



**Robotics and Automation (ELEC 4314)**

**Tutorial 9 Solution: Fuzzy Logic**

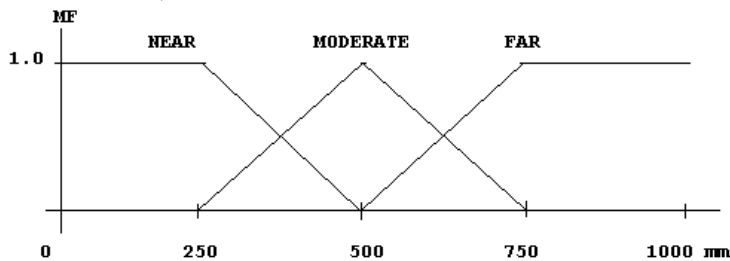
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**1. Wall-following Fuzzy System (Single Input Single Output type Simple fuzzy inference system)**

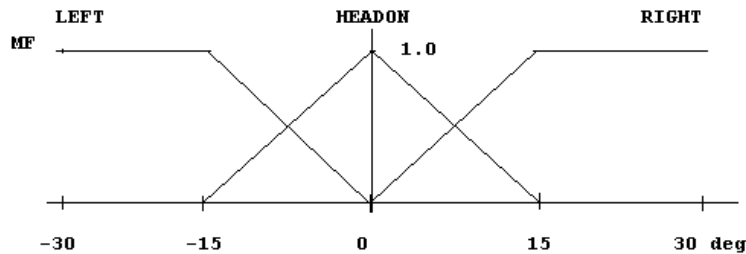
- Desired distance from the given wall is 500 mm.
- Desired heading angle is 0 degree. (Perpendicular to the given wall).

**[MF Design with triangles]**

Design 3 input Membership Functions (MFs) for single input sensor (left/right) - NEAR, MODERATE, FAR.



Design 3 output MFs for single output heading angle (left/right) - LEFT, HEADON, and RIGHT.



**[Rule design]**

Design fuzzy rules for wall-following behavior.

When we assume our input is a left sensor for left wall following, then the fuzzy rules can be composed based upon the expert's knowledge/experience.

- R1: IF left\_sensor is NEAR THEN head\_ang is RIGHT
- R2: IF left\_sensor is MODERATE THEN head\_ang is HEADON
- R3: IF left\_sensor is FAR THEN head\_ang is LEFT

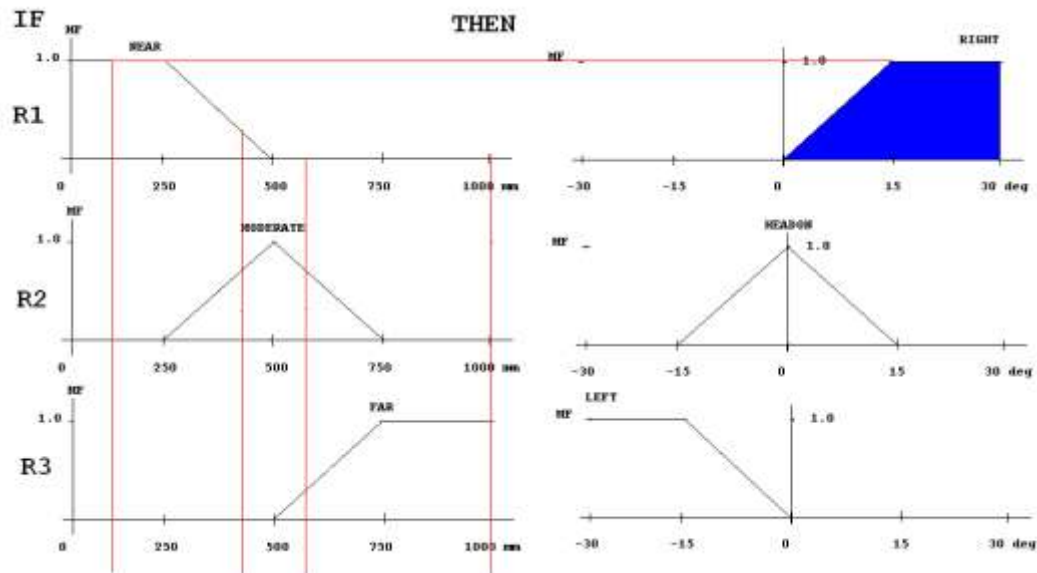
**[Inference & Defuzzification]**

Verify your fuzzy system by feeding inputs as 100mm, 400mm, 600mm, and 1000mm.

Calculate the inference of the fuzzy rules.

Defuzzify the output by applying the "fuzzy centroid" as in the lecture note.

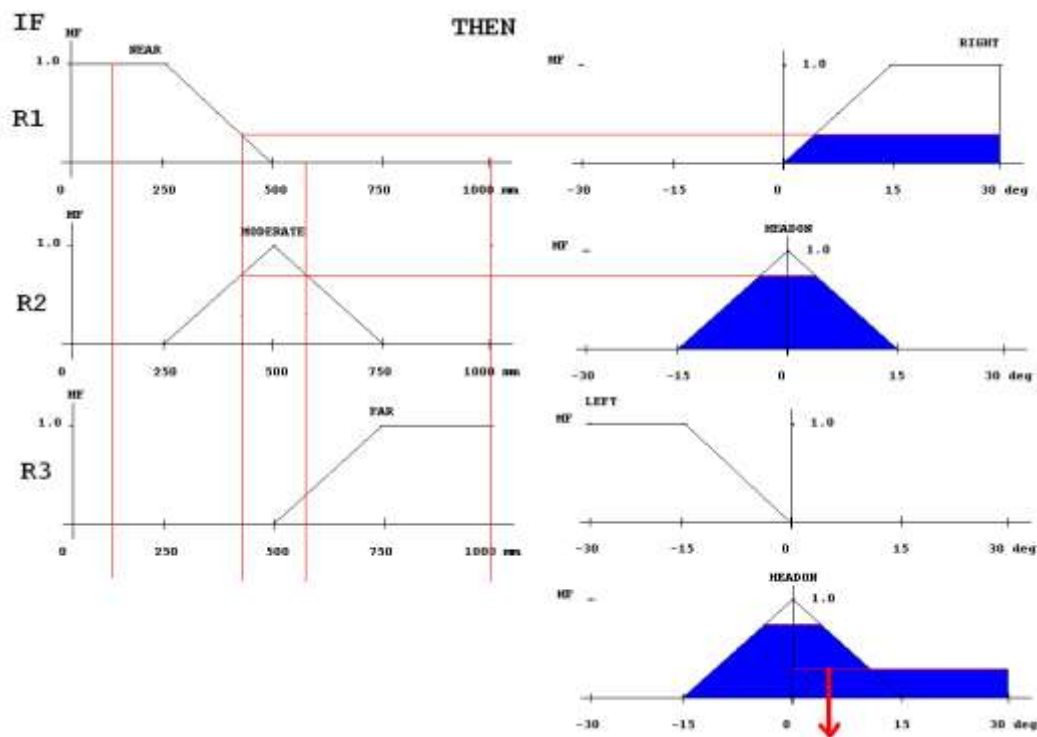
When the current input is 100mm, then the inference will be done as below.



The fuzzy rule R1 is being fired as the maximum rule strength and rules R2, R3 are not being fired with the input 100mm because the input membership values in R2, R3 are all zero. So, if we apply the “fuzzy centroid” method for de-fuzzification for shouldering case as in the lecture note, the output will be calculated as below.

$$\text{Output}_{100\text{mm}} = ((-30)*0 + 0*0 + 30*(1.0)) / (0 + 0 + 1.0) = 30.0 \text{ degrees.}$$

Does this make sense? If the input of the left sensor is 100mm (too close to the left wall), the output heading angle is 30.0 degrees (to move away from the given wall). Yes, it does. Similarly, the outputs when the inputs are 400mm, 600mm, 1000mm will be done as below respectively.



When the input is 400mm, there are partial rule firings for input MFs – NEAR and MODERATE. Each partial rule firings make its output MF’s membership degree – e.g. 0.2 for RIGHT and 0.8 for HEADON. Therefore, by applying the fuzzy centroid defuzzification method and considering the shouldering case, the calculation is done as follows.

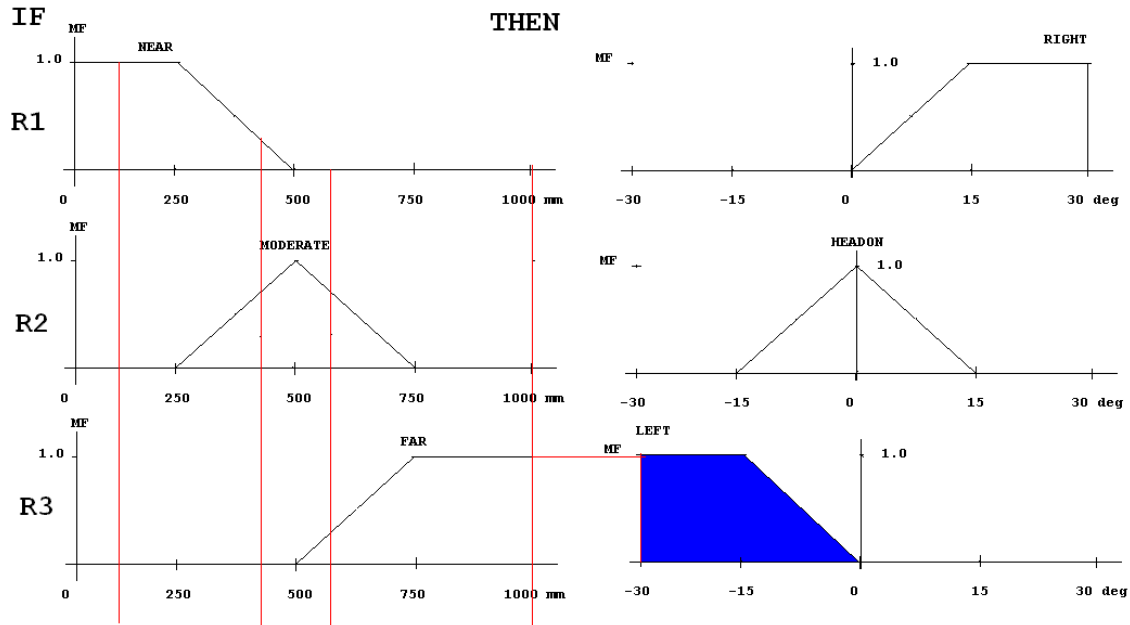
$$\text{Output}_{400\text{mm}} = ((-30)*0 + 0*0.8 + 30*(0.2)) / (0 + 0.8 + 0.2) = 6.0 \text{ degrees.}$$

Please note that the desired distance from the given (left) wall is 500mm and the desired heading angle is 0 degree. This means that when the input is getting closer to the desired distance, the output heading angle is getting closer to the desired heading angle.

Therefore, the I/O data of 400mm input and 6 degrees output makes sense according to the expert's knowledge.

In a similar way, the output for an input 600mm case will be -6.0 degrees.

Also, the inference process for calculating the output when an input is 1000mm is drawn next.



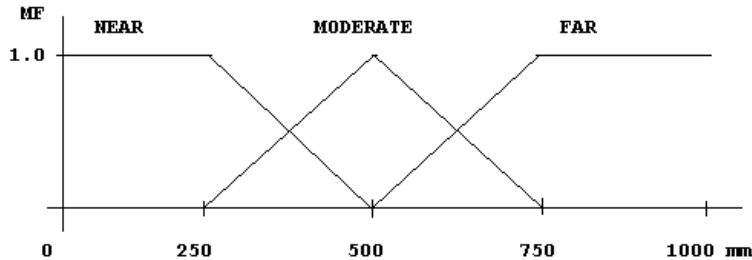
$$\text{Output}_{1000\text{mm}} = ((-30)*1.0 + 0*0 + 30*(0)) / (1.0 + 0 + 0) = -30.0 \text{ degrees.}$$

## 2. Obstacle Avoidance Fuzzy System (Single Input Single Output type Simple fuzzy inference system)

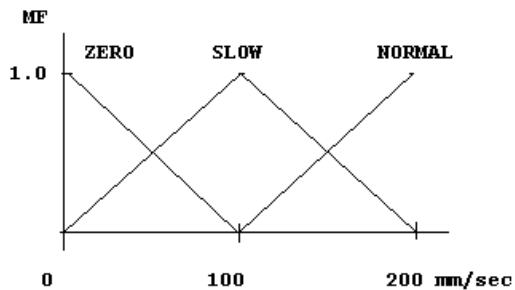
- Desired distance to stop against the obstacle is 250 mm.
- Normal linear velocity during the navigation is 200 mm/sec

### [MF Design with triangles]

Design 3 input MFs for single input for sensor (front) - NEAR, MODERATE, FAR.



Design 3 output MFs for single output for linear velocity - ZERO, SLOW, NORMAL.



### [Rule design]

Design fuzzy rules for obstacle avoidance behavior.

When we assume our input is a left sensor for left wall following, then the fuzzy rules can be composed based upon the expert's knowledge/experience.

- R1: IF front\_sensor is NEAR THEN lin\_vel is ZERO  
R2: IF front\_sensor is MODERATE THEN lin\_vel is SLOW  
R3: IF front\_sensor is FAR THEN lin\_vel is NORMAL

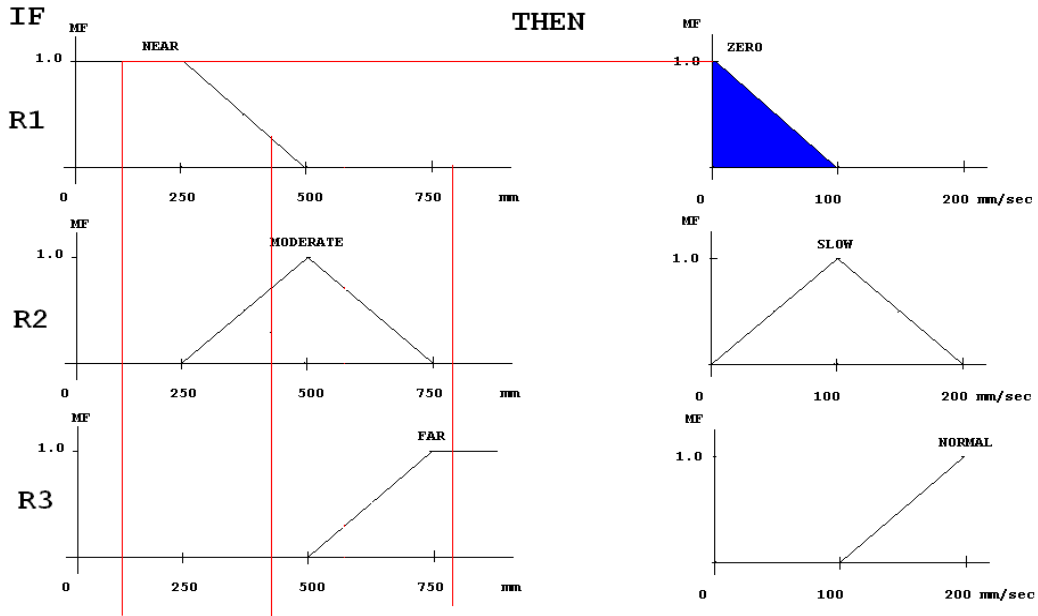
### [Inference & Defuzzification]

Verify your fuzzy system by feeding inputs as 200mm, 480mm, and 800mm.

Calculate the inference of the fuzzy rules.

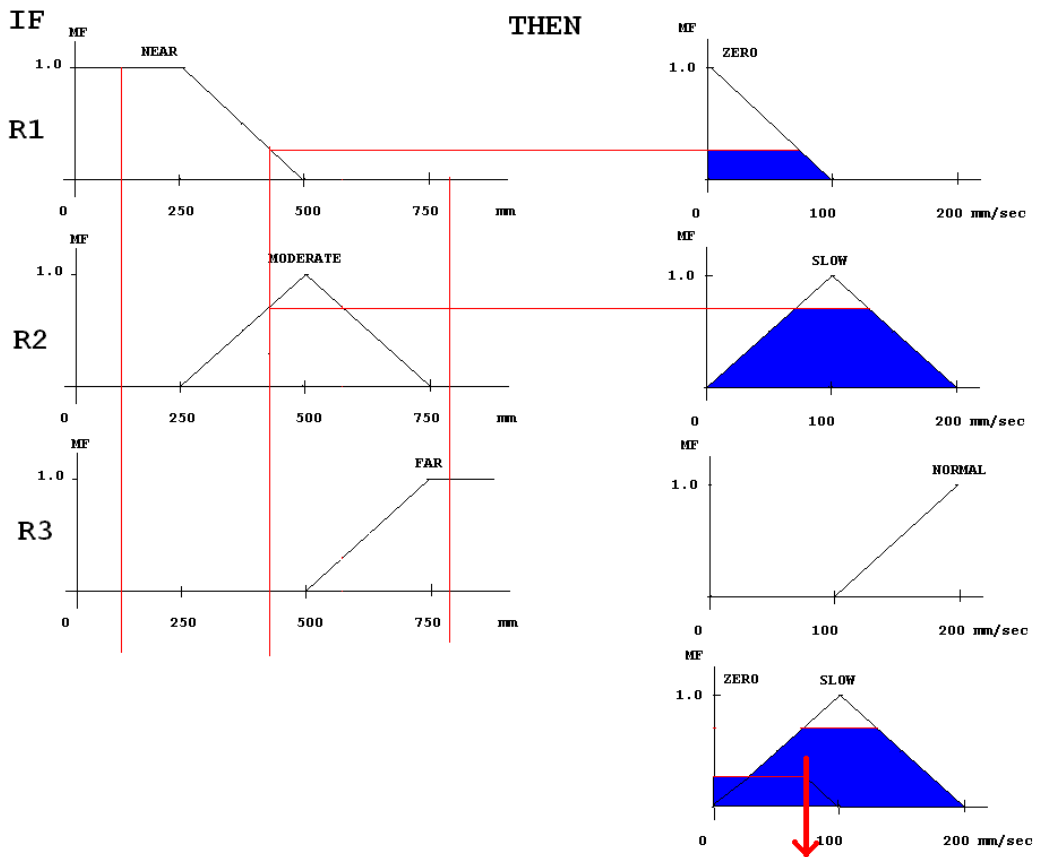
Defuzzify the output by applying the "fuzzy centroid" as in the lecture note.

When the input is 200mm, the inference diagram is shown below.



The input of 200mm fires the fuzzy rule R1 with full membership degree of output MF – ZERO, while the other rules R2, R3 are not being fired at all. So when calculating the defuzzification by considering without shoulders case,  

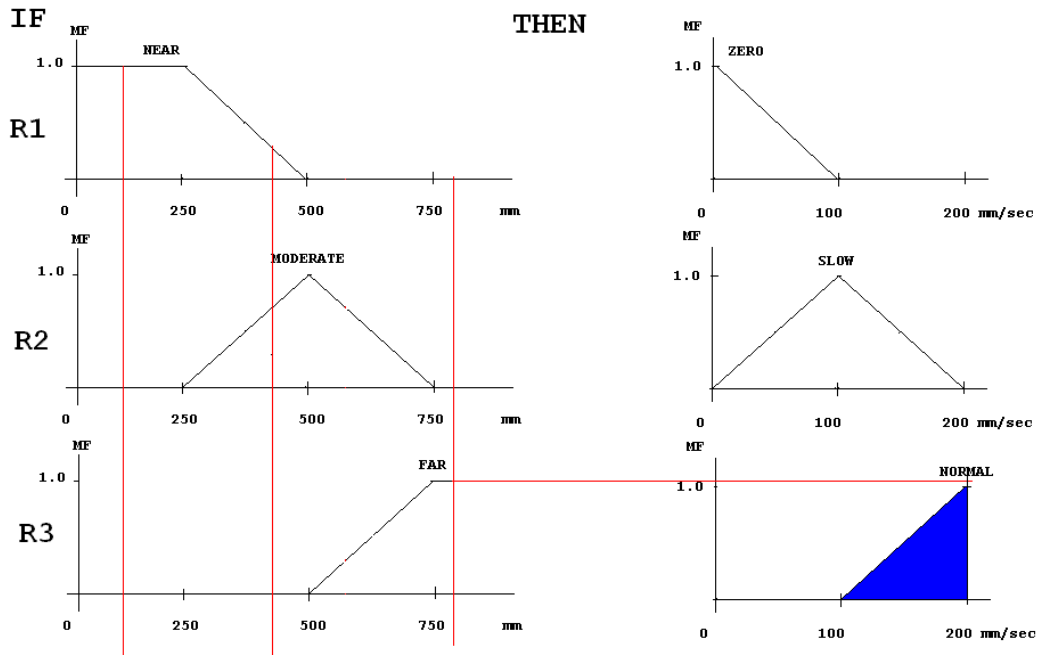
$$\text{Output}_{200\text{mm}} = (0 \cdot 1.0 + 100 \cdot 0 + 200 \cdot 0) / (1.0 + 0 + 0) = 0 \text{ mm/sec.}$$
 Then, how about the input of 480mm case? It's shown next.



As shown, the input of 480 mm for the front sensor fires parts of rules R1 and R2. So, for instance, the output MF ZERO has 0.1 rule firing and SLOW has 0.9 rule firing. Thus,  

$$\text{Output}_{480\text{mm}} = (0 \cdot 0.1 + 100 \cdot 0.9 + 200 \cdot 0) / (0.1 + 0.9 + 0) = 90 \text{ mm/sec.}$$
 This implies that when the front sensor of our robot returns 480 mm reading, we need to slow down our robot to the linear velocity of 90 mm/sec for obstacle avoidance.

Finally, the inference process for the input of 800mm case is done as below.



As the input 800mm fires fuzzy rule R3 only, there is a full firing for the output MF NORMAL.

$$\text{Output}_{800\text{mm}} = (0*0 + 100*0 + 200*1.0) / (0 + 0 + 1.0) = 200 \text{ mm/sec.}$$