Fuzzy Logic Controller

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Fuzzy logic controller is a system which is used to *control the* ***working*** of a **physical system** with the help of **FUZZY** logic.

Fuzzy Systems : Fuzzy Logic Controller

- Concept of fuzzy theory can be applied in many applications, such as fuzzy reasoning, fuzzy clustering, fuzzy programming etc.
- Out of all these applications, fuzzy reasoning, also called ”fuzzy logic controller (FLC)” is an important application.
- Fuzzy logic controllers are special expert systems. In general, a FLC employs a knowledge base expressed in terms of a fuzzy inference rules and a fuzzy inference engine to solve a problem.
- We use FLC where an exact mathematical formulation of the problem is not possible or very difficult.
- These difficulties are due to non-linearities, time-varying nature of the process, large unpredictable environment disturbances etc.

A general scheme of a fuzzy controller is shown in the following figure.

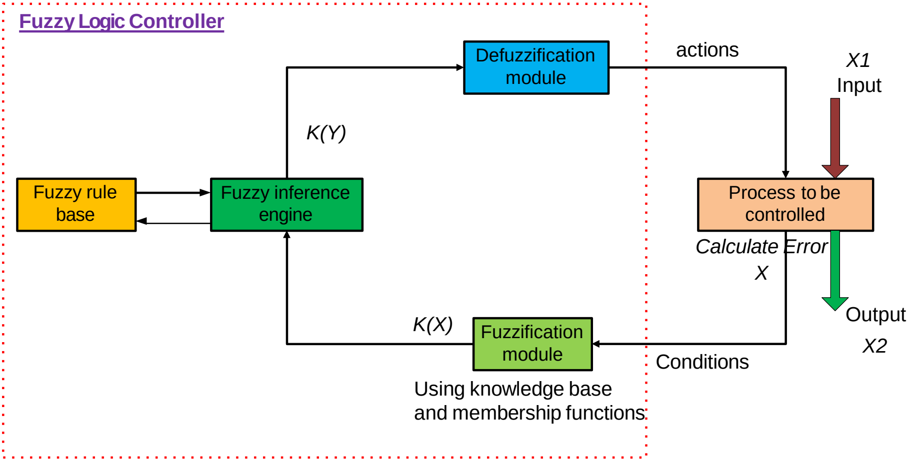


Figure 1

Fuzzy Inference System

The fundamental task of any FIS is to apply the if-then rules on fuzzy input and produce the corresponding fuzzy output.

Fuzzy inference (reasoning) is the actual *process of mapping from a given input to an output using fuzzy logic.*

FIS is applicable in fields such as *automatic control, data classification, decision analysis, expert systems and many more.*

Fuzzy Systems : Fuzzy Logic Controller

A general fuzzy controller consists of four modules:

1. a fuzzy rule base,
2. a fuzzy inference engine,
3. a fuzzification module, and
4. a defuzzification module.

Fuzzy Systems : Fuzzy Logic Controller

A fuzzy controller operates by repeating below steps

1. Measurements (inputs) are taken of all variables that represent relevant condition of controller process.
2. These measurements are converted into appropriate fuzzy sets to express measurements uncertainties. This step is called fuzzification.
3. The fuzzified measurements are then used by the inference engine to evaluate the control rules stroed in the fuzzy rule base. The result of this evaluation is a fuzzy set (or several fuzzy sets) defined on the universe of possible actions.
4. This output fuzzy set is then converted into a single (crisp) value (or a vector of values). This is the final step called defuzzification. The defuzzified values represent actions to be taken by the fuzzy contoller.

Why to use Fuzzy Logic in Control Systems?

- In traditional control systems, we need to know about the model and the objective function that is formulated in a very precise manner.
- Utilize human expertise and experience for designing controller
- The fuzzy control rules (If-Then rules) can be best used in designing a controller

The application of fuzzy logic control extends from individual process control to biomedical instrumentation and various security systems

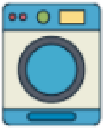
Type of Control Systems

- Open loop control systems
- Closed loop control systems

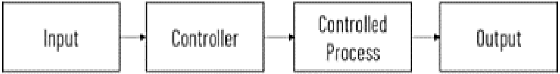
Open Loop Control System

The input control action is independent of the physical system output.

There is no feedback mechanism present in open fuzzy control system.



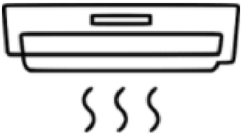
Washing Machine



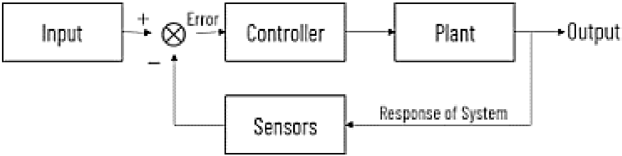
Closed Loop Control System

The new output of the system will depend on the previous output of the system.

The system has one or more feedback loops between its input and output.



Air Conditioner



Advantage of FLC

- Cheaper
- Robust
- Customizable
- Emulate human deductive thinking
- Reliability and efficiency

Disadvantage of FLC

- Requires lots of data to be applied
- Needs regular updating of the rules

Applications of FLC

- Traffic control
- Aircraft flight control
- Turbines Control
- Elevator control
- Home Appliances
- Robot navigation

Fuzzy Systems : Fuzzy Logic Controller

There are two approaches of FLC known.

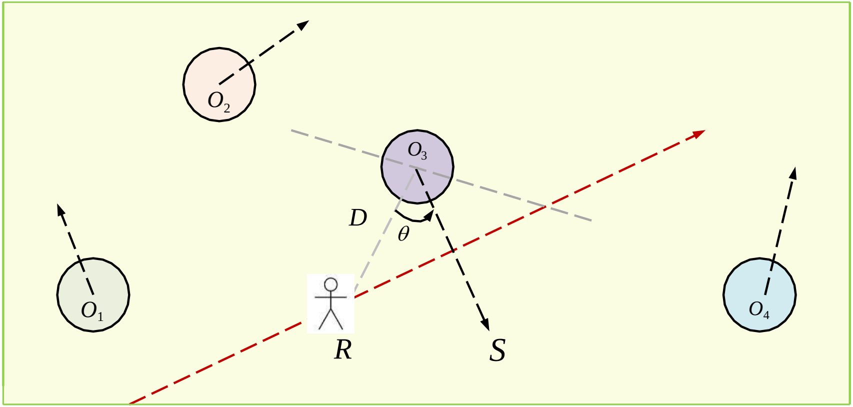
1. Mamdani approach
2. Takagi and sugeno's approach

- Mamdani approach follows linguistic fuzzy modeling and chacterized by its high interpretability and low accuracy.
- On the other hand, Takagi and Sugeno's approach follows precise fuzzy modeling and obtains high accuracy but at the cost of low interpretability.

Mamdani approach : Mobile Robot

- Consider the control of navigation of a mobile robot in the pressure of a number of moving objects.
- To make the problem simple, consider only four moving objects, each of equal size and moving with the same speed.

Mamdani approach : Mobile Robot



Mamdani approach : Mobile Robot

- We consider two parameters : D, the distance from the robot to an object and θ the angle of motion of an object with respect to the robot.
- The value of these parameters with respect to the most critical object will decide an output called deviation (δ).
- We assume the range of values of D is [0.1, ... 2.2] in meter and θ is [-90, ... , 0, ... 90] in degree.
- After identifying the relevant input and output variables of the controller and their range of values, the Mamdani approach is to select some meaningful states called "***linguistic states***" for each variable and express them by appropriate fuzzy sets.

Linguistic States

For the current example, we consider the following linguistic states for the three parameters.

Distance is represented using four linguistic states:

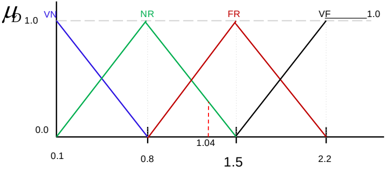
1. VN : Very Near
2. NR : Near
3. VF : Very Far
4. FR : Far

Angle (for both angular direction (θ) and deviation (δ)) are represented using five linguistic states:

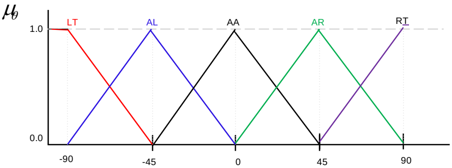
1. LT : Left
2. AL : Ahead Left
3. AA: Ahead
4. AR : Ahead Right
5. RT : Right

Linguistic States

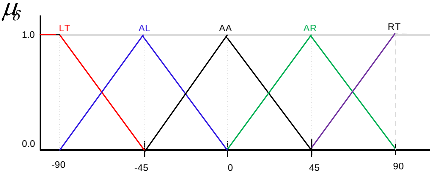
Three different fuzzy sets for the three different parameters are given below (Figure 3).



Distance D in mt



Angle θ in degree



Deviation δ in degree

Fuzzy rule base

Once the fuzzy sets of all parameters are worked out, our next step in FLC design is to decide fuzzy rule base of the FLC.

The rule base for the FLC of mobile robot is shown in the form of a table below.

Angle

distance

$$\begin{array}{cc} & \begin{array}{ccccc} LT & AL & AA & AR & RT \end{array} \\ \begin{array}{c} VN \\ NR \\ FR \\ VF \end{array} & \left[\begin{array}{ccccc} AA & AR & AL & AL & AA \\ AA & AA & RT & AA & AA \\ AA & AA & AR & AA & AA \\ AA & AA & AA & AA & AA \end{array}\right] \end{array}$$

Deviation

Fuzzy rule base for the mobile robot

Note that this rule base defines 20 rules for all possible instances. These rules are simple rules and take in the following forms.

- Rule 1: If (distance is VN) and (angle is LT) Then (deviation is AA)

  :

  :

- Rule 13: If (distance is FR) and (angle is AA) Then (deviation is AR)

  :

  :

- Rule 20: Rule 1: If (distance is VF) and (angle is RT) Then (deviation is AA)

Fuzzification of inputs

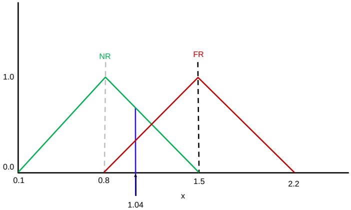
- The next step is the fuzzification of inputs. Let us consider, at any instance, the object O_3 is critical to the Mobile Robot and distance **D = 1.04 m** and angle $\boldsymbol{\theta}$**= 30^o** (see Figure 2).
- For this input, we are to decide the deviation $\boldsymbol{\delta}$ of the robot as output.

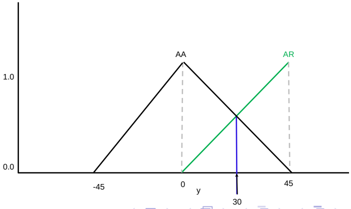
- From the given fuzzy sets and input parameters' values, we say that the distance D = 1.04m may be called as either **NR (near)** or **FR (far).**
- Similarly, the input angle $\theta = 30^o$ can be declared as either AA (ahead) or AR(ahead right).

Fuzzification of inputs

Hence, we are to determine the membership values corresponding to these values, which is as follows.

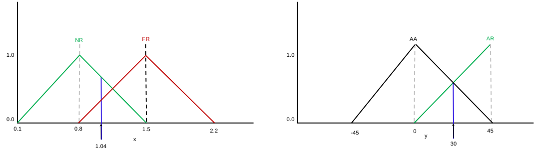
$$x = 1.04m$$
$$\mu_{NR}(x) = 0.6571$$
$$y = 30^o$$
$$\mu_{AA}(y) = 0.3333$$
$$\mu_{AR}(y) = 0.6667$$



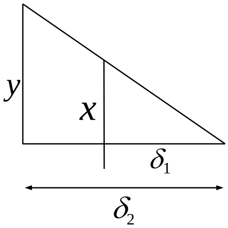


Fuzzification of inputs

Hint : Use the principle of similarity $\frac{x}{y} = \frac{\delta_1}{\delta_2}$



Thus, $\frac{x}{1} = \frac{1.5-1.04}{1.5-0.8}$, that is, $x = 0.6571$



Rule strength computation

There are many rules in the rule base and all rules may not be applicable.

For the given $x = 1.04$ and $\theta = 30^o$, only following four rules out of 20 rules are firable.

- $R1$: If (distance is NR) and (angle is AA) Then (deviation is RT)
- $R2$: If (distance is NR) and (angle is AR) Then (deviation is AA)
- $R3$: If (distance is FR) and (angle is AA) Then (deviation is AR)
- $R4$: If (distance is FR) and (angle is AR) Then (deviation is AA)

Fuzzy rule base

Angle

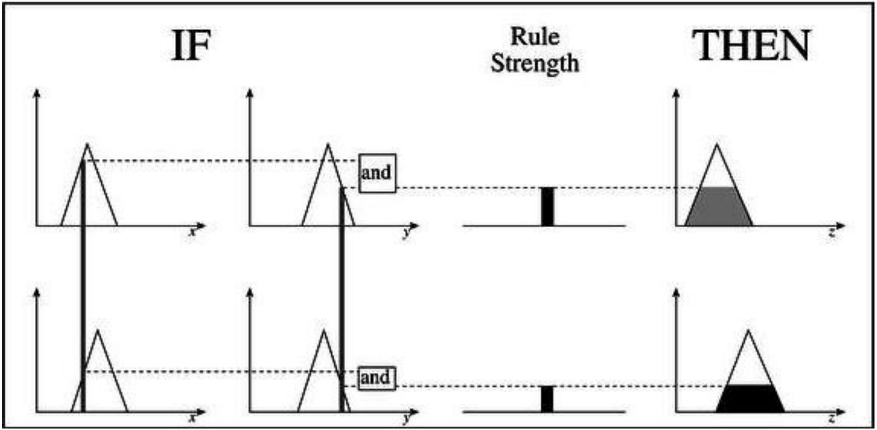
distance

$$\begin{array}{cc} & \begin{array}{ccccc} LT & AL & AA & AR & RT \end{array} \\ \begin{array}{c} VN \\ NR \\ FR \\ VF \end{array} & \begin{bmatrix} AA & AR & AL & AL & AA \\ AA & AA & RT & AA & AA \\ AA & AA & AR & AA & AA \\ AA & AA & AA & AA & AA \end{bmatrix} \end{array}$$

Deviation

Fuzzy rule base

Block diagram of Mamdani Fuzzy Interface System



Rule strength computation

The strength (also called α values) of the firable rules are calculated as follows.

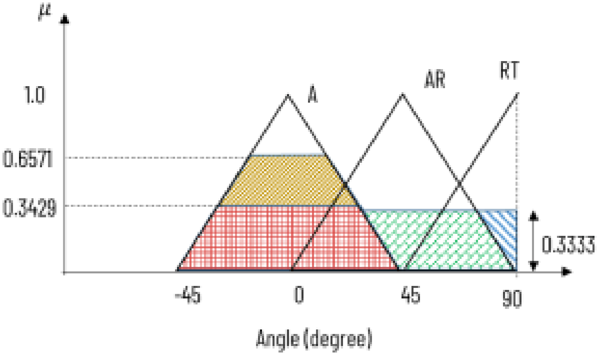
- $\alpha(R1) = min(\mu_{NR}(x), \mu_{AA}(y)) = min(0.6571, 0.3333) = 0.3333$
- $\alpha(R2) = min(\mu_{NR}(x), \mu_{AR}(y)) = min(0.6571, 0.6667) = 0.6571$
- $\alpha(R3) = min(\mu_{FR}(x), \mu_{AA}(y)) = min(0.3429, 0.3333) = 0.3333$
- $\alpha(R4) = min(\mu_{FR}(x), \mu_{AR}(y)) = min(0.3429, 0.6667) = 0.3429$

In practice, all rules which are above certain threshold value of rule strngth are selected for the output computation.

Fuzzy output

- We take min of membership function values for each rule.
- Output membership function is obtained by aggregating the membership function of result of each rule.
- Fuzzy output is nothing but fuzzy OR of all output of rules.

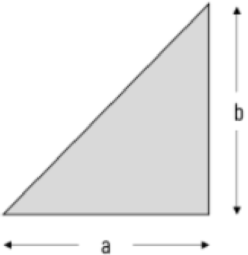
Illustration : Mobile Robot



To compute the final crisp value of deviation (δ) using Mamdani fuzzy inference method, we have to aggregate all fuzzy output functions on same axis using Defuzzification approaches to find final crisp value for decision making

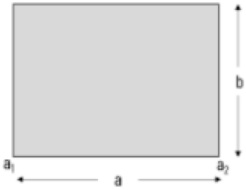
Defuzzification

Equation to compute are of some standard shapes



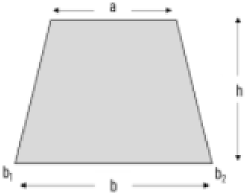
Area: (ab) / 2

Center: 2a/3



Area: ab

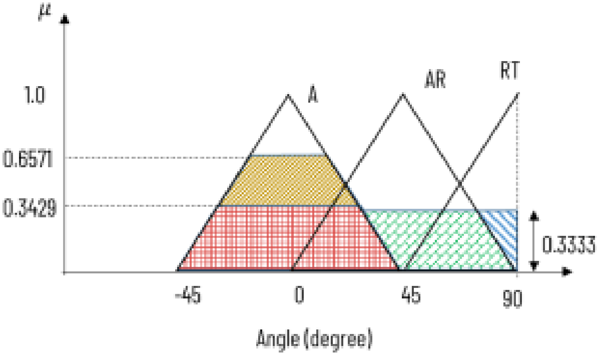
Center: $(a_1 + a_2) / 2$



Area: $1/2\ (a + b) \times h$

Center: $(b_1 + b_2) / 2$

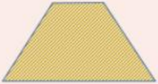
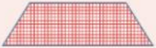
Illustration : Mobile Robot



Let us calculate the shaded region

Defuzzification

Using center of sum method

Fired Rule	Shaded Region	Area	Centroid
1	 45 90	12.5	71
2	 -45 45	39.7089	0
3	 0 90	25	45
4	 -45 45	25.5699	0

Defuzzification

From the combined fuzzified output for all four fired rules, we get the crisp value using Center of Sum method as follows.

$$x^* = \frac{(12.5 \times 71.0) + (39.7089 \times 0.0) + (25.0 \times 45.0) + (25.5699 \times 0.0)}{12.5 + 39.7089 + 25.0 + 25.5699}$$

$$x^* = 19.5809$$

Conclusion : Therefore, the robot should deviate by 19.58089 degree towards the right with respect to the line joining to the move of direction to avoid collision with the obstacle.

Thank you