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Temperature Control in A Shower Using Fuzzy Logic

Haziqah Mohd Nazahar, Amidora Idris
Department of Mathematics, Faculty of Science, UTM, Skudai, Johor Bahru, Malaysia
Corresponding author: amidora@utm.my

Abstract

Temperature control in showers presents a complex challenge due to the non-linear dynamics of water temperature and flow and varying user preferences. This study aims to investigate the implementation of a fuzzy logic-based system for automatic temperature and water flow control in showers. By leveraging fuzzy logic as a control method, this study provides valuable insights into developing advanced, adaptive temperature control systems that optimize energy usage and overall system performance. The Mamdani-type inference method used in the fuzzy logic controller enhances computational efficiency by simplifying defuzzification. The fuzzy controller provided a good step response, indicating precise and adaptive control. The classification of the target temperature, current water flow rate, and valve opening speed recommended in an earlier work will be accomplished by using fuzzy logic rules. The output comparisons were made, and the results demonstrate that the speed of the achieved valve opening is suitable for the system. The speed of the cold and hot water valves was determined with the help of the fuzzy logic controller. Implementing fuzzy logic-based temperature control systems can lead to more efficient water usage, enhanced user comfort, and improved system performance in showers and other temperature-sensitive applications.

Keywords: Temperature control; Fuzzy Logic; Fuzzy logic controller; Mamdani-type inference

1. Introduction

Fuzzy logic is a part of mathematical logic and computer science that deals with approximate reasoning and handling inaccurate knowledge. Unlike traditional logic, which only uses true (1) or false (0), fuzzy logic allows for values in between, reflecting partial truths. This approach is useful for variables that aren't strictly true or false, or yes or no.

Fuzzy logic works similarly to human thinking, making it valuable in artificial intelligence for solving unpredictable problems in a human-like way. It addresses the spectrum between absolute yes and no, unlike conventional computers which only understand strict yes or no inputs. The Fuzzy Logic Controller (FLC) is a popular intelligent control method that uses fuzzy logic to turn expert knowledge into an automatic control strategy. There are two types of FLCs: the Mamdani type and the Takagi-Sugeno type [1]. These two types of controllers differ slightly in how they determine outputs.

Fuzzy Logic Controllers (FLCs) are highly effective for precision control [2]. Over the last 20 years, significant research has focused on using fuzzy logic for controlling non-linear dynamic systems, such as temperature control systems. Traditional controllers use control theory concepts, ensuring the output reacts as intended through feedback. An FLC can adjust a room's temperature by comparing it to the surrounding air [3]. It controls the heater and air conditioner to maintain the desired temperature. This system uses fuzzy logic to regulate temperature efficiently.

Several researchers have shown that a simple FLC, with a limited number of rules, can effectively manage temperature control even with unknown dynamics or unpredictable delays, unlike more complex systems requiring extensive rules and computer processing. A fuzzy logic-based temperature control system typically includes a microcontroller, temperature sensor, operational amplifier, analogueto-digital converter, display interface circuit, and output interface circuit. This design strategy uses fuzzy logic to achieve precise temperature control [4].

There are many effective ways to control temperature. This research explores how a fuzzy logic controller, an intelligent method, can control the temperature of a shower. The aim is to design and implement an automatic system for controlling both temperature and water flow in showers. The research investigates a fuzzy logic-based temperature control system that heats a system to a defined temperature and maintains it securely. This study explores the fuzzy logic controller, assessing its efficiency, incorporating security measures, and demonstrating its ability to handle imprecise information. The study compares the system with traditional methods, explore adaptability, and create a simulated environment for testing. It outlines the expected duration, required resources, and potential applications, providing a clear framework for the research. This research is significant as it contributes to the field of temperature control systems by introducing an intelligent approach that enhances precision and efficiency. The findings could have applications in various industries where temperature control is critical.

By exploring the use of fuzzy logic for temperature regulation, this research aims to provide valuable insights into developing advanced and adaptive temperature control systems. The results may help optimize energy usage and overall system performance in diverse applications.

2. Literature review

2.1 Introduction to Temperature Control

A temperature controller is a device that regulates temperature with minimal user interaction. It takes input from a temperature sensor, like a thermocouple or resistance temperature detector (RTD), and compares the actual temperature to the desired setpoint. It then sends an output to a control element [5]. Temperature control is essential in various industries to maintain product quality, safety, and efficiency. It ensures consistent product characteristics, prevents safety risks, and improves energy efficiency. Precise control optimizes processes, extends equipment life, and is crucial in biotechnology, pharmaceuticals, medicine, and environmental applications. In manufacturing, healthcare, data centres, or the food industry, maintaining optimal temperatures is key to reliable and high-quality outcomes.

Temperature controllers can use different actuators, such as thermoelectric devices (Peltier devices) or resistive heaters, to manage temperature. They typically include a control algorithm, like a Proportional-Integral-Derivative (PID) system, to determine the necessary heating or cooling to reach and maintain the setpoint temperature [6].

2.2 Fuzzy Logic Controller (FLC)

Fuzzy Logic Controllers (FLCs) use fuzzy logic, a mathematical framework dealing with uncertainty and imprecision, to model and control complex systems. Fuzzy sets, or classes of items in which the change from membership to non-membership is gradual rather than abrupt, serve as the foundation for fuzzy logic controllers [7]. Here's a detailed discussion on the design and operation of Fuzzy Logic Controllers, including key components and parameters. Fuzzy Logic Controllers (FLCs) represent a sophisticated approach to control systems that has gained prominence in addressing the challenges posed by imprecision and uncertainty in various applications. At its core, fuzzy logic provides a mathematical framework for managing uncertainty through the use of fuzzy sets, membership functions, and linguistic variables. Within the context of temperature control, FLCs offer a versatile means of regulating systems by accommodating the inherent complexities associated with dynamic environments. From an analysis conducted by W.J.M. Kickert [8], they conclude that by applying fuzzy logic to the linguistic controller rules, it is shown that the fuzzy controller is identical to a multilevel relay under fairly general conditions. The components of FLCs include membership functions that model the degree of truth for linguistic variables, a rule base dictating decision-making processes, and defuzzification techniques for converting fuzzy output into precise control actions.

2.3 Application of Fuzzy Logic in Temperature Control

Fuzzy Logic Controllers (FLCs) have found wide-ranging applications in temperature control systems, offering an alternative to traditional methods. One key strength lies in their adaptability to diverse environments and their capacity to handle the inherent uncertainties associated with temperature regulation. Fuzzy logic's ability to capture and process linguistic variables facilitates a more intuitive and human-like decision-making process. In temperature control, FLCs have been successfully employed across various industries and sectors.

In industrial processes, where precise temperature control is essential for maximizing production efficiency and product quality, fuzzy logic's adaptability is demonstrated. The flexibility of FLCs in regulating heat treatment procedures, chemical reaction temperatures, and other production parameters is advantageous to manufacturing systems [9]. Fuzzy logic is especially well suited for dynamic and complex production contexts because of its capacity to handle nonlinearities and uncertainty.

Fuzzy logic has also been used by HVAC (heating, ventilation, and air conditioning) systems to effectively regulate temperature. With the help of FLCs, HVAC systems can adapt dynamically to changing circumstances, maximizing energy efficiency and guaranteeing optimal comfort. The use of fuzzy controllers in air conditioning systems has been advantageous in maintaining operating conditions and achieving energy savings, showing advantages over traditional controllers [10]. Maintaining desirable temperature levels in various places can be approached in a more nuanced and responsive manner due to fuzzy logic's flexibility in modelling imprecise inputs. For instance, in comparison to other places, the air temperature in Indonesia is higher due to its tropical environment and the equator passing across it. Because of this, the tool's accessibility and existence for cooling the space, particularly during the dry season, becomes highly significant [11].

2.4 Shower Background

A shower head is a piece of equipment that disperses water to spray or drop out. Originally designed for watering plants, it was later adapted for use as a shower and became a common bathroom appliance. The shower head's general components include the body, a switching component, a water distribution component, a rotor, a water outlet, a face cover, a water-saving device, a plug, and a button [12]. Typically, a thermostatic system in showers has two controls. A thermostatic valve regulates the water temperature, while a volume control valve manages the water's volume and on/off function. This system allows you to set a permanent temperature, ensuring the water is always at your preferred temperature every time you shower [13].

2.5 Mamdani-Fuzzy Logic

The application of fuzzy logic, along with other reasoning processes in the Mamdani fuzzy logic system, transforms crisp input into crisp output [14]. The essential elements of the Mamdani fuzzy logic system include components for fuzzification, inference engines, and defuzzification, as shown in Figure 1. A Mamdani fuzzy logic system's decision-making procedure is rule-based, following an IF-THEN framework [15].

The fuzzification step takes the crisp input and converts it into a fuzzy set output. The most commonly used technique for this is singleton fuzzification. Next, the inference section creates an implied fuzzy set for each rule in the rule base and determines the relevance of each rule to the current situation by generating a matching fuzzy set for each rule. The results of these computations produce an implied fuzzy set for each rule. In the defuzzification process, all the rules' inferred fuzzy sets are combined. The purpose of the defuzzification phase is to merge these inferred fuzzy sets to provide a clear, crisp output [16].

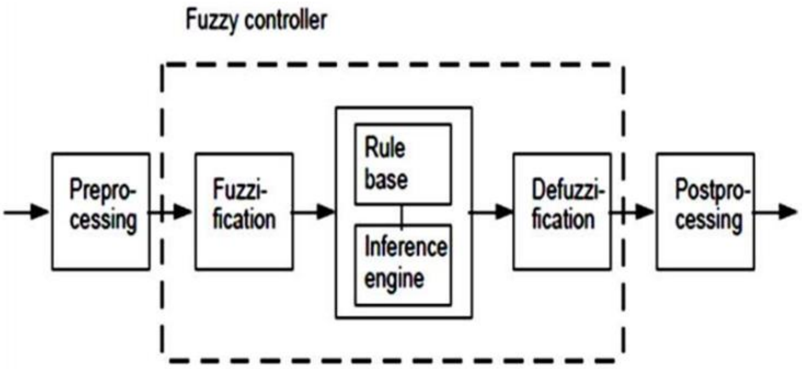

Figure 1: Fuzzy logic system

3. Research Methodology

3.1 Research design and framework

To ensure the study objectives are achieved, it is necessary to identify and follow specific research steps. First, definitions, concepts, and theories regarding fuzzy logic, fuzzy rules, and shower systems will be investigated to gain a deeper understanding of the research topic. Next, the input and output criteria for the fuzzy logic system, such as temperature and flow rate, need to be determined. After establishing the fuzzy logic and output criteria, fuzzy rule recommendations for the temperature controller of a shower be determined. Below shown the step for the work:

Step 1: Determine the fuzzy logic Input and Output for each data.
Step 2: Choose target temperature.
Step 3: Define the linguistic variable for each Input and Output.
Step 4: Obtain the degree of membership function namely temperature and flow using MATLAB (see Table 1 until Table 3).
Step 5: Obtain the output of cold water and hot water.
Step 6: Collect and analyse data.

The "IF-THEN" circumstances act as a framework for the construction of the fuzzy logic rule. The "IFAND-THEN" expression is used to determine each one of the adaptable rules that are used for controlling the system. The fuzzy rule can be seen in Table 4.

Table 1: Linguistic Variable for each function

Functions	Criterion	Fuzzy Construction
Input	Temperature	Cold
		Good
		Hot
	Flow	Soft
		Good
		Hard
Output	Cold	Close fast
		Close slow
		Steady
		Open slow
		Open fast
	Hot	Close fast
		Close slow
		Steady

		Open slow Open fast

Table 2: Fuzzy logic input for temperature

Linguistic Variable	**Temperature (Celsius, ℃)**
Cold	(-30) – (-1)
Good	0 – 10
Hot	11 – 30

Table 3: Fuzzy logic input for flow

Linguistic Variable	**Flow rate (m³/s)**
Soft	(-3.0) – (-0.1)
Good	0.0 – 0.4
Hard	0.5 – 3.0

Table 4: The fuzzy rule recommendation for the valve opening

IF	**Temperature**	**AND**	**Flow**	**THEN**	**Cold**	**Hot**
IF	Cold	AND	Soft	THEN	Open slow	Open fast
IF	Cold	AND	Good	THEN	Close slow	Open slow
IF	Cold	AND	Hard	THEN	Close fast	Close slow
IF	Good	AND	Soft	THEN	Open slow	Open slow
IF	Good	AND	Good	THEN	Steady	Steady
IF	Good	AND	Hard	THEN	Close slow	Close fast
IF	Hot	AND	Soft	THEN	Open fast	Open slow
IF	Hot	AND	Good	THEN	Open slow	Close slow
IF	Hot	AND	Hard	THEN	Close slow	Close fast

4. Result and Discussion

4.1 Analysis on case study

In this study, data was collected in Malaysia every evening over a period of 20 consecutive days in May 2023. The recorded data, shown in Table 5, includes target temperature ranges from -20℃ to 20℃ and flow rates between 0 m³/s and 1 m³/s, as flow rates cannot be negative. Since Malaysia experiences only two seasons, dry and rainy, warmer temperatures may be preferred during the rainy season and cooler temperatures during the dry season. Individual preferences for shower temperature can vary based on sensitivity to heat or cold, skin type, and overall comfort level.

The analysis revealed both negative and positive values in the calculated parameters for cold and hot scenarios, indicating deviations from some reference values or conditions. Correlation analysis was performed to explore relationships between temperature, flow rate, and the calculated parameters. The findings contribute to a deeper understanding of the dynamics and performance of shower systems under varying temperature and flow rate conditions, with implications for system optimization and efficiency. The data collection is shown in Table 5 below:

Table 5: Data in Malaysia on every evening for 20 days

No.	Temperature (℃)	Flow (m^3/s)	Cold	Hot
1	15	0.3	-0.049	-0.523
2	2	0.1	0.003	-0.15
3	-13	0.1	-0.371	0.18
4	20	0.1	0.18	-0.371
5	12	0.2	0.079	-0.438
6	-15	0.2	-0.438	0.079
7	-17	0.9	-0.633	-0.3
8	-20	0.1	-0.371	0.18
9	-5	0.1	-0.209	0.066
10	7	0.6	-0.3	-0.522
11	14	1	-0.3	-0.633
12	15	0.1	0.18	-0.371
13	-11	0.5	-0.637	-0.3
14	0	0.5	-0.3	-0.3
15	10	0.7	-0.3	-0.636
16	-18	0.2	-0.438	0.079
17	8	0.2	0.076	-0.35
18	-6	0.8	-0.491	-0.3
19	19	0.3	-0.049	-0.523
20	5	0.2	0.023	-0.269

4.2 Difference between input temperature and flow rate, and between output cold and hot

By comparing the input temperature with the flow rate, we can assess the efficiency of the system in delivering the desired temperature. A larger difference may indicate challenges in maintaining consistent temperatures, potentially due to variations in flow rate affecting the mixing of hot and cold water. Understanding these differences is crucial for ensuring a positive user experience, as sudden changes in water temperature or inconsistent flow rates can lead to discomfort for users. By analysing these differences, we can identify potential causes of discomfort and develop strategies for improving the overall shower experience.

Table 6 presents the absolute values of the differences between the input temperature and flow rate and the absolute values of the differences between the output temperatures for cold and hot water.

Table 6: The differences between the input temperature and flow rate and the absolute values of the differences between the output temperatures for cold and hot water

No.	Temperature (℃)	Flow (m^3/s)	Cold	Hot	Temp | flow difference	Cold | hot difference
1	15	0.3	-0.049	-0.523	14.7	0.474
2	2	0.1	0.003	-0.15	1.9	0.153
3	-13	0.1	-0.371	0.18	13.1	0.551

4	20	0.1	0.18	-0.371	19.9	0.551
5	12	0.2	0.079	-0.438	11.8	0.517
6	-15	0.2	-0.438	0.079	15.2	0.517
7	-17	0.9	-0.633	-0.3	17.9	0.333
8	-20	0.1	-0.371	0.18	20.1	0.551
9	-5	0.1	-0.209	0.066	5.1	0.275
10	7	0.6	-0.3	-0.522	6.4	0.222
11	14	1	-0.3	-0.633	13	0.333
12	15	0.1	0.18	-0.371	14.9	0.551
13	-11	0.5	-0.637	-0.3	11.5	0.337
14	0	0.5	-0.3	-0.3	0.5	0.000
15	10	0.7	-0.3	-0.636	9.3	0.336
16	-18	0.2	-0.438	0.079	18.2	0.517
17	8	0.2	0.076	-0.35	7.8	0.426
18	-6	0.8	-0.491	-0.3	6.8	0.191
19	19	0.3	-0.049	-0.523	18.7	0.474
20	5	0.2	0.023	-0.269	4.8	0.292

The fuzzy rule applied in the data proves accurate. For example, when the temperature is cold and the flow is soft, the cold-water valve opens slowly while the hot water valve opens quickly. The calculated parameters for both cold and hot water show both negative and positive values. Smaller values mean slower valve openings, while larger values indicate quicker openings. If the hot water value is larger, its valve opens faster, and vice versa.

A smaller difference between hot and cold values suggests better temperature balance, while a larger difference may indicate issues like temperature fluctuations or water mixing imbalances. Generally, a larger difference between temperature and flow correlates with a larger difference between output cold and hot values. This comparison is shown in Figure 2:

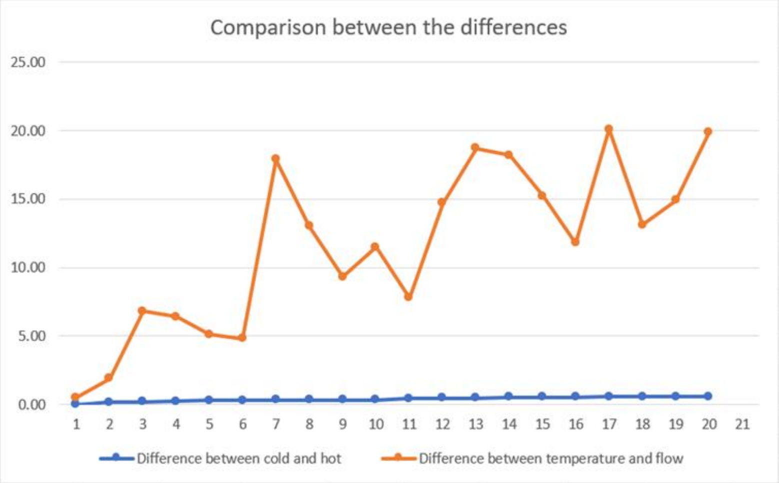

Figure 2: Result for comparison of the two differences

Figure 3 indicates that people in Malaysia may lean towards preferring cold water temperatures for showering over hot water. This preference is likely due to Malaysia's tropical climate, which is consistently hot and humid. In such weather, cold showers can provide a refreshing and cooling sensation, particularly after being outdoors in the heat. Additionally, some individuals may find cold water showers more comfortable or enjoyable than hot water showers. Factors like heat sensitivity, skin conditions, and personal preferences play a role in determining one's choice of water temperature for showering.

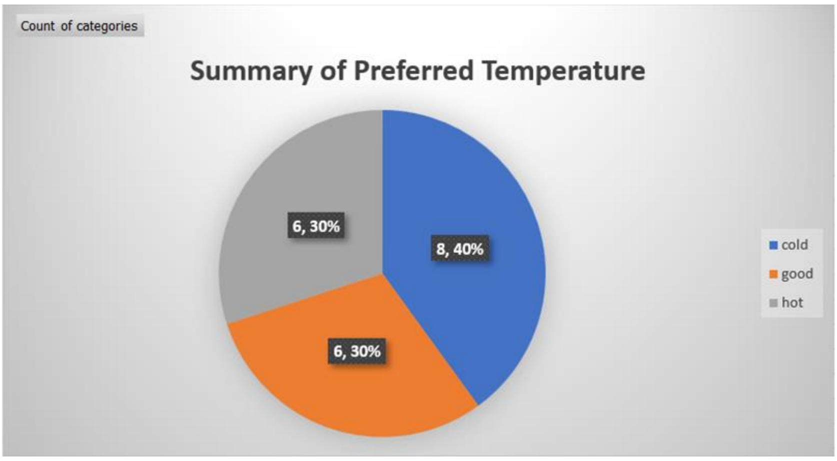

Figure 3: Pie chart of the summary preferred temperature

Conclusion

Temperature control in shower systems poses a real-life challenge, and this research aims to address it by implementing a fuzzy logic controller for efficient regulation. The study highlights the effectiveness and simplicity of the fuzzy logic control approach, particularly through the Mamdani-type inference method, which streamlines the defuzzification process for improved computational efficiency. Demonstrating the system's ability to accurately maintain a specified temperature level consistently showcases the practical viability of fuzzy logic in achieving precise temperature regulation. The research applies the fuzzy logic controller to real-world data, comparing its performance with traditional temperature control methods. Results suggest that the fuzzy logic control system offers a robust and efficient solution for managing temperature and flow rate in shower systems, indicating the potential benefits of fuzzy logic in process control applications. The system exhibits favourable step responses for both flow and temperature control with the fuzzy controller. In summary, this study encompasses the development, implementation, and evaluation of a fuzzy logic-based temperature control system for showers, focusing on achieving precise regulation, stability, efficiency, and adaptability to uncertain input conditions. These findings contribute to advancing the understanding and application of fuzzy logic in temperature control systems, particularly in showering environments.

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