Fuzzy and Neuro-Fuzzy Systems

University of Coimbra (Masters in Intelligent Systems)
Subject: Computational Learning

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Abstract

This Assignment is divided by two parts. The first one consists on a Simulink implementation of a fuzzy controller and test it with Mamdani type and Sugeno type systems with the assigned group transfer function of:

$$TransferFunction = \frac{2s+2}{s^3+3s^2+4s+2}$$

The objective of this part was achieve the best combination of variables for regulation of the system with changes of rules, scale factors and diffusions. The second part of the assignment was to implement a neuro-fuzzy system for modeling dynamic processes with the same group assign transfer function. This system is build around random data, determining the functions of belonging to the antecedents and the constant of consequents.

Part A

1 Introduction

Automatic control is a scientific and technological area that manipulates systems with feedback mechanisms in order to keep the output equal to the reference. But in reality, the objective is to minimize the error every moment. This fuzzy controllers are classified by they decision function. There are two main groups, the Mandani and the Sugeno. The Mandani are based on fuzzy implication functions and composition operators for output definitions. By the other hand, Sugeno's don't need these. They use 3 key variables, reference changes, load disturbances and disturbances in the actuator. The objective of this part A is trying to approximate the output of the system with the reference by changing the scale values.

2 Making Controllers

The controller structure are composted by 12 elements:

Controller	Nº Rules	Function
Mandani	9	Triangular
	9	Gaussian
	9	Trapezoidal
	25	Triangular
	25	Gaussian
	25	Trapezoidal
Sugeno	9	Triangular
	9	Gaussian
	9	Trapezoidal
	25	Triangular
	25	Gaussian
	25	Trapezoidal

Table 1: Part A Controllers

The test is 300 seconds long and it's divided in various sections:

0-50s	Perception of signal is analyzed
50-100s	The way the controller fits the function
100-150s	The actuator error is induced
150-200s	Recover after the error.
200-250s	The load error is induced

Table 2: Controller Analysis

3 Procedure

This was the hardest part of the Assignment. As the project description tells us, finding the right scale values for the system is no easy task. For all simulation we used 300s runtime.

3.1 Square wave form

The first tests we took was the square wave form. We made various runs to determine, by analyzing our integral quadratic error, what was the ideal interval for the scales. We found out that for the square wave form, the first scale had a drastic impact on the system and the right intervals were between [0.6,0.8]. After we found out what was the right scale1 interval, we changed the values of scale2 for each interval in scale1 and we got this results we got from all the simulations:

Scale 1 factor	Scale 2 factor	Integral Error (Average)
0.1	1	213
0.5	1	52.1
0.6	1	47.7
0.6	2	37.2
0.6	5	28.6
0.6	8	25
0.6	9	25.4
0.7	1	47.2
0.7	4	28.9
0.7	5	27
0.7	7	25
0.7	8	25.7
0.7	9	24.1
0.7	10	23.9
0.8	1	46.5
0.8	2	35.8
0.8	5	27.4
0.8	7	24.3
0.8	8	23.9
0.8	9	24

Table 3: Square wave form simulation results.

Now let's look at some graphs from the best systems:

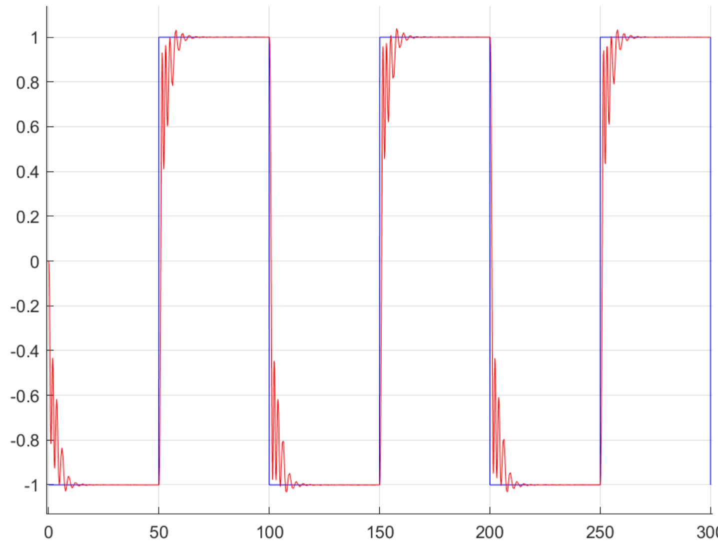

Figure 1: Gaussian Sugeno 9 Rules - Scale1=0.7 & Scale2=10 with Error=16.7

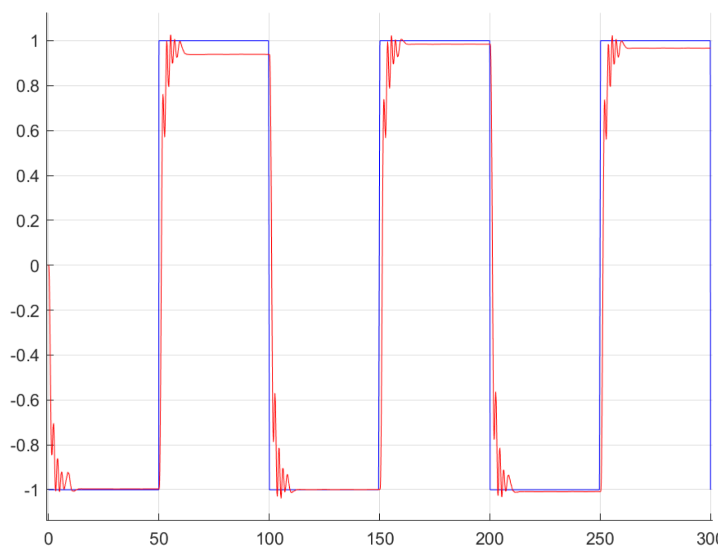

Figure 2: Trapezoidal Mandani 25 Rules - Scale1=0.8 & Scale2=8 with Error=22.3

3.2 Tracking problem test

For this case we study if the controller is good for tracking problems. For this we used wave form(sine) that gives us sinusoidal reference. We made different runs to get the best scale to get the lowest error with better performance. These were the global results we got:

Scale 1 factor	Scale 2 factor	Integral Error (Average)
0.01	1	115.31
0.01	10	131.21
0.1	1	106.58
0.2	1	81.59
0.3	1	64.84
0.4	1	47.49
0.5	1	33.93
0.6	1	25.31
0.7	1	19.57
0.8	1	15.52
0.9	1	12.59
1	1	10.41
2	1	2.72
3	1	1.00
4	1	0.685
5	1	0.452
6	1	0.324
7	1	0.255
15	1	0.065
100	1	111259

Table 4: Sine wave form simulation results.

The table shows that the lowest error we got was 0.065 with Scale1=15 and Scale2=1. Let's have a look at the graphs from this simulation and it's table:

Controller	Nº Rules	Function	Integral Error (Average)
Mandani	9	Gaussian	0.166
Mandani	9	Trapezoidal	0.161
Mandani	9	Triangular	0.149
Mandani	25	Gaussian	0.011
Mandani	25	Trapezoidal	0.014
Mandani	25	Triangular	0.014
Sugeno	9	Gaussian	0.029
Sugeno	9	Trapezoidal	0.115
Sugeno	9	Triangular	0.056
Sugeno	25	Gaussian	0.022
Sugeno	25	Trapezoidal	0.010
Sugeno	25	Triangular	0.036

Table 5: Best sine wave form simulation group results.

Graphs from the best and worse from this simulation group:

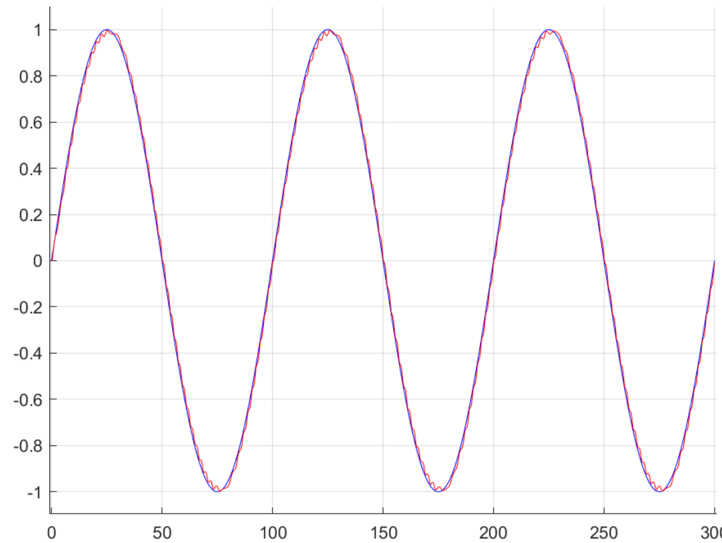

Figure 3: Gaussian Mandani 9 Rules - Scale1=15 & Scale2=1 with Error=0.166

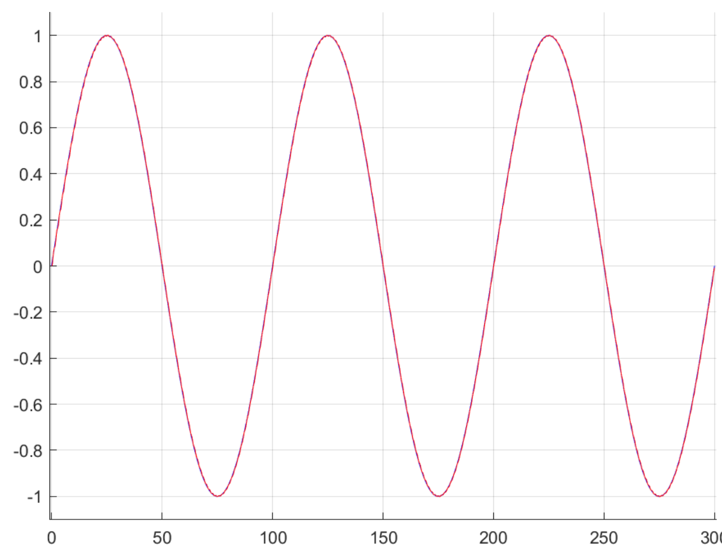

Figure 4: Gaussian Mandani 25 Rules - Scale1=15 & Scale2=1 with Error=0.011

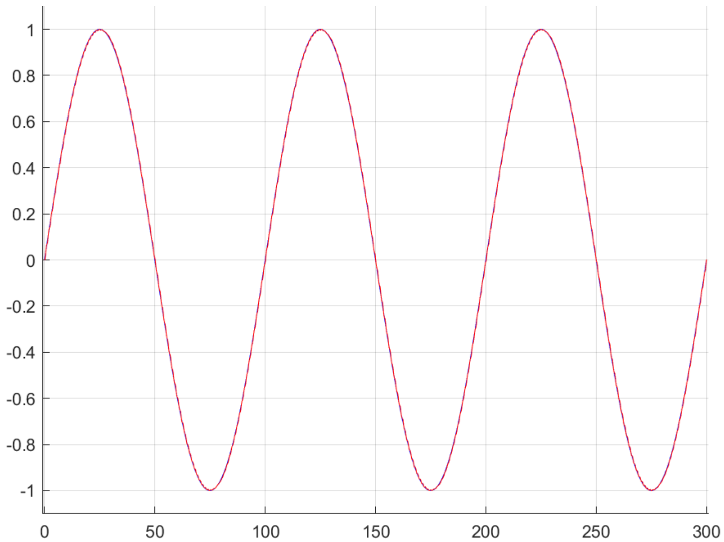

Figure 5: Trapezoidal Sugeno 9 Rules - Scale1=15 & Scale2=1 with Error=0.010

The results we can extract from this test is that the controllers that has 25 Rules have always better results than the 9 ones and the Scale1 importance for the sine wave test have a great impact on the system. All these Results can be seen in the folder of the Project code.

4 Conclusion

With the results we got from this part of the assignment we can conclude that the controllers with 25 rules are always better than the 9 rules, because the error is lower. Likewise, the controllers Mandani with Gaussian function better withstand perturbation by the actuator. The function triangular better withstand to perturbations on the actuator and load. At last, the results are very dependent of the scales factors and the activate function.

Part B

1 Introduction

In the second part of the assignment the objective is to modulate our transfer function using neuro-diffuse systems. From our transfer function and random data, the functions of belonging of the antecedents and consequent constant of neuro-diffuse system is constructed. Subtractive method and fuzzy c-means were used to determine the initial rules. The optimization of the error is done through back-propagation and the hybrid method.

2 Structure

Analyzing out transfer function we found out that the number of poles is greater than the number of zeros. With this data we can say that the input at one instant only affects the output at the next instant. So knowing that the system is third order we can say that the memory goes k-3. Finally, we needed to transform our activate function to a discrete one:

$$\frac{0.4917z^2 + 0.0653z - 0.0905}{1.0000z^3 - 0.7654z^2 + 0.2816z - 0.0498}$$

Here are the results we got from this section:

Clustering	Optimization Method	mse
Fuzzy C-Means	Hybrid	6.0664e-11
Fuzzy C-Means	Retro-Propagation	4.0024e-05
Subtractive	Hybrid	7.7526e-11
Subtractive	Retro-Propagation	3.0798e-05

Table 6: Part B Results

3 Conclusion

Looking at the previous table we can conclude that the best for clustering is the Fuzzy C-Means using a optimization method of hybrid. We can also conclude that the hybrid method gives the lowest error than the retro-propagation.