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ODOUR POLLUTION CONTROL USING TYPE-2 FUZZY LOGIC CONTROLLER

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Abstract

This investigation aims to develop an odour reduction system simulation using a Type-2 Fuzzy Logic Controller (T2FLS). T2FLC is a further development of the classic fuzzy logic (Type-1 Fuzzy Logic Controller or T1FLC). Where the membership function of T2FLC is also fuzzy. A test by several references indicates that the performance of T2FLC is better than the T1FLC. The proposed T2FLC is tested and compared to the PID controller and T1FLC. The test is based on simulation using MATLAB and Simulink®. Three attempts are carried out to compare the performance of the three controllers using three different gain (C), time delay (L), and time constant (T) values. This shows that type-2 fuzzy is the most reliable method for magnifying C, L, and T values with rise time = 1.368 seconds, maximum overshoot = 60%, and settling time = 8.989 seconds.

Keywords: Fuzzy logic Type 2, MATLAB, Odour pollution, Simulink.

1. Introduction

Ammonia gasses have been the major contributor to livestock odour pollution. Bioflavonoids from yucca schidigera plants can be used to neutralize odour pollution that is generated from livestock waste [1]. However, the process is still carried out by spraying regularly and manually. In order to be more efficient and effective, an automatic control system is needed. Because conventional control systems cannot solve complex problems, primarily when implemented under uncertain conditions, the fuzzy logic controller is one of the artificial intelligence-based control systems that have been created. The advantages of fuzzy logic control are that it can compensate for non-linearity and uncertainties [2]. The two known fuzzy logic systems are type-1 fuzzy logic systems, and type-2 fuzzy logic systems, based on the type of membership function (MF) used [3]. In conditions with uncertainties, for example, those found in an unstructured environment, type-1 fuzzy sets have some deficiencies. It is possible to accommodate uncertainties and handle such disturbances dynamically using interval type-2 fuzzy sets. The interval type-2 fuzzy set is an extension of the type-1 fuzzy set that maintains the simplicity of the type-1 fuzzy set [4]. The type-1 fuzzy set is based on the precise and crisp type-1 fuzzy membership function (T1MF), and the type-2 fuzzy set uses an additional dimension of MF called (T2MF) [3].

Meivita et al. [5] have developed a prototype of an electrostatic filter based on fuzzy logic control to reduce particulate matter pollution in the air. The system regulates the number of charges emitted by ozone generators using feedback signals from a semiconductor gas sensor and a laser dust sensor. The result shows that implementing this control system can lower PM10 particulates by 80% in 10 minutes while maintaining a low ozone level during air purification. Caglayan et al. [6] used fuzzy logic in their research on controlling harmful gas in livestock houses. The paper describes a fuzzy logic-based ventilation algorithm that can calculate various fan speeds under pre-defined boundary conditions to eliminate harmful gases from the manufacturing environment. The result shows that optimum fan speeds under pre-defined boundary conditions have been presented.

Kobersi et al. [7] have developed a heating system using a fuzzy logic controller. The result of the experiment showed that the fuzzy logic system has a maximum overshoot of 1%, which is better than the conventional method. In all experimental conditions, the heating system with fuzzy logic control response is reasonable, as expected, and does not exceed the maximum and minimum required temperatures.

A hybrid electric autonomous vehicle is investigated in the presence of significant uncertainty and ambiguity in the road environment and driver behaviour by Phan et al. [4]. It is demonstrated that when the vehicle operates under uncertain and ambiguous road conditions, the interval type-2 fuzzy logic controller saves more battery life than the type-1 fuzzy logic controller. The interval type-2 fuzzy logic controller enables the carbon footprint reduction in autonomous vehicles, as desired by stakeholders in the automotive industry.

Hasan et al. [8] used an interval type-2 fuzzy logic controller to control the positioning of the pneumatic servo actuator system. The goal is to ensure and accommodate the nonlinear system and its parameter uncertainty. The result shows that the smooth and unsaturated state voltage control action obtained stabilizes the pneumatic servo actuator system and minimizes the position tracking error of the system output. The proposed controller achieves a 20% improvement compared to the previous controller.

This study aims to develop an odour reduction system simulation and find the best method for the system to achieve settling time by comparing three control systems. MATLAB and Simulink® are used to simulate the system. The result shows that using a type-2 fuzzy logic controller is the best method for the system.

2. Methods

The level of ammonia gas is not predictable with certainty when and how much are in the air, making the control valve with the manual method challenging to do. The existence of uncertainty influenced by external disturbances does not guarantee that the control will be perfect. An accurate mathematical control model is needed [9] for this linear control problem.

In order to get a good control effect, it is necessary to use automatic controls such as fuzzy logic control [10]. The primary purpose of fuzzy logic is to provide logical control in uncertain circumstances [11]. The valve has uncertain characteristics, and observation-based control does not work effectively [12]. Therefore, since the characteristics of the object being controlled are uncertain (nonlinear), it is more appropriate to use fuzzy logic control [10].

Fuzzy control can save time in obtaining mathematical model equations in nonlinear plants that are not easy to obtain mathematical equation models for [13]. Because of its flexibility and independence, the fuzzy mathematical model can manipulate uncertain conditions [11].

An interval type 2 fuzzy set, also referred to as a function approximation application of the fuzzy sets, is another fuzzy system to handle unexpected driving conditions. This is a helpful control system with better performance than Type 1 fuzzy sets when dealing with different uncertainties like rule uncertainties, dynamic uncertainties, noises and external disturbances [4].

Figure 1. Shows an overview of the system to be simulated with two inputs and one output. Each input is E and E obtained from the scaling factor Ce and Cd. The output value in the system uses the result of the G value in the form of a transfer function by utilizing the characteristics of the valve so that the system can control the portion opening in the simulation. The system on the variables is modelled as in Eq. (1).

$$G = \frac{Ce^{-Ls}}{Ts+1} \tag{1}$$

where C, L, and T are the gain, time delay, and time constant.

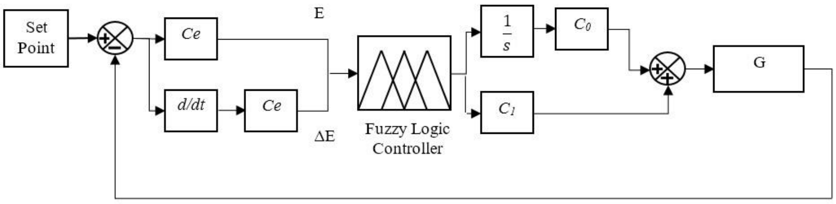
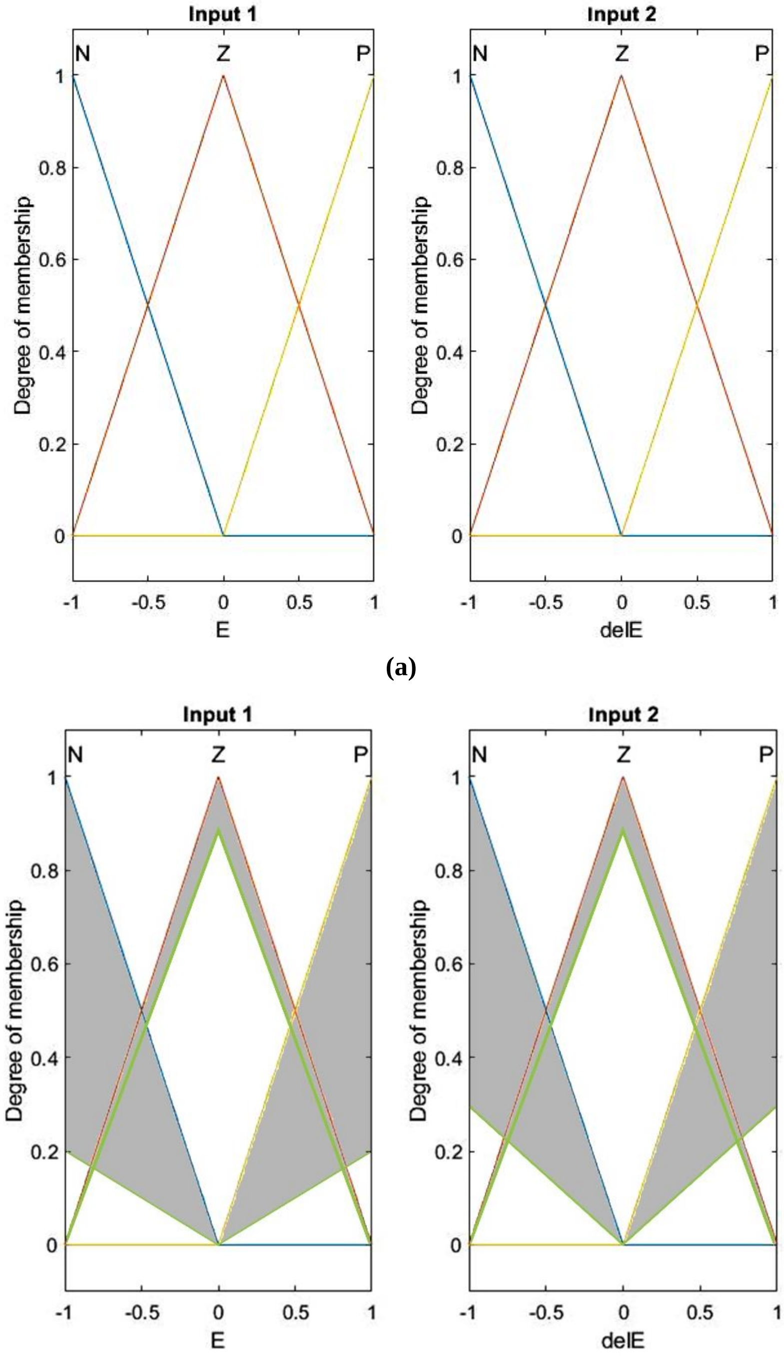


Fig. 1. Block diagram system using fuzzy logic Type-2.

The odour pollution control system using fuzzy control type-2 has two inputs, E and ΔE.



(a)

(b)

Fig. 2. Input fuzzy logic control; (a) for Type-1, (b) for Type-2.

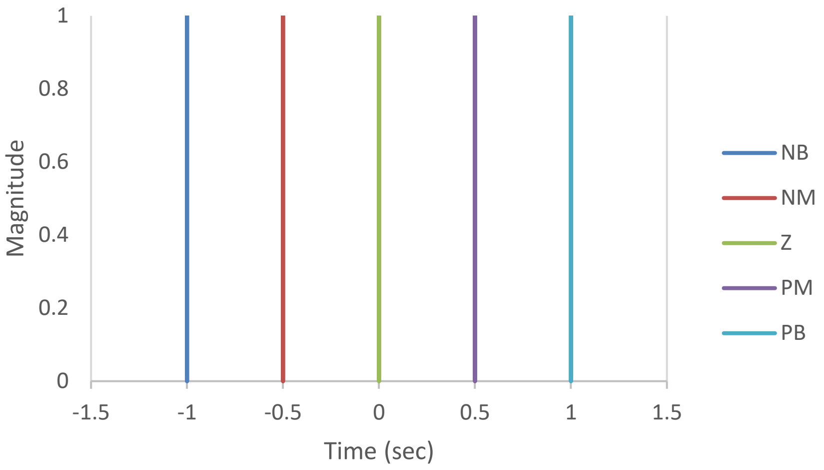


Fig. 3. Output fuzzy logic control.

The membership function for the input is shown in Fig. 2, while the membership function of the output is shown in Fig. 3. The full details of the rules are as follows:

- If ‘E’ is ‘N’ AND ‘delE' is 'N', then 'NB'.
- If ‘E’ is ‘Z’ AND ‘delE’ is ‘N’ then ‘NM’.
- If ‘E’ is ‘P’ AND ‘delE’ is ‘N’ then ‘Z’.
- If ‘E’ is ‘N’ AND ‘delE’ is ‘Z’ then ‘NM’.
- If ‘E’ is ‘Z’ AND ‘delE’ is ‘Z’ then ‘Z’.
- If ‘E’ is ‘P’ AND ‘delE’ is ‘Z’ then ‘PM’.
- If ‘E’ is ‘N’ AND ‘delE’ is ‘p’ then ‘Z’.
- If ‘E’ is ‘Z’ AND ‘delE’ is ‘P then ‘PM’.
- If ‘E’ is ‘P’ AND ‘delE’ is ‘P’ then ‘PB’.

The research was conducted using simulation. The valve in the system is made as a transfer function using a mathematical model [14] as Eq. (2).

$$H(s) = \frac{Y(s)}{X(s)} = \frac{1{,}25}{3s+1} \tag{2}$$

with H(s) as a transfer function, X(s) as the input signal, Y(s) as the output signal, and s as complex frequency.

This model is implemented on the valve by entering the characteristic value of the valve, which has a maximum travel of 15mm in a time constant of 3 seconds. Valve pressure has a standard range of 3 to 15 psig. The signal from the valve is modelled using Eq. (3) [14].

$$Y(s) = \frac{Range\ of\ Stem}{Pressure\ Range} = \frac{15mm}{(15-3)psi} = 1.25 \text{ psi/mm} \tag{3}$$

From the above calculation, it can be concluded that the value of G = H(s) is in the equation. The values of C, L, and T, which are variables of the transfer function G, will be assigned a value according to the valve characteristics, which will later be simulated in several control systems such as PID and fuzzy type-1 because this study focuses on proving fuzzy type-2 regarding the performance of the system.

3. Results and Discussion

This study compares the performance of a type-1 fuzzy logic controller with a type-2 fuzzy logic controller and a conventional PID controller. For this experiment, a simulation program has been created using MATLAB and the Fuzzy Logic Controller Simulink® block. Three attempts are carried out to compare the performance of the three controllers using three different gain (C), time delay (L), and time constant (T) values. The first experiment tested the program using the transfer function based on the valve characteristics, which this study used as a benchmark. The second experiment was carried out by changing the gain (C), time delay (L), and time constant (T) values. The membership value was changed to the Membership Function in the last experiment. The three experiments carried out will be taken into account from the performance of the three methods to obtain the best method that is more optimal and robust against any changes. The output is shown in Figs. 4 to 6.

3.1. First experiment

This experiment was carried out by testing the system using a transfer function value that adjusts to the characteristics of the valve in the method section. The graph of this experiment is shown in Fig. 4, and the data obtained are shown in Table 1.

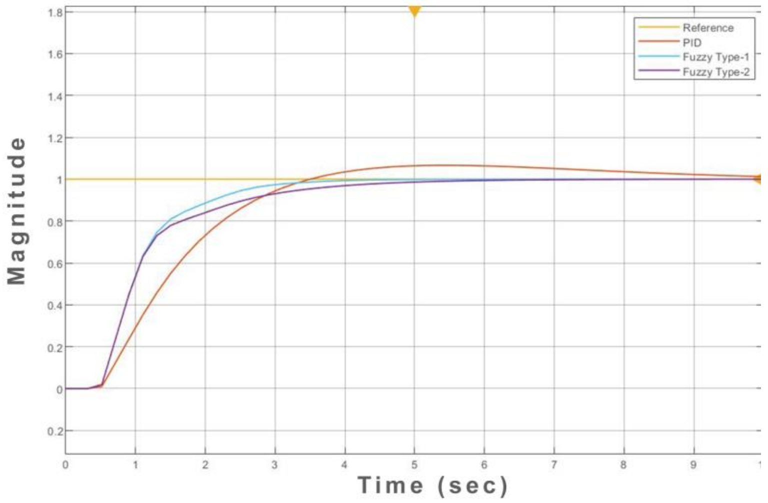


Fig. 4. Comparison of the three controllers using the valve characteristic transfer function.

Table 1. Result of the first experiment.

Constant	System	Rise Time (s)	Max Overshoot (%)	Settling Time (s)
C = 1.25	PID	3.514	7	> 10
L = 0.50	Type-1 Fuzzy	4.731	0	4.731
T = 3.00	Type-2 Fuzzy	6.865	0	6.865

In this experiment, it was found that Fuzzy type-1 and type-2 outperformed conventional PID because these two methods did not have an overshoot value, so the rise time and settling time values started at the same time. From these two types of fuzzy, it is found that Fuzzy Type-1 is superior to Fuzzy Type-2 because the duration of Rise time and Settling time is faster with a time difference of 2,134 seconds.

3.2. Second experiment

In this second experiment, testing was carried out by changing the values of C, L, and T. Changes in the values were made by enlarging and reducing these values.

3.2.1. Reducing the value of C, L, and T

This experiment was conducted by reducing the values of C, L, and T from the first experiment. The value of C = 1, L = 0.25, and T = 2.75. The experimental graph is shown in Fig. 5, and the experimental data are shown in Table 2

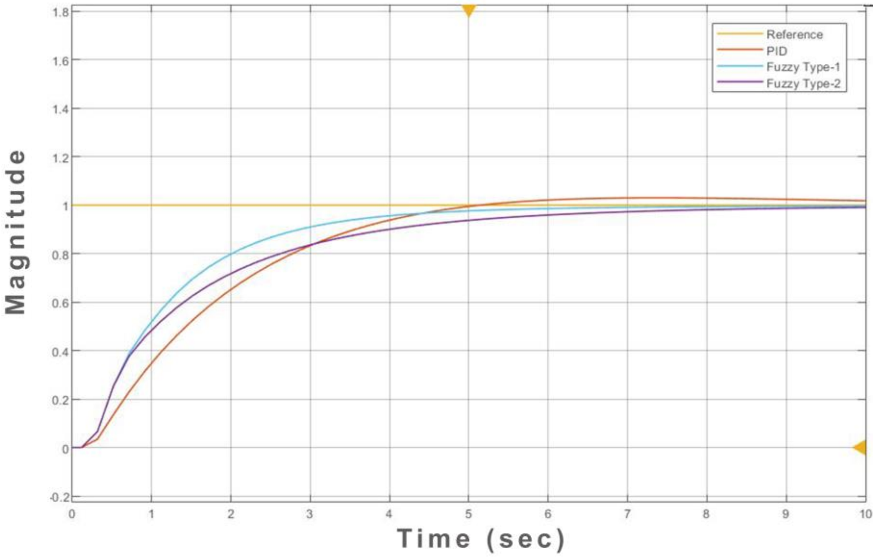


Fig. 5. Comparison of the three controllers after reducing the C, L, and T values.

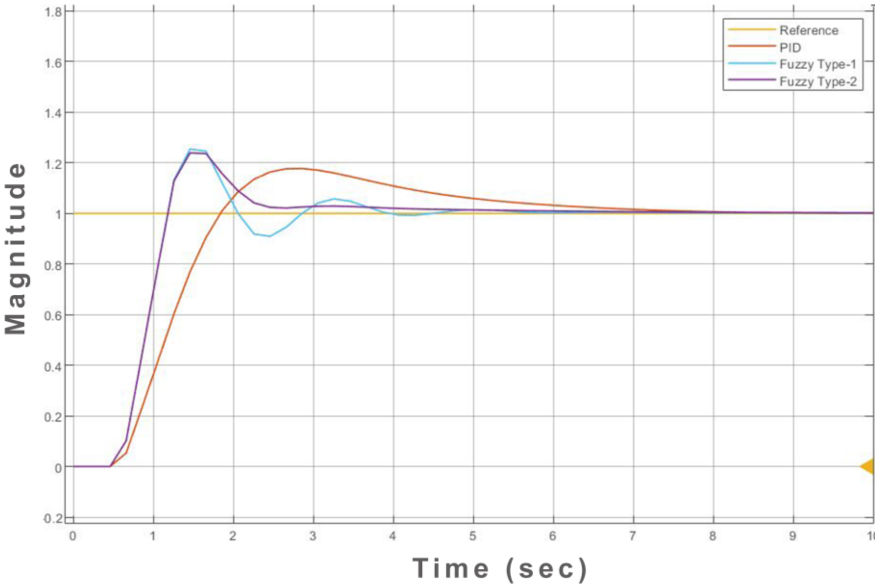
Table 2. Result of reducing values.

Constant	System	Rise Time (s)	Max Overshoot (%)	Settling Time (s)
C = 1	PID	5.167	3.2	> 10
L = 0.25	Type-1 Fuzzy	9.813	0	9.813
T = 2.75	Type-2 Fuzzy	>10	0	>10

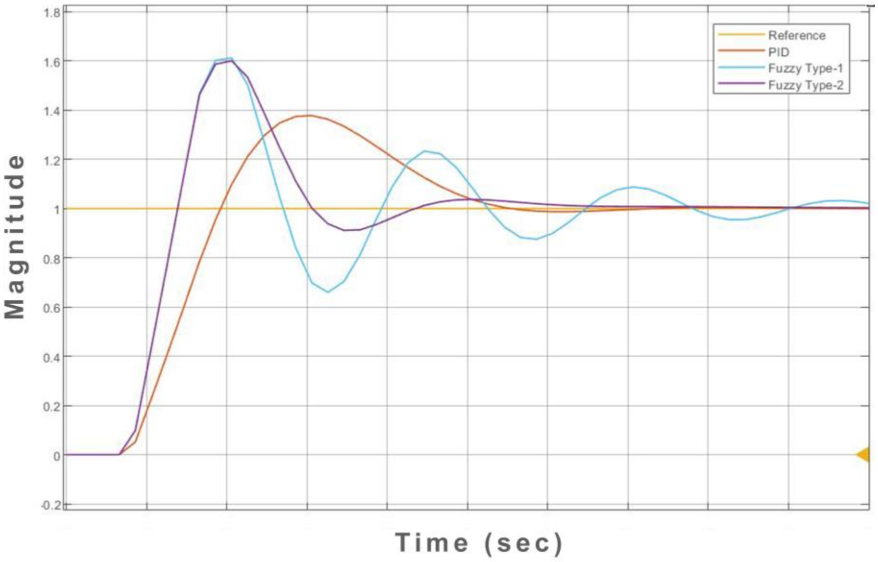
In this experiment, It is shown that the type-1 fuzzy still outperforms the other two methods, as evidenced by the absence of an overshoot value and a fast settling duration, even though it has a longer rise time than PID.type-2 fuzzy is considered to have low performance in this experiment with a reasonably long rise time and settling time, although it does not have an overshoot value.

3.2.2. Enlarging the value of C, L, and T

This experiment was carried out by increasing the three values compared to the first. The values used are C = 2.25, L = 2 that are shown in Fig. 6(a), and T = 6 and C = 2.5, L = 0.8, T = 4 will be shown in Fig. 6(b). The experimental data are shown in Table 3.



(a)



(b)

Fig. 6. Comparison of the three controllers after enlarging the C, L, and T values; (a) for C = 2.25, L = 0.6, T = 3.5, (b) for C = 2.5, L = 0.8, T = 4.

Table 3. Result of enlarging values.

Constant	System	Rise Time (s)	Max Overshoot (%)	Settling Time (s)
C = 2.25	PID	1.832	17.9	8.840
L = 0.6	Type-1 Fuzzy	1.180	25.5	7.610
T = 3.5	Type-2 Fuzzy	1.180	24.3	7.783
C = 2.5	PID	1.919	37.5	9.286
L = 0.8	Type-1 Fuzzy	1.386	61.4	>10
T = 4	Type-2 Fuzzy	1.386	60	8.989

In the experiment, it was found that type-1 and type-2 fuzzy logic controllers outperform the conventional PID controller in terms of Rise time. The type-1 fuzzy logic controller's performance is better compared to the type-2 fuzzy logic controller because the duration of Settling time is faster, with a time difference of 0.173 seconds.

By increasing the three values of C, L, and T, the experimental results show that the three controllers have good performance. However, type-2 fuzzy can be stated as the best method in this experiment because it has quite stable values compared to changes in the value parameters of the other two methods.

From the experiments that have been carried out above, it can be seen that the performance of type-2 fuzzy can outperform the performance of the other two methods by increasing the values of C, L, and T. The superiority of this method can be proven based on two experiments in enlarging these values obtained. The results show that this method has the most stable and robust value for the increase in gain, time delay, and time constant values.

The results of this study follow research conducted by Phan et al. [4] which states that fuzzy type2 has advantages, especially when compared to fuzzy type-1 in the case of dynamic uncertainties. The results of this study are also strengthened by research conducted by Hosseini et al. [15], which states that fuzzy type-2 more capable of capturing the uncertainty and achieving better performance result than fuzzy type-1.

4. Conclusions

In this experiment, the performance test of the proposed system was completed at MATLAB and Simulink®. The conventional PID controller, type-1 and type-2 fuzzy logic controllers were compared. Three attempts are carried out to compare the performance of the three controllers using three different gain (*C*), time delay (*L*), and time constant (*T*) values. The results indicate that type-2 fuzzy has superior performance when compared to conventional PID and type-1 fuzzy if the values of C, L, and T are greater than the transfer function valve characteristics used as research standards. This shows that type-2 fuzzy is the most reliable method in the case of magnification of C, L, and T values with rise time = 1.368 seconds, maximum overshoot = 60%, and settling time = 8.989 seconds.

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