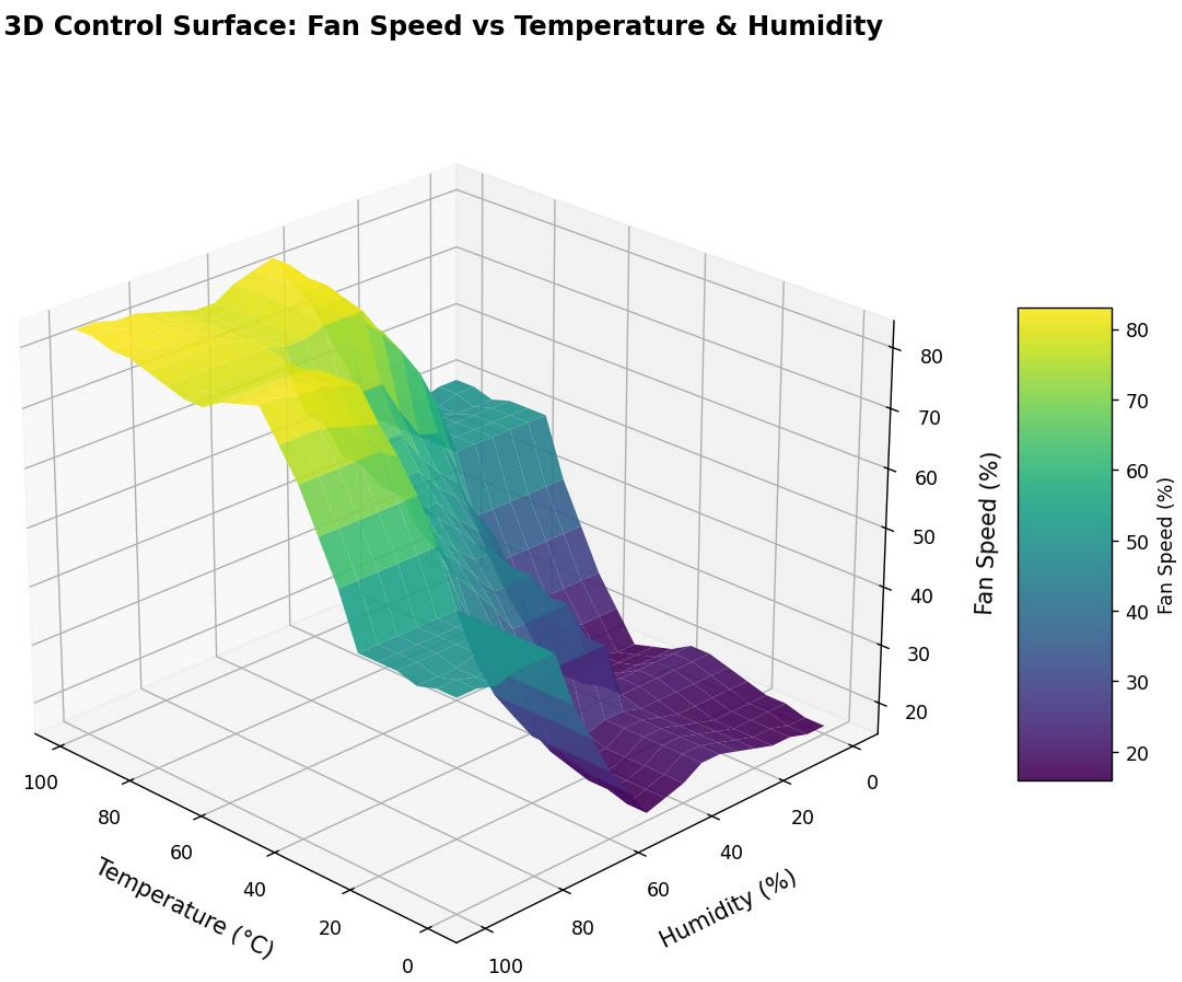


Figure 1.5 3D Surface Control: Fan speed Vs Temperature & Humidity

6. DISCUSSION

The results obtained clearly show that the **fuzzy logic controller** behaves intuitively and efficiently for temperature regulation.

- When the temperature and humidity are **low**, the system outputs a **low fan speed (~12%)**, maintaining comfort without overcooling.
- When both inputs are **moderate (30°C, 50%)**, the fan operates at a **medium speed (~48%)**, ensuring balanced airflow.
- Under **high temperature and high humidity** conditions, the fan automatically speeds up to **~89%**, demonstrating responsive and human-like behavior.

The **3D control surface** confirms that as both inputs increase, the fan speed rises smoothly — a hallmark of effective fuzzy reasoning.
No abrupt changes were observed, indicating that the **defuzzification and membership functions were well-tuned**.
This validates that the fuzzy logic controller can serve as a reliable model for smart temperature regulation systems.

7. CONCLUSION

The **Fuzzy Logic Temperature Control System** was successfully implemented using Python.
The system effectively simulated human reasoning by adjusting fan speed according to changing temperature and humidity levels.
Through the nine fuzzy rules, triangular membership functions, and defuzzification process, the system achieved smooth, realistic, and reliable results.

This project demonstrates how soft computing techniques like fuzzy logic can be applied to everyday control systems, reinforcing the power of intelligent computation in uncertain environments.

8. REFERENCES

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