Fuzzy Logic Controller in COG and MAMDANI Method

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ABSTRACT

This project uses MATLAB and the MATLAB Fuzzy logic toolbox to describe the fuzzy logic controller process in a waterbath temperature control system. The primary goal is to get the waterbath system's output temperature as close as possible to the intended set point temperature within the allotted time period while maintaining good performance, stability, smoothness, and the least amount of overshoot. Seven linguistic variables were used in this system, and the fuzzy logic control system used 7*7 matrix rules. In this system, the Gaussian membership function will be used. The inference engines will employ the Max-min (MAMDANI) approach and the center of gravity singleton method for defuzzification. The outcomes of the optimized, effective, and high-performing Simulink model are shown. When the temperature of the desired output is equal to the temperature that the user first defined in the step inputs of the simulation model, the waterbath system produces the desired output temperature.

INTRODUCTION

The waterbath temperature control system is widely used in process of industry applications. The most common usage of this temperature control is in the production of beverage items like chocolate drinks, strawberry milk drinks, etc. The architecture of a fuzzy logic controller includes 49 rules and the Gaussian Membership function. The best accuracy of the defuzzified value is obtained using the center of gravity singleton approach (COGs). The final result is minimally infected if the temperature is above the permitted range. Thus, it is necessary to quickly reach the set point temperature, within the designated time period, and to minimize overshoot and inaccuracy.Its initial application was to regulate the physical procedure suggested by MAMDANI. Then, due to its successful integration into important industrial systems, fuzzy logic controller is receiving more interest.

For unstable dynamics and non-linear systems, FLC performs better than traditional PI Controllers because it can adapt to changing circumstances. In contrast to model-based controllers, FLC is a type of knowledge-based controller that may be designed and implemented at any level without the need for a mathematical model of the process. Water baths are used in the application of sample, thawing, bacterial exams, warming reagents, coin form determination, and microbiological laboratory for incubations because they keep heat of water extremely well in industrial clinical laboratories and waste water plants. Since fuzzy logic controllers do not require mathematical modeling, they differ from other controllers in that they are specifically based on the understanding of system conduct and experimentation acquired through the use of control engines. Since fuzzy logic controllers do not require mathematical modeling, they differ from other controllers in that they are specifically based on the understanding of system conduct and experimentation acquired through the use of control engines.

The following are FLC's benefits:

- Superior performance
- Low electricity usage
- Low cost and complexity
- The capacity to translate hazy information held by human specialists
- Simple to use technology
- Support for software and hardware design implementation
- It is simple to transfer results from one product to another
- The capacity to regulate erratic systems and robust controller behavior

Fuzzy controllers are more reliable since they can work under a larger variety of situations and with noise and disturbances of various types. A fuzzy controller can be created for less money than other controllers that accomplish the same task. Because fuzzy controllers use both a human operator strategy and naturally occurring expressions for their rules, they are more adaptable and simpler to grasp and adjust. Learning how to operate fuzzy controllers, create them, and use them in practical applications is simple.

COG and MAMDANI METHOD

The system dynamics for controlling the temperature of the waterbath is,

$$\frac{dT}{dt} = \frac{F}{V}(T_i - T) + \frac{Q}{VC_p(\rho)}$$

$$\frac{d_y(t)}{dt} = \frac{F(t)}{C} + \frac{Y_0 - Y(t)}{RC}$$

where

t represents the passing of time.
T is the sample duration.
The output temperature is Y(t).
F(t) is the heat entering the system.
Y0 is equal to the constant room temperature.
C is the thermal capacity of the system.
R is the thermal resistance of the system's boundaries to the environment.

Taking the laplace transform of equation

$$sY(s) = \frac{F(s)}{C} + \frac{y_0(s)}{RC} - \frac{Y(s)}{RC}$$

$$a = \frac{1}{RC}, b = \frac{1}{C} \; and \; U(s) = F(s) + \frac{ay_0(s)}{b}$$

$$sY(s) + \frac{Y(s)}{RC} = \frac{F(s)}{C} + \frac{y_0(s)}{RC}$$

$$Y(s)\left(s + \frac{1}{RC}\right) = \frac{F(s)}{C} + \frac{y_0(s)}{RC}$$

$$Y(s)(s + a) = bF(s\,) + ay_0(s)$$

$$Y(s)(s + a) = b\left[F(s) + \frac{ay_0(s)}{b}\right]$$

$$Y(s)(s + a) = b[U(s)]$$

$$\frac{Y(s)}{U(s)} = \left(\frac{b}{s+a}\right) = G(s)$$

Taking transform,

$$G(z) = \frac{Y(z)}{U(z)} = \frac{(bz)}{(z-a)(z-1)}$$

The remaining parameter can be stated by symbolizing a,b as some constant values dependent on R and C

$$a = e^{-\alpha(T)}$$

and

$$b = \frac{\beta}{\alpha}(1 - e^{-\alpha T})$$

The values of the parameters, which are $\alpha = 1.00151 \times 10^4$ and $\beta = 8.67973 \times 10^{-3}$, were taken from an actual water plant.

$$G(z) = \frac{Y(z)}{U(z)} = \frac{0.26z}{(z-0.9969)(z-1)}$$

$$G(z) = \frac{Y(z)}{U(z)} = \frac{0.26z}{z^2-1.9969z+1.9969}$$

Considering that $T \geq 30$ sec limits the sample period.

DEFUZZIFIED VALUES TESTING

Comparing manually calculated results using the COGs approach

1. Allow incorrect temperature to be -0.8.
   Temperature change error equals -0.6
   mistake e(k): MN at (0.3), LN at (0.7).
   Error de(k) MN derivative
   According to the values, the output membership function must be plotted.

   a) The output is LN (-0.8496) if e(k) is LN and de(k) is MN.
   b) The result is MN (-0.8496) if e(k) and de(k) are both MN.

   Using the simplest possible way,

   μ1=min {0.7,1} =0.7

   μ2=min {0.3,1} =0.3

2. The membership member function for the conclusion drawn from the rules,

   μ1(x)=min {0.7, LN}

   μ2(x)=min {0.3, LN}

   Given that $\mu_1(x)$=min$\{0.7, LN\}$

   Use the center of gravity singleton method to calculate the μ crisp value.

$$\mu = \frac{\sum_i \mu(s_i)s_i}{\sum_i \mu(s_i)}$$

$$\mu = \frac{0.7\times\mu_{LN}}{0.7}$$

$$\mu = \frac{0.7\times-0.8496}{0.7}$$

$$\mu = -0.8496$$

The computed value of the output signal is -0.8496 and is established by the aforementioned procedure.

MATLAB testing

```
Command Window
File  Edit  Debug  Desktop  Window  Help
>> fuzzy
>> f=readfis('waterbath')

f =

            name: 'waterbath'
            type: 'mamdani'
       andMethod: 'min'
        orMethod: 'max'
    defuzzMethod: 'centroid'
       impMethod: 'min'
       aggMethod: 'max'
           input: [1x2 struct]
          output: [1x1 struct]
            rule: [1x49 struct]

>> evalfis([-0.8,-0.6],f)

ans =

   -0.8467
```

The final value of hand calculation is compared to MATLAB, both equal. As a result, the defuzzified value is accurate and the FLC rule base used in this system is supported.

DESIGN PROCEDURE:

1.FLC, or fuzzy logic controller

The FLC is designed to control the water temperature of the water bath system using two inputs and a single output. Error (e), derivative of error (de), and u, the fuzzy logic controller's output signal, are the FLC's inputs. Figure shows the block diagram of FLC with a temperature control mechanism for the water bath.

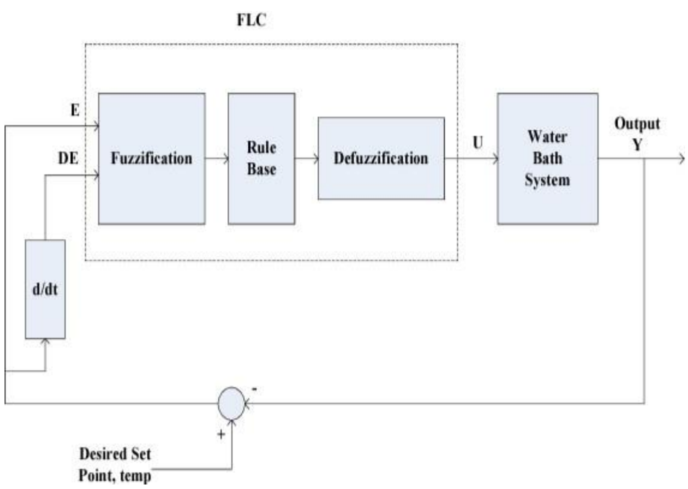

Figure 1: Block diagram for FLC

The fuzzy logic controller consists of three components. The output of the FLC is the control signal, which is the input of the water bath system, which produces the actual temperature. These are fuzzification, which transforms crisp values into fuzzy values, defuzzification, which transforms fuzzy values into non-fuzzy values [crisp values], and rule base, which is a collection of rules to apply in a particular system. The difference between the desired set point temperature and the actual temperature received as feedback from the water bath system is known as the erroneous temperature value. By taking the derivative of error temperature with respect to time, the derivative of error temperature is obtained. The five GUI tools were used by this system to implement the FLC.

Five GUI tools in the fuzzy logic toolbox can be used to design, edit, and research fuzzy inference systems. The FLC's FIS editor window is shown in the figure. It contains the FIS editor, Membership function editor, Rule viewer, Surface viewer, and Rule editor.

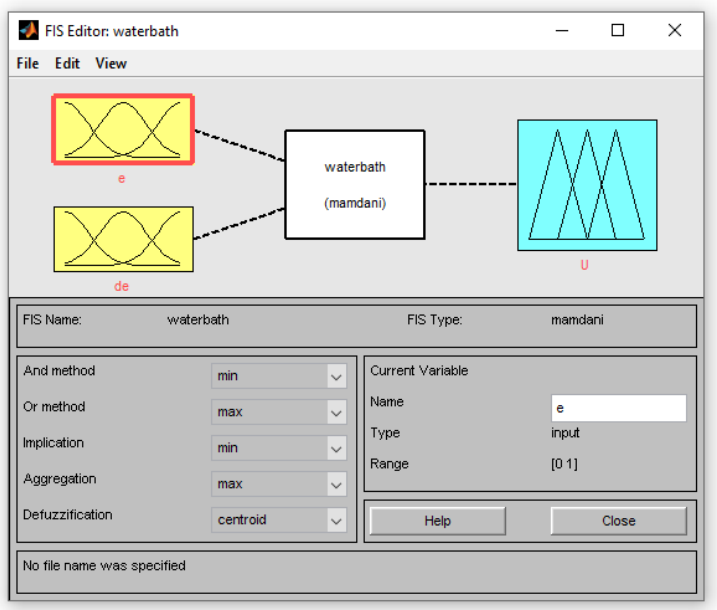

Figure 2: FIS editor of FLC

2.Membership Functions:

The common range [-1,1] is used to establish the FLC's two input and single output membership functions. Equal base and 50% over lab between the vincity membership functions are used for the Gaussian membership function. Large Negative (LN), Medium Negative (MN), Small Negative (SN), Zero (ZE), Small Positive (SP), Medium Positive (MP), and Large Positive (LP) are the seven fuzzy set of FLC inputs and outputs. Figure presents the inputs and outputs' Gaussian Membership function.

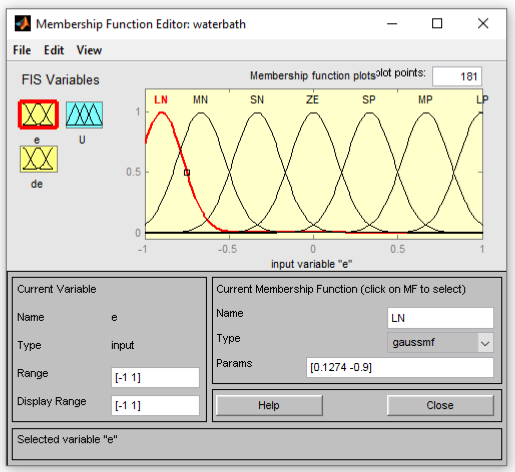

Figure 3: Gaussian Membership function for error temperature

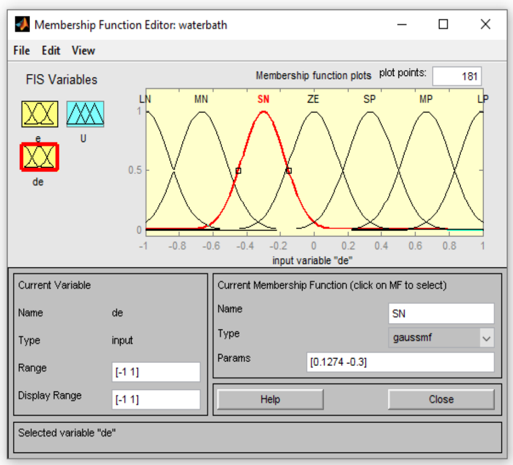

Figure 4: Gaussian Membership function for change of error

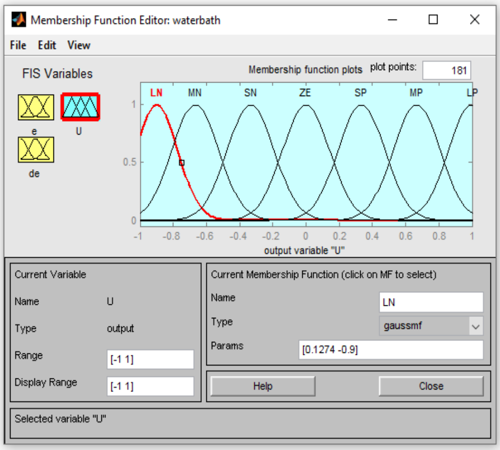

Figure 5: Gaussian Membership function for control signal

Where ,

Large Negative (LN)

Medium Negative (MN)

Small Negative (SN)

Small Positive(SP)

Zero(ZE)

Medium-Grade Positive(MP)

Large Positive (LP)

Basis for Rules

DE/E	LN	MN	SN	ZE	SP	MP	LP
LP	ZE	SP	MP	LP	LP	LP	LP
MP	SN	ZE	SP	MP	LP	LP	LP
SP	MN	SN	ZE	SP	MP	LP	LP
ZE	LN	MN	SN	ZE	SP	MP	LP
SN	LN	LN	MN	SN	ZE	SP	MP
MN	LN	LN	LN	MN	SN	ZE	SP
LN	LN	LN	LN	LN	MN	SN	ZE

The FLC is designed using 49 rules and the seven linguistic factors. According to the guidelines, if the error temperature is LN and its derivative is MP, the control signal should be SN, as shown in the table.

The 49 rules listed here are:

1. In the event where e is LN and de is LP, then u is ZE
2. In the event where e is LN and de is MP, then u is SN
3. In the event where e is LN and de is LP, then u is MN
4. In the event where e is LN and de is ZE, then u is LN

5. In the event where e is LN and de is SN, then u is LN
6. In the event where e is LN and de is MN, then u is LN
7. In the event where e is LN and de is LN, then u is LN
8. In the event where e is MN and de is LP, then u is SP
9. In the event where e is MN and de is MP, then u is ZE
10. In the event where e is MN and de is SP, then u is SN
11. In the event where e is MN and de is ZE, then u is MN
12. In the event where e is MN and de is SN, then u is LN
13. In the event where e is MN and de is MN, then u is LN
14. In the event where e is MN and de is LN, then u is LN
15. In the event where e is SN and de is LP, then u is MP
16. In the event where e is SN and de is MP, then u is SP
17. In the event where e is SN and de is SP, then u is ZE
18. In the event where e is SN and de is ZE, then u is SN
19. In the event where e is SN and de is SN, then u is MN
20. In the event where e is SN and de is MN, then u is LN
21. In the event where e is SN and de is LN, then u is LN
22. In the event where e is ZE and de is LP, then u is LP
23. In the event where e is ZE and de is MP, then u is MP
24. In the event where e is ZE and de is SP, then u is SP
25. In the event where e is ZE and de is ZE, then u is ZE
26. In the event where e is ZE and de is SN, then u is SN
27. In the event where e is ZE and de is MN, then u is MN
28. In the event where e is ZE and de is LN, then u is LN
29. In the event where e is SP and de is LP, then u is LP
30. In the event where e is SP and de is MP, then u is LP
31. In the event where e is SP and de is SP, then u is MP
32. In the event where e is SP and de is ZE, then u is SP
33. In the event where e is SP and de is SN, then u is ZE
34. In the event where e is SP and de is MN, then u is SN
35. In the event where e is SP and de is LN, then u is MN
36. In the event where e is MP and de is LP, then u is LP
37. In the event where e is MP and de is MP, then u is LP
38. In the event where e is MP and de is SP, then u is LP
39. In the event where e is MP and de is ZE, then u is MP
40. In the event where e is MP and de is SN, then u is SP
41. In the event where e is MP and de is MN, then u is ZE
42. In the event where e is MP and de is LN, then u is SN
43. In the event where e is LP and de is LP, then u is LP
44. In the event where e is LP and de is MP, then u is LP
45. In the event where e is LP and de is SP, then u is LP
46. In the event where e is LP and de is ZE, then u is LP
47. In the event where e is LP and de is SN, then u is MP
48. In the event where e is LP and de is MN, then u is SP
49. In the event where e is LP and de is LN, then u is ZE

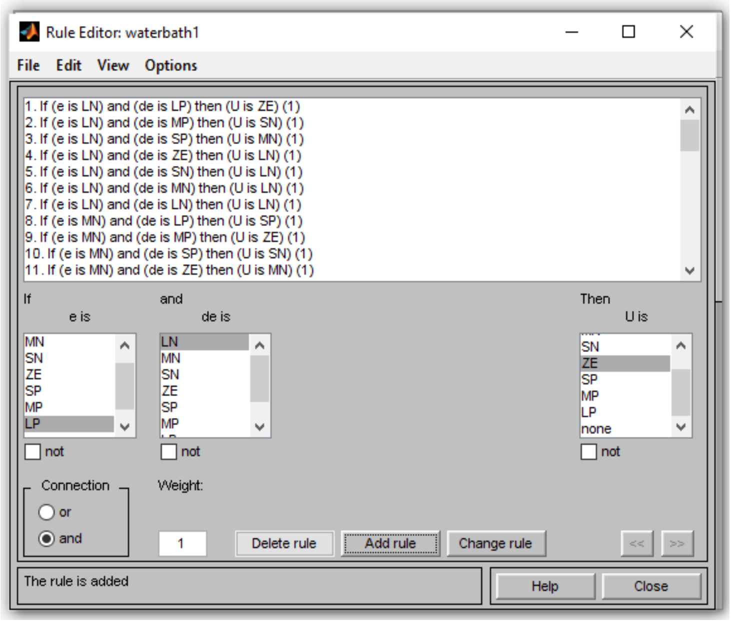

Figure 6: Rule editor of FLC

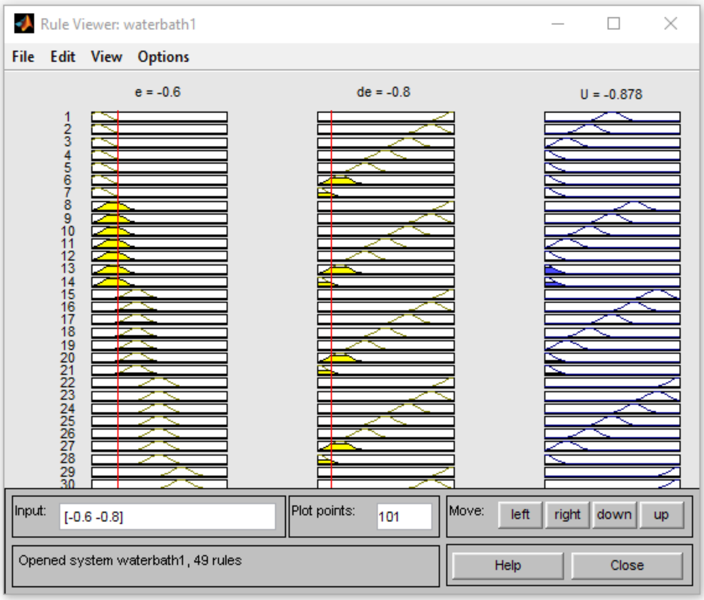

Figure 7: Rule viewer of FLC

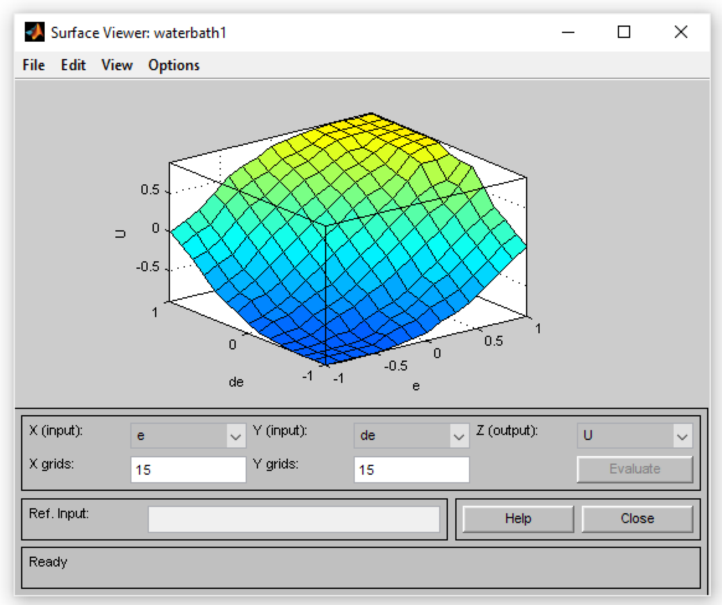

Figure 8: Surface viewer of FLC

The rule editor's ability to build rule declarations in an if-then format is based on representations of input and output that can be changed and described using the FIS Editor. By using the menu items in the five GUI tools, the Fuzzy system can be saved, closed, opened, and edited. The FLC function block parameter is shown. It is necessary to save the fuzzy inference system as a .fis file in order for it to function in the fuzzy logic toolbox. To simulate the tank model, this .fis file must then be inserted in the fuzzy logic controller block. So, by writing the name .fis in this block, the fuzzy block parameter is essentially required to send and save the current fuzzy inference system into the workspace.

Desired at point Temperature (°C)	Specified time period (in minutes)
35	$0 \leq t \leq 30$
45	$30 < t \leq 60$
55	$60 < t \leq 90$
65	$90 < t \leq 120$
75	$120 < t \leq 150$
85	$150 < t \leq 180$
75	$180 < t \leq 210$
65	$210 < t \leq 240$
55	$240 < t \leq 270$

As a result, the desired Temperature is specified in the input. 35 has been entered as the Initial Temperature value for $0 < t \leq 30$ minutes. In the following step, the following time intervals are set: $30 < t \leq 60$min, 55 for $60 < t \leq 90$ min , 65 for $90 < t \leq 120$ min , 75 for $120 < t \leq 150$min ,85 for $150 < t \leq 180$ min , 75 for $180 < t \leq 210$ min , 65 for $210 < t \leq 240$ min and 55 for $240 < t \leq 270$ min. As can be seen, FLC is quickly operated and delivers the result based on the user's requirements. As a result, the system's performance is good and efficient when using the COGs method and gaussian membership function.

CONCLUSION

This project explains how a fuzzy logic controller's ability to control temperature in a water bath system is evaluated. The MATLAB Simulink and MATLAB Fuzzy Logic Toolbox are used to run this system. To achieve the best outcome for this system, 49 additional rules and the Gaussian Membership function are applied. It is clear that the FLC operates quickly and delivers results in accordance with user requirements. The center of gravity method and Gaussian membership produce a good and efficient result.

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