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 Max-min (MAMDANI) method and the center of gravity singleton method will be used by the inference engines for defuzzification. The waterbath system generates the desired output temperature when it coincides with the temperature that the user initially defined in the step inputs of the simulation model.

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. In order to avoid overshoot and inaccurate results, it is essential to reach the set point temperature quickly and within the allotted time frame. Its initial use was to control 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. Model-based controllers must have a mathematical model of the process in order to be designed and implemented, but FLCs are a type of knowledge-based controller that can be created and implemented at any level. Because they maintain water's heat so effectively, water baths are used in the application of sample, thawing, bacterial exams, warming reagents, coin form determination, and microbiological laboratory for incubations. 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 ability to control erratic systems and strong controller behavior

Since they can function in a wider range of conditions and with different types of noise and disturbances, fuzzy controllers are more dependable. More affordable than other controllers that perform the same task is the creation of a fuzzy controller. 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.
Y(t) is the output temperature.
The system's heat input is represented by F(t).
Y_0 is equivalent to the constant temperature in a room.
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,

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

By symbolizing a, b as some constant values based on R and C, the final parameter can be stated.

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

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. Assume that the temperature is incorrect, at -0.8.
   Error due to temperature change equals -0.6.
   erroneous values for e(k): MN at (0.3), BN at (0.7).
   Derivative of error de(k) MN.
   The output membership function needs to be plotted based on the values.

   a) e(k) must be BN and de(k) must be MN for the output to be BN (-0.8496).

   b) If e(k) and de(k) both have MN values, the answer is MN (-0.8496).

   In the simplest manner,

   μ1=min {0.7,1} =0.7

   μ2=min {0.3,1} =0.3

2. For the conclusion derived from the rules, the membership member function,

   μ1(x)=min {0.7, BN}

   μ2(x)=min {0.3, BN}

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

To determine the crisp value, apply the center of gravity singleton method.

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

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

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

$$\mu = -0.8496$$

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. The FLC rule base employed in this system is thus supported, and the defuzzified value is precise.

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 depicts the FLC block diagram with a water bath temperature control system.

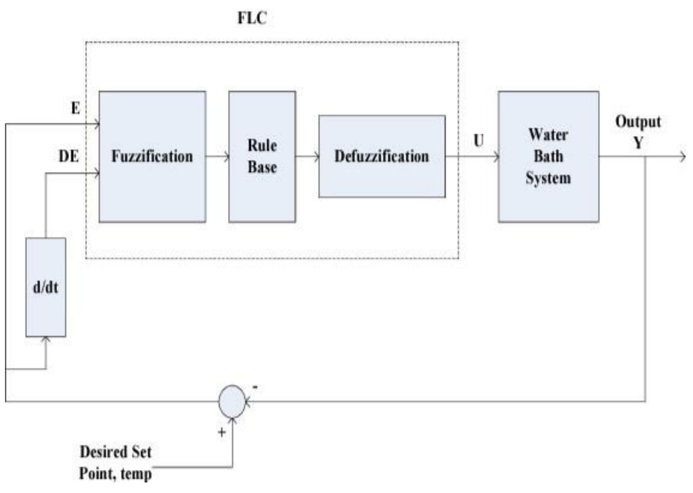

Figure 1: Block diagram for FLC

The fuzzy logic controller consists of three components. The water bath system's input receives the control signal from the FLC as its output, which generates 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. Erroneous temperature value is the difference between the actual temperature and the desired set point temperature as reported by the water bath system. The derivative of error temperature can be obtained by taking the error temperature's derivative with respect to time. 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.

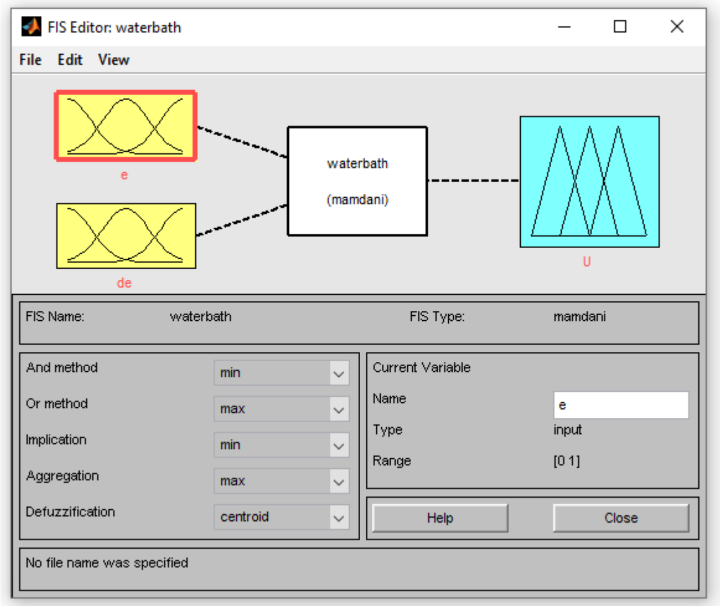

Figure 2: FIS editor of FLC

2.Membership Functions:

The common range [-1,1] is used to establish the FLC's two input and single output membership functions. The Gaussian membership function uses the vincity membership functions with equal base and 50% over lab. The seven fuzzy set of FLC inputs and outputs are Big Negative (BN), Moderately Negative (MN), Low Negative (LN), Zero (ZE), Small Positive (SP), Positive in the Medium Range (MP), and Big Positive (BP). Figure presents the inputs and outputs Gaussian Membership function.

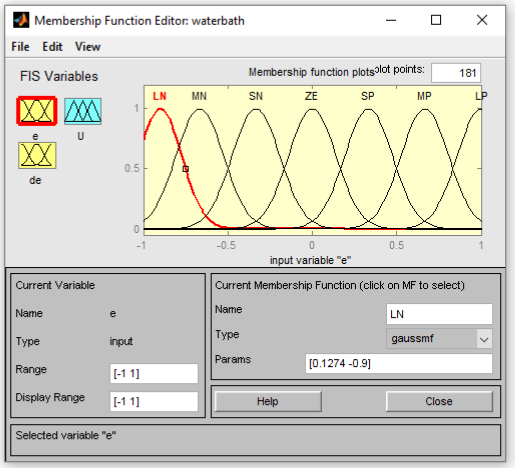

Figure 3: Gaussian Membership function for error temperature

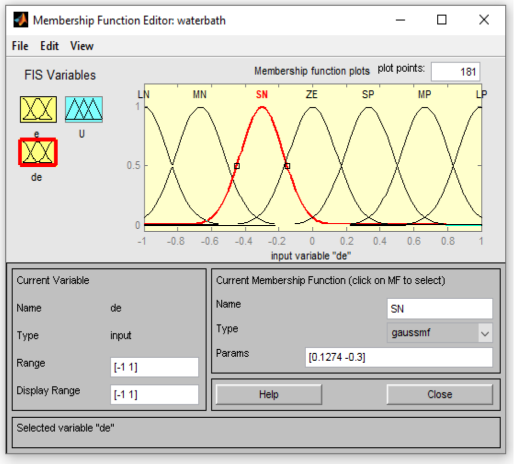

Figure 4: Gaussian Membership function for change of error

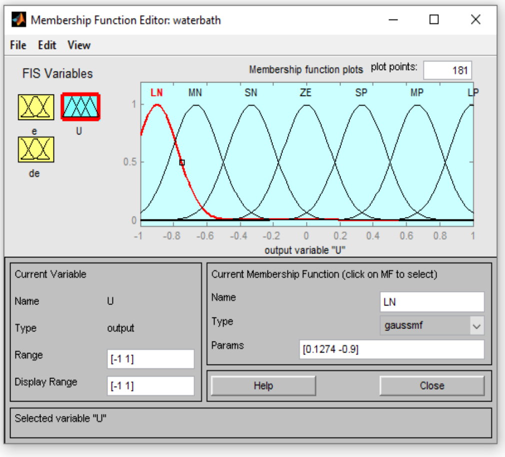

Figure 5: Control signal's Gaussian Membership function

Where,

Big Negative (BN)

Moderately Negative (MN)

Low Negative (LN)

Small Positive (SP)

Zero (ZE)

Positive in the Medium Range (MP)

Big Positive (BP)

Basis for Rules

DE/E	BN	MN	LN	ZE	SP	MP	BP
BP	ZE	SP	MP	BP	BP	BP	BP
MP	LN	ZE	SP	MP	BP	BP	BP
SP	MN	LN	ZE	SP	MP	BP	BP
ZE	BN	MN	LN	ZE	SP	MP	BP
LN	BN	BN	MN	LN	ZE	SP	MP
MN	BN	BN	BN	MN	LN	ZE	SP
BN	BN	BN	BN	BN	MN	LN	ZE

The FLC is designed using 49 rules and the seven linguistic factors. The control signal should be LN in accordance with the recommendations if the error temperature is BN and its derivative is MP, as shown in the table.

These are the 49 rules that are listed here:

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

5. In the event where e is BN and de is LN, then u is BN
6. In the event where e is BN and de is MN, then u is BN
7. In the event where e is BN and de is BN, then u is BN
8. In the event where e is MN and de is BP, 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 LN
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 LN, then u is BN
13. In the event where both e and de are MN, u is BN
14. In the event where e is MN and de is BN, then u is BN
15. In the event where e is LN and de is BP, then u is MP
16. In the event where e is LN and de is MP, then u is SP
17. In the event where e is LN and de is SP, then u is ZE
18. In the event where e is LN and de is ZE, then u is LN
19. In the event where e is LN and de is LN, then u is MN
20. In the event where e is LN and de is MN, then u is BN
21. In the event where e is LN and de is BN, then u is BN
22. In the event where e is ZE and de is BP, then u is BP
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 LN, then u is LN
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 BN, then u is BN
29. In the event where e is SP and de is BP, then u is BP
30. In the event where e is SP and de is MP, then u is BP
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 LN, then u is ZE
34. In the event where e is SP and de is MN, then u is LN
35. In the event where e is SP and de is BN, then u is MN
36. In the event where e is MP and de is BP, then u is BP
37. In the event where e is MP and de is MP, then u is BP
38. In the event where e is MP and de is SP, then u is BP
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 LN, 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 BN, then u is LN
43. In the event where e is BP and de is BP, then u is BP
44. In the event where e is BP and de is MP, then u is BP
45. In the event where e is BP and de is SP, then u is BP
46. In the event where e is BP and de is ZE, then u is BP
47. In the event where e is BP and de is LN, then u is MP
48. In the event where e is BP and de is MN, then u is SP
49. In the event where e is BP and de is BN, then u is ZE

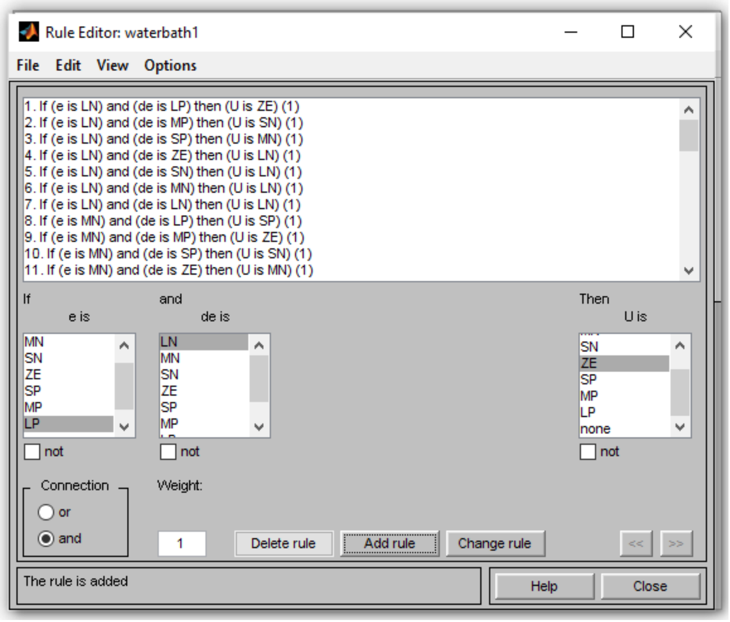

Figure 6: FLC's rule editor

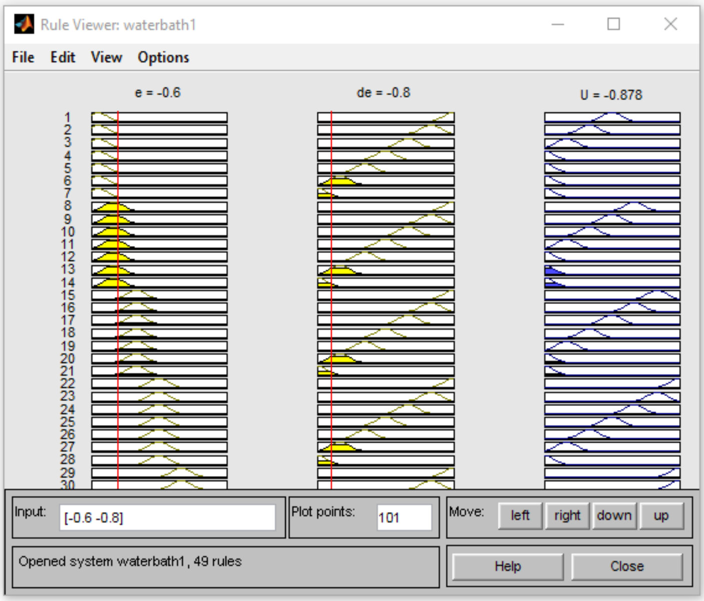

Figure 7: FLC's rule viewer

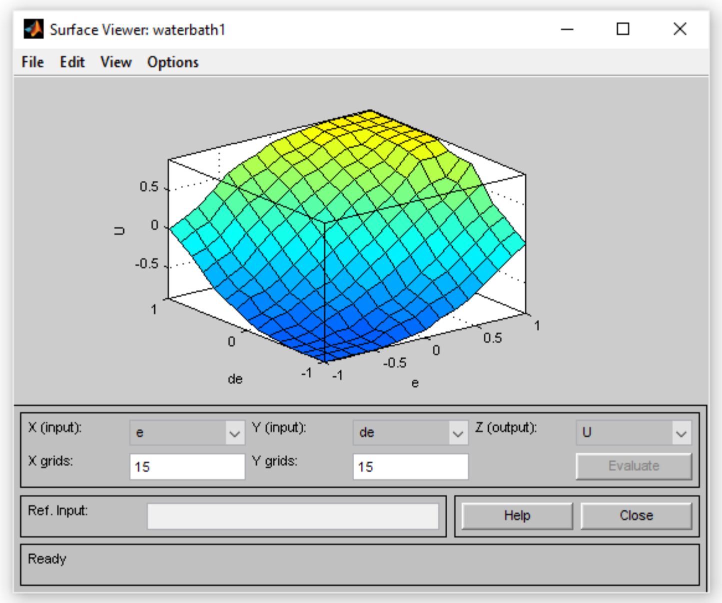

Figure 8: FLC's surface viewer

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. The five GUI tools menu allow users to save, close, open, and edit the Fuzzy system. It displays the FLC function block parameter. The fuzzy inference system must be saved as a .fis file in order to work with the fuzzy logic toolbox. This .fis file must then be added to the fuzzy logic controller block in order to simulate the tank model. The fuzzy block parameter is thus essentially required to send and save the current fuzzy inference system into the workspace by writing the name .fis in this block.

Desired at this time Temperature (°C)	Specified time frame (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 input contains the desired Temperature. The Initial Temperature value for $0 < t \leq 30$ minutes has been set to 35. The following step involves setting the following time intervals: $30 < t \leq 60$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 operates quickly and produces the desired outcome based on the user's specifications. 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. This system is operated using MATLAB Simulink and MATLAB Fuzzy Logic Toolbox. 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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