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Investigating the Effect of Different Membership Functions on Control Performance in Fuzzy Logic-Based Liquid Level Control

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Açar sözlər: *qeyri-səlis məntiq, məntiq nəzarətçisi, simulyasiya, nəzarətçi, riyazi model*

The fuzzy logic approach gives machines the ability to process people's specific data and operate by taking advantage of their experiences and intuitions. It uses symbolic expressions instead of numerical expressions to achieve this ability. The foundation of a fuzzy logic controller is built on verbal expressions and the logical relationships between them. Mathematical modeling of the system is not required when implementing a fuzzy logic controller (FLC) (Akyazı et al., 2011).

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Developing a fuzzy logic controller is easy because it doesn't require mathematical expressions. Therefore, fuzzy logic can be easily used in complex nonlinear systems (Akyazı et al., 2011; Chak, 2021). FLC has emerged in recent years as an alternative to classical control methods in controlling systems that change over time, are nonlinear, and especially those whose mathematical model is not fully known (Dharamniwas et al., 2012).

The first application of fuzzy logic was by Mamdani in 1974, in the form of controlling a steam engine. Since then, fuzzy logic has been used in many fields such as water treatment control, subway control, electronic markets, automotive products, heat, liquid, and gas flow control, and chemical and physical process control (Mamdani & Assilian, 1975). Liquid level control plays a very important role in food processing, wastewater treatment, milk production, filtration processes, nuclear energy production, pharmaceutical industry, coatings and many other industrial applications (Gani et al., 2013).

Controlling the liquid level in a tank is difficult due to the nonlinear dynamic nature of the system. In such systems, fuzzy logic-based control yields very successful results. In this study, a fuzzy logic-based control method was created in Matlab/Simulink for level control of a water tank. The opening of the valve that provides water outlet in the tank represents the loading of the system. The fuzzy logic-based control was tested by changing the valve opening ratio. Four different controllers were designed using triangular, trapezoidal, Gaussian and bell-type membership functions to control the system. The controllers obtained using different membership functions were applied to the system separately under the same conditions and the performance of each membership function on the control was examined. The success of the control system will be demonstrated by reaching the reference level values in a short time with very small error values.

Mathematical Model of the Water Tank System

In this study, a level model of a water tank system was created for use in simulation. The model of this tank is in the shape of a rectangular prism with a base area of A and a height of H. The tank has a control valve for water inlet and a drain valve for water outlet. The control valve is automatically adjusted by a control signal generated by the controller. The drain valve is adjusted manually by the user according to the water demand. The general structure of the water tank system is shown in Figure 1.

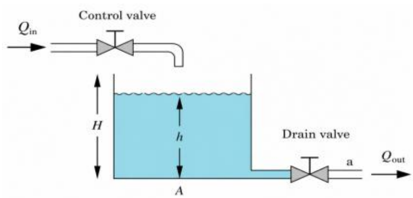

Figure 1
Water tank system

The Simulink model of the flow control valve used to control the amount of water flowing into the tank is shown in Figure 2.

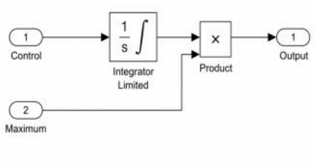

Figure 2
Simulink model of the valve (Mamdani, & Assilian, 1975; Nazha, et al., 2025)

The amount of water flowing from a cross-sectional outlet of a height h in a water tank is expressed by equation 1. The change in the water level in a tank is expressed by equation 2 (Dharamniwas, Ahmad, Redhu, & Gupta, 2012; Nazha, et al., 2025).

$$Q_{out} = a\sqrt{2gh} \qquad (m^3/s) \tag{1}$$

$$\frac{dh}{dt} = \frac{Q_{in} - Q_{out}}{A} = \frac{Q_{in} - a\sqrt{2gh}}{A} \qquad (m) \tag{2}$$

A Simulink model of the water tank was created using Equation 2. This model is shown in Figure 3.

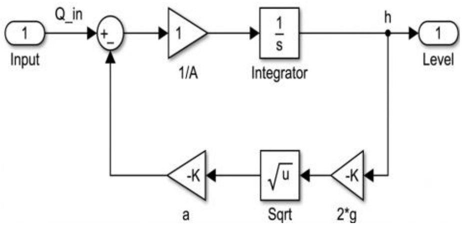

Figure 3
Simulink model of the water tank

Source. Mamdani & Assilian, 1975; Nazha et al., 2025

The values related to the water tank model used in the simulation study are given in Table 1.

Table 1
Water tank specifications

Description	Symbol	Value
Base area	A	1 m^2
Height	H	2 m
Outlet cross-section	A	0,01 m^2
Initial water level	h_0	0 m
Gravitational acceleration	G	9,82 m/s^2
Water inlet flow rate	Qin	0,05 m^3/s

Simulation Studies
All system elements were modeled with MATLAB/Simulink. The general Simulink model of the system was created as shown in Figure 4. The reference water level values determined in the study were given as 0.5 m in the 0-200 second range, 1.5 m in the 200-400 second range, and 0.75 m in the 400-600 second range. In order to create a disruptive effect in the system, the drain valve, which was initially 50% open, was opened to 75% at the 300th second of the study.

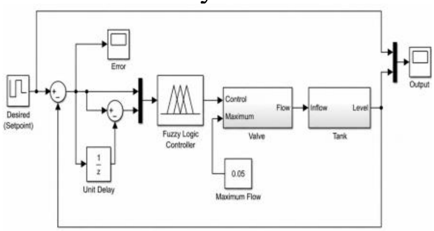

Figure 4
Simulink model of the system

In this study, the control of a water level control system was implemented using a fuzzy logic controller. The behavior of the system output was investigated by using different membership functions (triangle, trapezoid, Gaussian, bell) within the fuzzy logic controller.

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