ECE 657 Spring 2020
Assignment 4

Guidelines

- In your submission, upload two files only: A report with all the answers to the problems and a code file (if needed) for problem 4. Do **not** upload a compressed file.
- All problems should be solved by hand with *detailed* steps. You can use MATLAB or Python for the inferencing step of Problem 4 **only**. Fuzzy Toolbox in MATLAB and skfuzzy in Python are permitted for this problem.
- State any assumptions you make throughout.
- Make sure all your sketches are clear and that they show where each point lies.

Deadline

July 31st 2021, 11:59 PM

PROBLEM 1

We are given a dynamic process guided by the fuzzy logic control system with the following two fuzzy control rules:

Rule 1 If x is A_1 and y is B_1 Then z is C_1

Rule 2 If x is A_2 and y is B_2 Then z is C_2

Where x_0 and y_0 are the sensor readings for the linguistic input variables x and y and z is the consequent linguistic variable. The fuzzy predicates for the linguistic variables are given by A_1, A_2, B_1, B_2, C_1 and C_2, which membership functions are as:

$$\mu_{A_1}(x) = \begin{cases} \dfrac{x-2}{3} & 2 \le x \le 5 \\ \dfrac{8-x}{3} & 5 < x \le 8 \end{cases} \qquad \mu_{A_2}(x) = \begin{cases} \dfrac{x-3}{3} & 3 \le x \le 6 \\ \dfrac{9-x}{3} & 6 < x \le 9 \end{cases}$$

$$\mu_{B_1}(y) = \begin{cases} \dfrac{y-5}{3} & 5 \le y \le 8 \\ \dfrac{11-y}{3} & 8 < y \le 11 \end{cases} \qquad \mu_{B_2}(y) = \begin{cases} \dfrac{y-4}{3} & 4 \le y \le 7 \\ \dfrac{10-y}{3} & 7 < y \le 10 \end{cases}$$

$$\mu_{C_1}(z) = \begin{cases} \dfrac{z-1}{3} & 1 \le z \le 4 \\ \dfrac{7-z}{3} & 4 < z \le 7 \end{cases} \qquad \mu_{C_2}(z) = \begin{cases} \dfrac{z-3}{3} & 3 \le z \le 6 \\ \dfrac{9-z}{3} & 6 < z \le 9 \end{cases}$$

Further assume that at time t_1 we are reading the sensor values at $x_0(t_1) = 4$ and $y_0(t_1) = 8$. Using the Mamdani inferencing system and the Mean of Maximum (MOM) defuzzifcation1 strategy, find the final control output at time t_1. What is the value of the control output when we use the largest of maximum (lom) defuzzification strategy?

PROBLEM 2

In the art of navigation, gyros are often used along with accelerometers to navigate. Biases are calculated on gyros. But as the cost of gyro goes down, the turn-on-to-turn-off reliability of the bias goes down; i.e., decreased gyro cost implies decreased reliability. Let us pose a bias, called x-gyro bias, as denoted by the symbol x_{gb}. This problem is actually continuous, but we will discretize it. We have uncertainty about the nominal value of the bias, and we construct a fuzzy set about the nominal x_{gb}, as follows:

$$\underset{\sim}{A} = \left\{ \frac{.2}{x_{gb}-3\delta_x} + \frac{.4}{x_{gb}-2\delta_x} + \frac{.6}{x_{gb}-\delta_x} + \frac{.8}{x_{gb}} \right.$$
$$\left. + \frac{.6}{x_{gb}+\delta_x} + \frac{.4}{x_{gb}+2\delta_x} + \frac{.2}{x_{gb}+3\delta_x} \right\}$$

For this problem, let x_{gb}=2°/hour and δ_x=0.1. We get

$$x\text{-gyro bias} = \underset{\sim}{A} = \left\{ \frac{.2}{1.7} + \frac{.4}{1.8} + \frac{.6}{1.9} + \frac{.8}{2.0} + \frac{.6}{2.1} + \frac{.4}{2.2} + \frac{.2}{2.3} \right\}$$

Let $\underset{\sim}{B}$ be a fuzzy set describing an accelerator bias in the x direction, where the normal bias = $0.3\,g$, where g is the acceleration due to gravity. The membership function might look like

$$\underset{\sim}{B} = \left\{ \frac{.1}{.25} + \frac{.4}{.27} + \frac{.9}{.3} + \frac{.4}{.33} + \frac{.1}{.35} \right\}$$

(a) Using classical implication operator $\mu_{\underset{\sim}{R}} = \max[\min(\mu_{\underset{\sim}{A}}, \mu_{\underset{\sim}{B}}), (1-\mu_{\underset{\sim}{A}})]$, find a relation R for IF $\underset{\sim}{A}$ THEN $\underset{\sim}{B}$.

(b) Say we have to change x-gyros and the new gyro has the following fuzzy bias:

$$\underset{\sim}{A}' = \left\{ \frac{0}{1.7} + \frac{.5}{1.8} + \frac{.7}{1.9} + \frac{.95}{2.0} + \frac{.7}{2.1} + \frac{.5}{2.2} + \frac{0}{2.3} \right\}$$

Calculate the associated accelerometer bias using

(i) Max-min composition, $\underset{\sim}{T} = \underset{\sim}{A}' \circ \underset{\sim}{R}$

(ii) Max-product composition, $\underset{\sim}{T} = \underset{\sim}{A}' \circ \underset{\sim}{R}$

PROBLEM 3

Discuss how genetic algorithm is different from genetic programming.

PROBLEM 4

A robot is navigating in an environment where there are obstacles it needs to avoid. The robot is equipped with sensors that can detect the obstacle. It also relays the distance and angle relative to the robot. Using these measurements, create a fuzzy inferencing system to decide the *Speed* and *Steering.*

The following fuzzy quantities are defined, with their corresponding states:

D	Distance from obstacle	N=Near, F=Far, VF=Very Far
A	Angle with obstacle	S=Small, M=Medium, L=Large
S	Speed	SS= Slow Speed, MS=Medium Speed, FS=Fast Speed, MS= Maximum Speed
ST	Steering Turn	MST= Mild Turn, SST=Sharp Turn, VST= Very Sharp Turn

The universe of each of the quantities are defined below

Fuzzy Quantity	**Minimum Value**	**Maximum Value**	**Step**
D	0	10	0.5
A	0	90	1
S	0	5	0.2
ST	0	90	1

Assume that the angles and steering are the same for both right and left directions. For example, a reading of angle=-55° is the same as angle=55° for your fuzzy system.

In your design, please consider the following preliminary behavior *as a guide.* Note that the system's behavior is **not limited** to these actions but **must include** them:

- When an obstacle is detected, avoid it: does not matter which direction; left or right
- When there is no obstacle move forward
- Speed is reduced when turning away from an obstacle
- Speed is increased when cruising (when there is no obstacle)

1. Design a fuzzy system including:
    a. The membership functions for each of the fuzzy quantities (following the provided states)
    b. The rule base that will be used for inferencing
    c. The inferencing system that will be used (Mamdani, Sugeno, etc…)
    d. The defuzzification method
2. Explain your choices in 1-**c** and 1-**d** with details**.**
3. Provide at least 2 examples of inputs and show your system's output control command. Note: You can do this step using MATLAB or Python.

Please provide detailed calculations and state any assumptions you make (if any).