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Smart Temperature Regulation using Fuzzy Logic Controller (FLC)

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Abstract- Achieving efficient and stable temperature regulation remains a challenge for both industrial and domestic applications, especially where conventional PID control methods require precise modelling and struggle with nonlinear or uncertain systems. This paper presents a fuzzy logic–based temperature control system that improves performance by mimicking human decision-making. By using temperature error and change in error as input variables and processing them with linguistic rules, the proposed controller effectively manages uncertainties to achieve smoother, more reliable control. Simulation and experimental data confirm that this fuzzy controller reduces overshoot, provides faster responses, and enhances stability compared to traditional methods. Its design shows clear potential for use in industrial heating, smart homes, and thermal management.

Keywords- Fuzzy Logic Control, Temperature Regulation, Nonlinear Systems, Intelligent Control Systems, Error and Change in Error.

I. INTRODUCTION

Many industrial operations, such as thermal power systems, chemical processing, semiconductor production, and HVAC applications, depend on accurate temperature regulation. Precise control is difficult in these systems because they frequently display nonlinear dynamics, time-varying characteristics, and external disturbances. Because of their straightforward design and ease of use, conventional control strategies—in particular, proportional-integral-derivative (PID) controllers—are extensively used. However, they may have drawbacks, including overshoot, oscillations, and diminished robustness under unpredictable operating conditions, and their effectiveness heavily relies on precise mathematical modelling and parameter tweaking.

Intelligent control methods have been investigated more and more to get around these restrictions. Among these, Lotfi A. Zadeh's fuzzy logic control (FLC) offers a useful framework for managing nonlinearities and system uncertainties without the need for an explicit mathematical model. Based on approximation reasoning, FLC maps input variables to control actions using linguistic variables, membership functions, and a rule-based inference mechanism.

Temperature error (e) and change in error (Δe) are the two input variables used to build the control strategy in a conventional fuzzy logic-based temperature management system. A fuzzification interface is used to process these inputs, converting crisp numerical values into fuzzy sets with predetermined membership functions. An inference engine, usually based on Mamdani or Sugeno methods, is then used to analyse a rule base made up of expert-defined IF-THEN rules. After that, a defuzzification procedure—typically the centroid method—is used to transform the fuzzy output into a clear control signal.

The capacity of the suggested fuzzy controller to deliver reliable and flexible control performance in the face of nonlinearities and uncertainties is its main advantage. Compared to classical controllers, it guarantees better transient response, less steady-state error, and smoother control action. The design and implementation of a fuzzy logic-based temperature management system are the main topics of this study, with particular attention paid to the creation of membership functions, rule base optimisation, and performance assessment.

Objectives

To create a fuzzy logic-based temperature management system that doesn't require a precise mathematical model in order to regulate temperature in nonlinear and uncertain contexts.

- To provide suitable input and output variables, namely temperature error (e) and change in error (Δe), and to specify the membership functions that correspond to them for efficient fuzzification.
- To create an optimum rule foundation made up of IF-THEN language rules that guarantee stable system behaviour and appropriately describe the control approach.
- To put into practice an inference method for handling fuzzy inputs and producing appropriate control actions.
- To obtain an accurate control signal for the actuator by performing defuzzification utilizing techniques such as the centroid technique.
- To evaluate the system's performance using important metrics like rising time, settling time, overshoot, and steady-state error.

II. METHODOLOGY

A Fuzzy Logic Controller (FLC) is used in the design of the suggested temperature control system to modify the control input (heater/fan) and control the output temperature. The process includes rule-based inference, fuzzification, defuzzification, and mathematical formulation of input variables.

Error Calculation and System Modelling

Maintaining the system temperature at the intended setpoint T is the control goal. The fuzzy controller's input variables are:
Error (e):

T−T(t) = e(t)
Error Change (Δe):
Δe(t) = e(t)−e(t−1)

The system deviance and its dynamic behaviour are represented by these two variables.

Fuzzification

The crisp inputs e(t)and Δe(t)are converted into fuzzy linguistic variables using membership functions.
Typical linguistic terms:

- Negative Large (NL) Negative Small (NS)
- Zero (Z)
- Positive Small (PS)
- Positive Large (PL)

Each membership function maps the input to a degree of belonging in the range $[0,1]$

$$\mu_A(x): X \to [0,1]$$

where $\mu_A(x)$represents the membership degree of the input xin fuzzy set A.
Construction of Rule Bases
A series of IF-THEN rules are used to describe the control strategy:
Example guidelines:

The output is high if e is PL and Δe is PS,
medium if e is Z,
and low if e is NL.

Depending on the permutations of inputs, a matrix representation of the rule base is possible.

Defuzzification

The aggregated fuzzy output is converted into a crisp control signal using the centroid (center of gravity) method:

$$u = \frac{\int y \cdot \mu_{out}(y)\, dy}{\int \mu_{out}(y)\, dy}$$

where:

u= control output (heater power)
$\mu_{out}(y)$= aggregated membership function

Control Signal Application

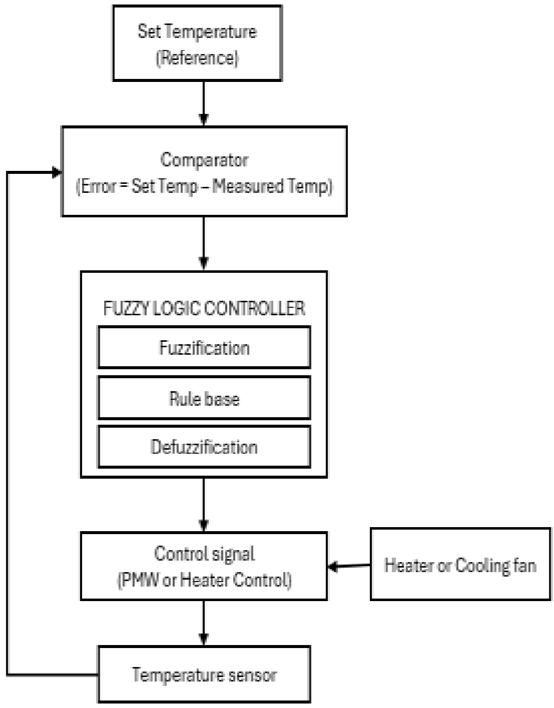
The defuzzified output u(t)is applied to the actuator (heater or cooling fan), which adjusts the system temperature. The process operates in a closed-loop manner:

$$T(t+1) = f\big(T(t), u(t)\big)$$

where f(·)represents the system dynamics.
Performance Evaluation
The system performance is evaluated using standard time-domain specifications:

- Rise Time (t_r)
- Settling Time (t_s)
- Overshoot (M_p)
- Steady-State Error (e_{ss})

BLOCK DIAGRAM

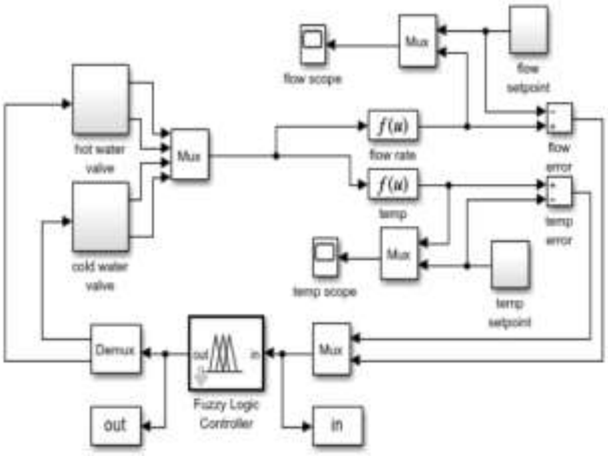


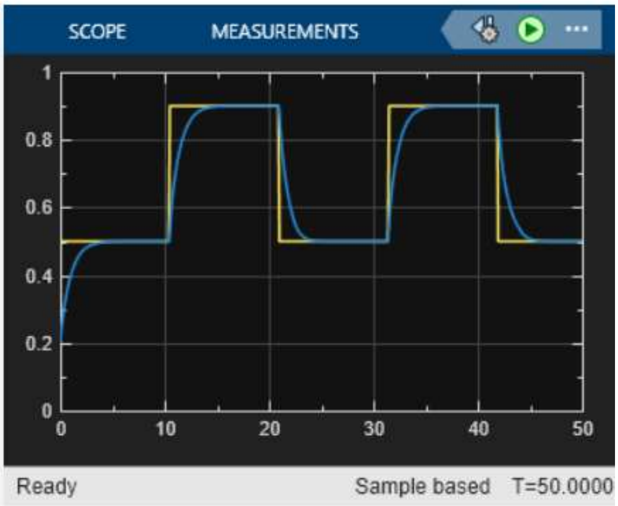
- The fuzzy logic controller, actuator, and temperature sensor make up the system.
- An error signal is produced by comparing the measured temperature with the reference temperature.
- The fuzzy logic controller processes this error and produces a control signal.
- To control temperature, the heating or cooling element is driven by the control signal.
- Continuous temperature monitoring and adjustment are made possible by a feedback loop.

III. MATLAB SIMULATIONS

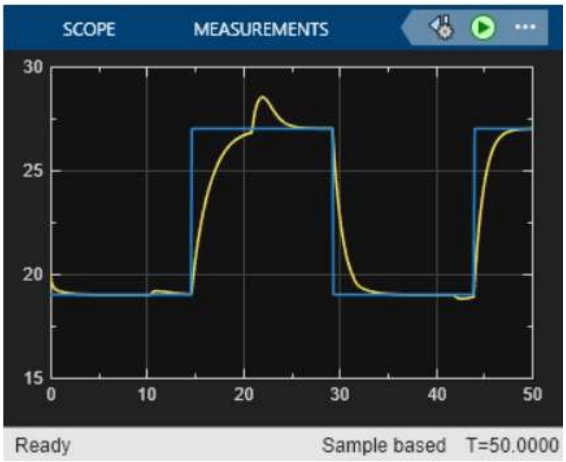
With this arrangement, hot and cold water valves allow you to regulate the shower's temperature and flow rate.

The model uses a Mux block to concatenate the input signals because the fuzzy system has two inputs. The input of the Fuzzy Logic Controller block is linked to the output of the Mux block. In a similar manner, a Demux block attached to the controller is used to retrieve the two output signals.





View the temperature simulation results. There are temperature deviations when the controller adjusts to meet a new flow setpoint.



IV. RESULTS AND DISCUSSION

When tracking the intended temperature setpoint, the fuzzy logic controller (FLC) exhibits a steady and fluid reaction. With little fluctuations, the output temperature progressively increases to the setpoint

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Important findings:

- Adaptive control action allows the system to attain a fast rising time.
- When compared to traditional techniques, overshoot is much decreased.
- There is very little steady-state inaccuracy in the answer.
- Even with minor disruptions, the system maintains its stability.

Discussion

The FLC's enhanced performance allows it to successfully manage uncertainties and nonlinearities. The fuzzy controller dynamically modifies the control action in response to system variables, in contrast to PID controllers that depend on set gain parameters.

Smoother transitions between control states are made possible by the use of language principles, which lessens sudden changes in the control signal. As a result, oscillations are reduced and stability is improved. Furthermore, the fuzzy controller is better suited for intricate and practical thermal processes since it does not require a precise mathematical description of the system.

The simulation findings verify that the suggested fuzzy logic-based temperature control system performs better in terms of robustness and transient responsiveness. It works especially well in cases where system parameters change or are hard to accurately model.

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