

FUZZY LOGIC AND PID CONTROL FOR LEVEL AND TEMPERATURE CONTROL IN MIXING TANK USED IN INDUSTRIAL AREAS

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Abstract

The level and temperature control of the mixing tank used in industrial areas must be done correctly. The mixing tank, which is a nonlinear system, provides hot and cold water flow by means of two pumps. The amount of water flow is controlled by valves and the desired temperature and level control is provided in the tank. The level and temperature control of the mixing tank was performed using Matlab / Simulink software. The control of the generated model is realized by fuzzy logic control methods which are one of modern control methods and PID control method which is a traditional control method.

Keywords: Mixing tank, nonlinear system, level control, temperature control, fuzzy logic controller, PID controller, process control, control systems, modern control techniques, traditional control methods, simulation, system modeling.

INTRODUCTION

The control of mixing tanks is important for industrial applications such as the food industry, agricultural spraying, textiles, wastewater treatment, milk production, nuclear energy production, chemical processing, and the pharmaceutical industry [1]. Industrial liquid mixing processes, which consist of a mixture of two or more liquids, are controlled by control and automation systems. The mixing tank is a multi-input, multi-output, nonlinear dynamic system [2].

Fuzzy logic applications are used in heat, electric current, liquid gas flow control, and chemical and physical process control. Because the fuzzy logic approach does not require a mathematical model, its most successful applications are in systems with poorly defined mathematical models, time-varying, and nonlinear systems [3].

In this study, a two-input, two-output mixing tank and its control system were modeled using the MATLAB/Simulink

simulation program. Hot and cold water flows are provided to the mixing tank by two pumps. The water flow rate is controlled by valves, achieving the desired water temperature and level in the tank. A two-input, two-output fuzzy logic-based control method was developed to control the system. The system's operation was tested in a simulation environment.

1. SYSTEM MODELLING

A rectangular prism-shaped water tank was used in this study. Hot and cold water is supplied to the tank by pumps operating at a flow rate of 0.25 m³/s. The flow rate of hot and cold water entering the tank is adjusted by valves controlled by controllers according to the desired water level and temperature.

The discharge valve used for water discharge is adjusted by the user. The general structure of the water mixing tank system is shown in Figure 1.

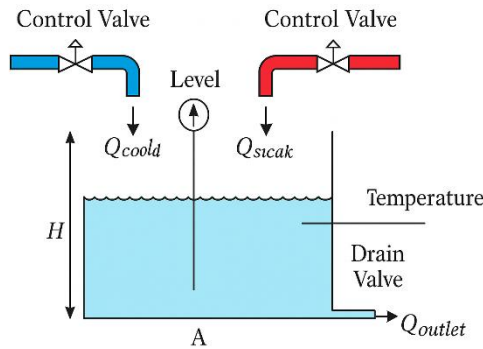


Fig. 1. General Structure of the System

The hot water temperature T_1 and cold water temperature T_2 entering the mixing tank are assumed constant. The hot water flow into the tank is defined as $Q_{hot} = Q_{max} * C_{hot}$, and the cold water flow is defined as $Q_{cold} = Q_{max} * C_{cold}$. Here, Q_{max} represents the pump capacity; 2 represents the openness ratio of the control valves (0-1). The total water flow into the tank is defined as $Q_{input} = Q_1 + Q_2$, the temperature of the mixing water is defined as T , and the flow rate of the water leaving the tank is defined as Q_{output} . The differential equations representing the system dynamics for controlling the water level and temperature in the tank are given in equations 1, 2, and 3 [1-4].

$$Q_{output} = a \sqrt{2gh} \quad (1)$$

$$\frac{dh}{dt} = \frac{1}{A} (Q_{hot} + Q_{cold} - Q_{output}) \quad (2)$$

$$\frac{dT}{dt} = \frac{1}{Ah} (Q_{hot}(T_1 - T) + Q_{cold}(T_2 - T)) \quad (3)$$

Here, h represents the height of the water in the tank; A represents the tank's base area. The values related to the structure of the water mixing tank used in this study are given in Table 1.

Table 1. Characteristics of the Water Mixing Tank

Description	Symbol	Value
Base Area	A	2 m ²
Outlet Cross-Section	a	0.025 m ²
Height	H	2 m
Gravitational Acceleration	g	9.81 m/s ²
Initial Level	h_0	0.1 m
Pump Capacity	Q_{max}	0.25 m ³ /s
Hot Water Temperature	T_1	70 °C
Cold Water Temperature	T_2	5 °C
Initial Temperature	T_0	10 °C

2. FUZZY LOGIC

2.1 The Concept Of Fuzzy Logic

In engineering and other branches of science, systems are modeled using precise mathematical models.

Classical control theory can also produce powerful analyses and good solutions using these models. However, in cases where the precise mathematical model of the system is unknown, classical logic either fails to produce a solution at all or fails to provide the desired performance.

The inadequacy of classical logic in such cases and its inability to adequately reflect the functioning of the human mind led scientists to focus on fuzzy logic. It was first proposed as a mathematical concept in an article written by Lotfi A. Zadeh in 1965 [5].

2.2 Fuzzy Logic Defuzzification Methods

Fuzzy logic is a method of obtaining precise values at the output of a set.

Common strategies used in the defuzzification method are described below.

2.2.1 Fuzzy Logic Defuzzification Methods

$$Z_{AM} = \frac{\int_z \mu_c(z)zdz}{\int_z \mu_c(z)dz} \quad (5)$$

Among these methods, the center of gravity method is the most commonly used decantation method.

2.2.2 Bisector of Area Method

$$Z_{ACO} = \int_a^{z_{ACO}} \mu_c z dz = \int_{z_{ACO}}^{\beta} \mu_c z dz \quad (6)$$

2.2.3 Mean of Maxima Method

$$Z_{EBO} = \frac{\int_z z dz}{\int_z dz} \quad (7)$$

2.2.4 Smallest of Maxima Method

The result is a method that takes the edge of the output membership function closest to the origin as the net output value, which has the maximum level in the output fuzzy set.

2.2.5 Largest Maximum Method

The result is a method that takes the edge of the output membership function that is farthest from the origin as the sharp output value, with the maximum level in the output fuzzy set.

2.3 Fuzzy Logic Defuzzification Methods

The fuzzy logic controller has emerged in recent years as a practical alternative to classical control methods for controlling time-varying, nonlinear systems, especially those whose mathematical models are not fully known [6]. The fuzzy logic controller, in its general structure, consists of four

basic components: fuzzification, inference, defuzzification, and knowledge base.

A general BMD block diagram is shown in Figure 2.

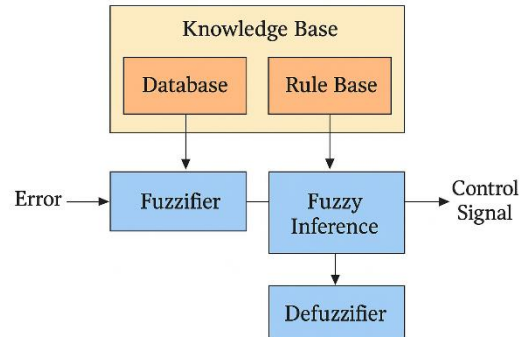


Fig. 2. Fuzzy Logic Controller Structure

The fuzzification unit is the process of converting input information received from the system into symbolic values, which are linguistic qualifiers.

Using the membership function, the fuzzy sets to which the input information belongs and the membership degree are determined, and linguistic variable values such as minimum and maximum are assigned to the entered numerical value.

The fuzzy inference unit produces fuzzy results by applying the fuzzy values received from the fuzzification unit to the rules in the rule base. The connections between inputs and outputs are established using the rules in the rule base.

The value obtained in this unit is translated from the rule table into a linguistic expression and sent to the fuzzification unit. The most widely used method among fuzzy inference methods, and the one used in this study, is the Mamdani method.

The fuzzification unit obtains three non-fuzzy, real values that can be used in practice from the fuzzy information received from the decision-making unit. Fuzzification is the process of converting

fuzzy information into crisp results. A knowledge base consists of a data table that collects information about the system to be controlled. Connections between inputs and outputs are established using the rules in the rule base.

When developing a rule base for a system, input values that can affect the system output must be identified. Fuzzy control rules are typically derived from expert knowledge.

3. MATLAB/SIMULINK STRUCTURE OF THE SYSTEM

In this study, the mixing tank model was obtained by creating models of all system elements using the MATLAB/Simulink simulation program. The Simulink model of the flow control valve used to control the flow rate of water entering the tank is shown in Figure 3.

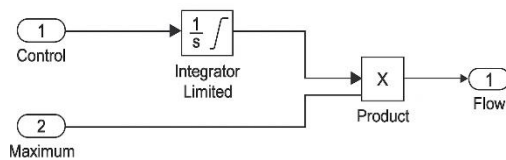


Fig.3. Flow Control Valve Model

The Matlab/Simulink model of the mixing tank is shown in Figure 4.

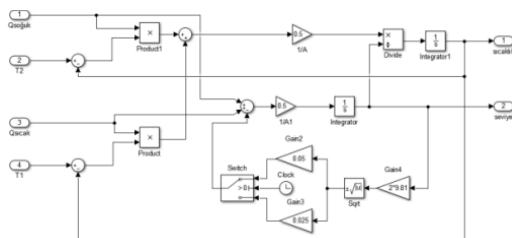


Fig.4. Matlab/Simulink Model of Mixing Tank

4. FUZZY LOGIC CONTROLLER DESIGN

Unlike classical logic, fuzzy logic doesn't have just two levels, such as 1 and 0. Fuzzy logic operates with more levels. One of the most popular applications is the use of five levels. These levels are: NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small), and PB (Positive Big). Fuzzy logic is a control method that is mathematically more complex, but easier to solve with a human-like observer/operator.

Fuzzy logic tools (Fuzzy Logic Toolbox) are used to design fuzzy logic controllers in the Matlab/Simulink environment. This tool library provides a GUI interface for the user, through which the types and values of membership functions, and the rules between specified input variables and output variables are defined. Following these steps, the methods and tools used in the fuzzy logic controller are defined. Following these definitions, a control model is created in the MATLAB/Simulink environment using a fuzzy logic controller. The Simulink model of the system, where temperature and level control are created using a fuzzy logic controller for this study, is shown in Figure 5.

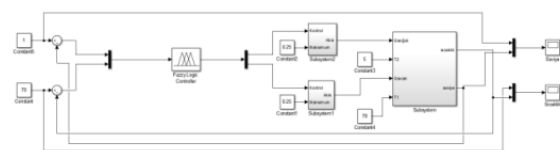


Fig.5. Fuzzy Logic Controller Matlab/Simulink Model

Defining membership functions is a crucial step for a fuzzy logic controller. The types, number, and ranges of membership functions must be carefully determined in this step.

There are many frequently used membership functions in the literature. Triangular, Trapezoidal, and Gaussian membership functions are some of them.

During this study, a two-input, two-output fuzzy logic controller was designed. The input variables were temperature and level, while the output variables were the hot and cold parameters.

Figure 6 below shows the design of a two-input, two-output fuzzy logic controller.

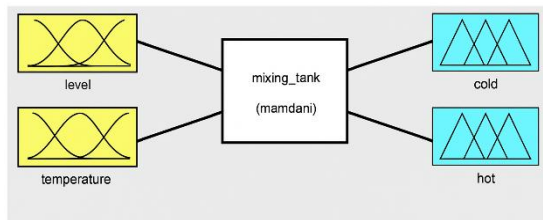


Fig.6. Fuzzy Logic Controller Design

Five membership functions were used. All membership functions were selected as Gaussian membership functions. The level parameter, the input variable, was kept between -1 and +1. The ranges of the other variables (temperature, hot, and cold) were kept between -100 and +100.

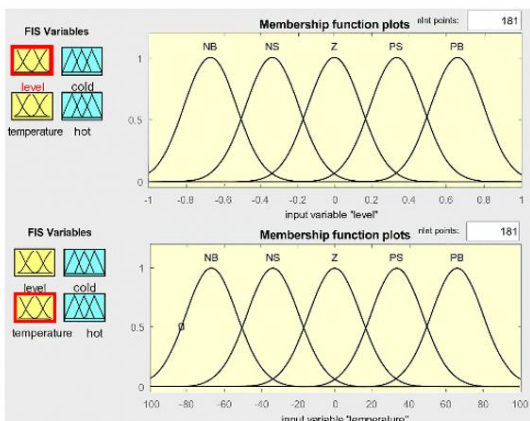


Fig.7. Fuzzy Logic Controller Input Parameters

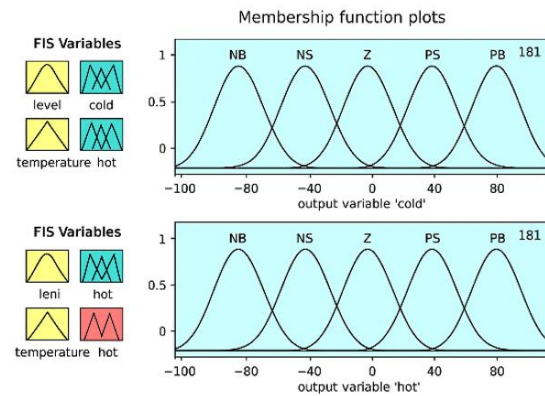


Fig.8. Fuzzy Logic Controller Output Parameters

The membership functions used in this study are shown in Figures 7 and 8 on the FIS editor. The performance of the fuzzy logic controller designed using the membership functions mentioned above is determined by comparing the input and output signals.

Table 2. Fuzzy Logic Rule Table with 25 Rules

		C_{cold}				
		TEMPERATURE				
LEVEL	C_{hot}	NB	NS	Z	PS	PB
	NB	Z	NS	NB	NB	NB
	NS	PS	Z	NB	NB	PB
	Z	NB	NS	Z	PS	PB
	PS	NB	NS	PS	PB	PB
	PB	Z	PS	PB	PB	PB
		ZE	PS	PB	PB	PB

In fuzzy logic controller systems, the rules between input and output are created using the IF-Then logic structure. These rules are a crucial factor for level and temperature control in the mixing tank. The rule table created for this study, consisting of 25 rules, is shown in Table 2.

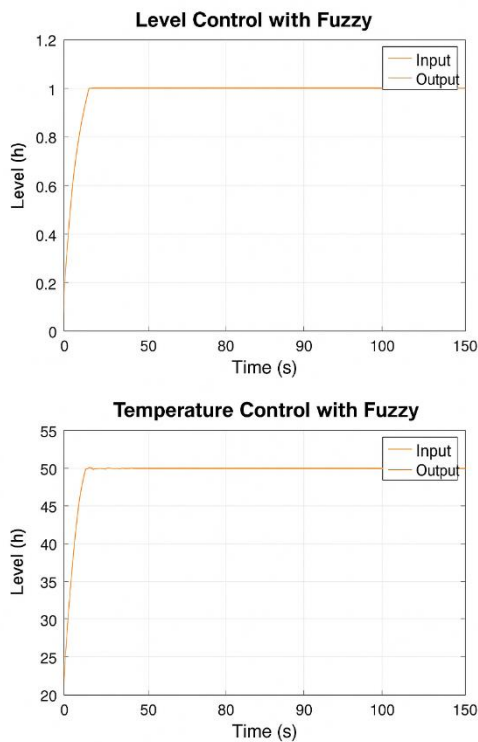


Fig.9. Level and temperature control with Fuzzy Logic

The level controller successfully brought the water level in the tank close to the reference values. At the same time, the temperature controller brought the water temperature to the desired value.

5. PID CONTROL

PID controllers are the most frequently used controllers in industrial applications due to their robust and efficient performance. Each of the proportional (P), integral (I), and derivative (D) gain parameters that make up the PID controller affects the system's operation in various ways. Each component of the PID controller is governed by a gain coefficient. These gain coefficients have different values for each system. Figure 10 shows the control block diagram of the PID controller.

The output of the PID controller is expressed in Equation 4.

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{d}{dt} e(t) \quad (8)$$

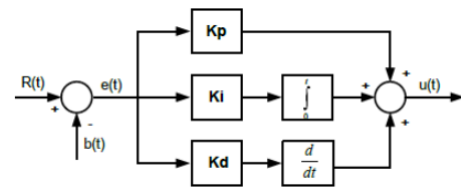


Fig.10. PID Controller Block Diagram

A proportional controller (K_p) is effective in reducing the rise time, but it can never eliminate the steady-state error. An integral controller (K_i) is effective in eliminating the steady-state error, but it can make the transient response worse.

A derivative controller (K_d) is effective in increasing system stability, reducing overshoot, and improving the transient response.

The effects of each controller (K_p , K_i , K_d) on a closed-loop system are shown in Table 3.

Table 3. Independent Effects of P, I, and D Settings

Controller	Rise time	Overshoot	Steady-state error
K_p	Decrease	Increase	Slightly decrease
K_i	Slightly decrease	Increase	Significantly decrease
K_d	Slightly	Decrease	Not important

Because K_p , K_i , and K_d are interdependent, these relationships may not be completely accurate. Changes in one controller also affect the other controllers.

For this reason, the table above is used only as an estimation reference when determining the K_p , K_i , and K_d values.

6. PID CONTROLLER DESIGN

Two separate PID controllers were designed to control the flow rate of hot and cold water entering the tank. The PID controller's K_p , K_i , and K_d gain parameters were calculated as $K_p=1.5$, $K_i=0.00003$, and $K_d=5$. The Matlab/Simulink model, which creates the temperature and level control system of the liquid mixture tank with two separate PID controllers, is shown in Figure 11.

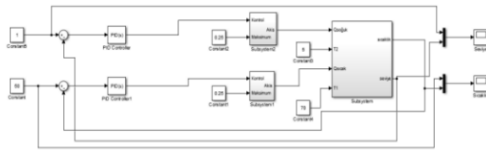


Fig.11. PID Controller Matlab/Simulink Model

The graphs of the liquid mixture tank's level and temperature control with the PID controller, as a scope output in the Matlab/Simulink environment, are shown in Figure 12.

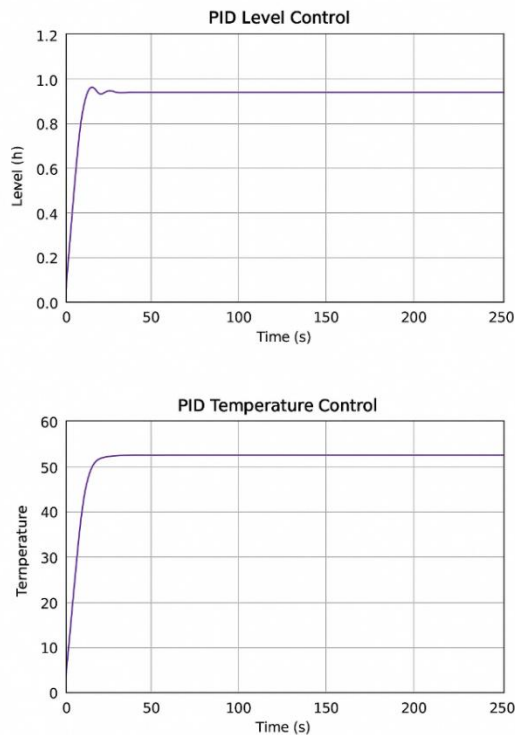


Fig.12. Level and temperature control with PID

With the PID controller control design, temperature control has been successfully brought closer to the desired level.

CONCLUSION

In this study, the level and temperature control system of a two-inlet, two-outlet liquid mixture tank was modeled using MATLAB/Simulink. Successful results were achieved using fuzzy logic control in controlling the system's level and temperature variables.

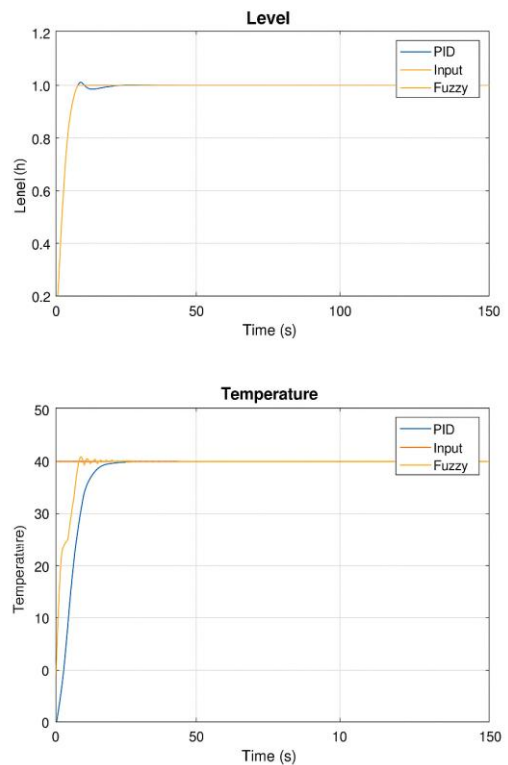


Fig.13. Level-temperature control diagram with PID and BMD

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