RULE-BASED FUZZY SYSTEM

1. DESIGN A FUZZY SYSTEM INCLUDING:

A. THE MEMBERSHIP FUNCTIONS FOR EACH OF THE FUZZY QUANTITIES

In this, Generalised Bell Membership Function (gbellmf) is used. It is chosen because width of the curve, slope of curve and smoothness of curve can be controlled.

$$f(x; a, b, c) = \frac{1}{1 + \left|\frac{x - c}{a}\right|^{2b}}$$

Where, a specifies width of curve, b specifies the shape of curve, if its value is larger than we get sharper curve means steeper curve, c specifies the central value of the curve.

Here, gbellmf() is used because we want the possibility of more than one x value can have $\mu(x) = 1$.

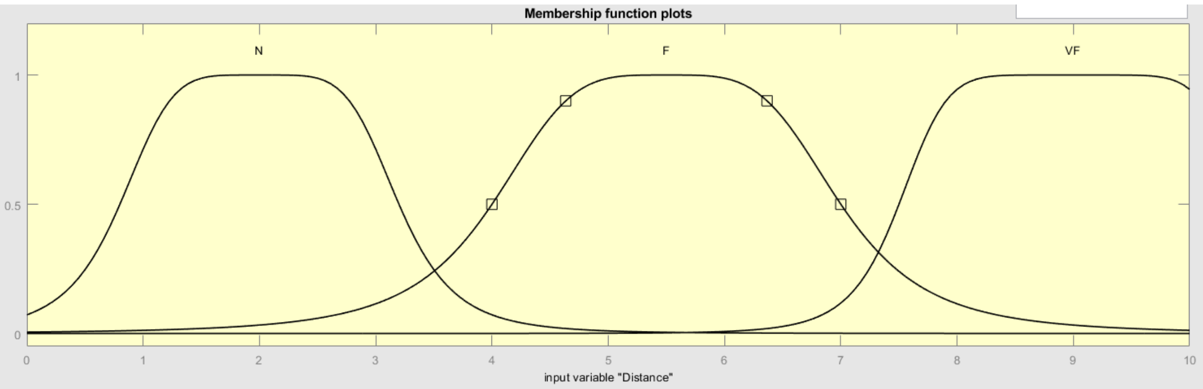
The calculations for $\mu(x)$ for each x value in all fuzzy quantities is below:

Distance

Minimum value: 0 ; Maximum value: 10 ; Step: 0.5 Here I have assumed the distance is considered in meters.

$\mu_N(x) = \frac{1}{1 + \left\|\frac{x - 2}{1.2}\right\|^5}$	$\mu_F(x) = \frac{1}{1 + \left\|\frac{x - 5.5}{1.5}\right\|^4}$	$\mu_{VF}(x) = \frac{1}{1 + \left\|\frac{x - 9}{1.5}\right\|^7}$

Where, $0 \leq x \leq 10$.



Near Fuzzy Set (N)				
x	a	b	c	μ(x)
0	1.2	2.5	2	0.072149644
0.5	1.2	2.5	2	0.246806459
1	1.2	2.5	2	0.713329052
1.5	1.2	2.5	2	0.98759709
2	1.2	2.5	2	1
2.5	1.2	2.5	2	0.98759709
3	1.2	2.5	2	0.713329052
3.5	1.2	2.5	2	0.246806459
4	1.2	2.5	2	0.072149644
4.5	1.2	2.5	2	0.024847278
5	1.2	2.5	2	0.010136205
5.5	1.2	2.5	2	0.004715343
6	1.2	2.5	2	0.002424109
6.5	1.2	2.5	2	0.001346661
7	1.2	2.5	2	0.000795629
7.5	1.2	2.5	2	0.000494172
8	1.2	2.5	2	0.000319898
8.5	1.2	2.5	2	0.000214411
9	1.2	2.5	2	0.000148031
9.5	1.2	2.5	2	0.000104847
10	1.2	2.5	2	7.59317E-05

Far Fuzzy Set (F)				
x	a	b	c	μ(x)
0	1.5	2	5.5	0.005502
0.5	1.5	2	5.5	0.008035
1	1.5	2	5.5	0.012195
1.5	1.5	2	5.5	0.019392
2	1.5	2	5.5	0.032635
2.5	1.5	2	5.5	0.058824
3	1.5	2	5.5	0.114731
3.5	1.5	2	5.5	0.240356
4	1.5	2	5.5	0.5
4.5	1.5	2	5.5	0.835052
5	1.5	2	5.5	0.987805
5.5	1.5	2	5.5	1
6	1.5	2	5.5	0.987805
6.5	1.5	2	5.5	0.835052
7	1.5	2	5.5	0.5
7.5	1.5	2	5.5	0.240356
8	1.5	2	5.5	0.114731
8.5	1.5	2	5.5	0.058824
9	1.5	2	5.5	0.032635
9.5	1.5	2	5.5	0.019392
10	1.5	2	5.5	0.012195

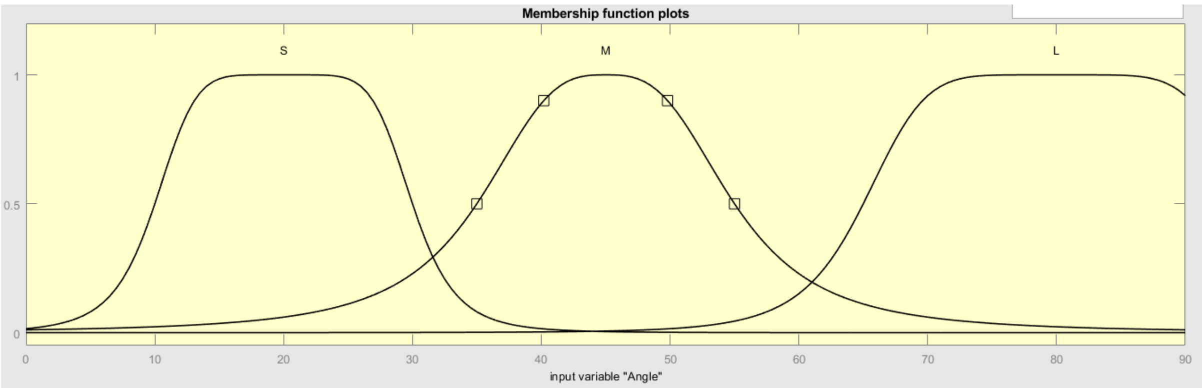
Very Far Fuzzy Set (VF)				
x	a	b	c	μ(x)
0	1.5	3.5	9	3.57223E-06
0.5	1.5	3.5	9	5.32972E-06
1	1.5	3.5	9	8.14714E-06
1.5	1.5	3.5	9	1.27998E-05
2	1.5	3.5	9	2.07464E-05
2.5	1.5	3.5	9	3.48522E-05
3	1.5	3.5	9	6.10314E-05
3.5	1.5	3.5	9	0.000112215
4	1.5	3.5	9	0.000218652
4.5	1.5	3.5	9	0.000457038
5	1.5	3.5	9	0.001041756
5.5	1.5	3.5	9	0.002648566
6	1.5	3.5	9	0.007751938
6.5	1.5	3.5	9	0.027231298
7	1.5	3.5	9	0.117764256
7.5	1.5	3.5	9	0.5
8	1.5	3.5	9	0.944708423
8.5	1.5	3.5	9	0.999542962
9	1.5	3.5	9	1
9.5	1.5	3.5	9	0.999542962
10	1.5	3.5	9	0.944708423

Angle

Minimum value: 0 ; Maximum value: 90 ; Step: 1.

$\mu_S(x) = \dfrac{1}{1 + \left\lvert \dfrac{x-20}{10} \right\rvert^6}$	$\mu_M(x) = \dfrac{1}{1 + \left\lvert \dfrac{x-45}{10} \right\rvert^3}$	$\mu_L(x) = \dfrac{1}{1 + \left\lvert \dfrac{x-80}{15} \right\rvert^6}$

Where, $0 \leq x \leq 90$.



Small Fuzzy Set (S)				
x	a	b	c	µ(x)
0	10	3	20	0.015385
1	10	3	20	0.020813
2	10	3	20	0.028561
3	10	3	20	0.039781
4	10	3	20	0.056252
5	10	3	20	0.080706
6	10	3	20	0.11724
7	10	3	20	0.171621
8	10	3	20	0.250879
9	10	3	20	0.360808
10	10	3	20	0.5
11	10	3	20	0.65298
12	10	3	20	0.792303
13	10	3	20	0.894735
14	10	3	20	0.955424
15	10	3	20	0.984615
16	10	3	20	0.995921
17	10	3	20	0.999272
18	10	3	20	0.999936
19	10	3	20	0.999999
20	10	3	20	1
21	10	3	20	0.999999
22	10	3	20	0.999936
23	10	3	20	0.999272
24	10	3	20	0.995921
25	10	3	20	0.984615
26	10	3	20	0.955424
27	10	3	20	0.894735
28	10	3	20	0.792303
29	10	3	20	0.65298
30	10	3	20	0.5
31	10	3	20	0.360808
32	10	3	20	0.250879
33	10	3	20	0.171621
34	10	3	20	0.11724
35	10	3	20	0.080706
36	10	3	20	0.056252
37	10	3	20	0.039781
38	10	3	20	0.028561
39	10	3	20	0.020813
40	10	3	20	0.015385
41	10	3	20	0.011525
42	10	3	20	0.008743
43	10	3	20	0.00671
44	10	3	20	0.005206
45	10	3	20	0.004079
46	10	3	20	0.003227
47	10	3	20	0.002575
48	10	3	20	0.002071
49	10	3	20	0.001678
50	10	3	20	0.00137
51	10	3	20	0.001125
52	10	3	20	0.00093
53	10	3	20	0.000774
54	10	3	20	0.000647
55	10	3	20	0.000544
56	10	3	20	0.000459
57	10	3	20	0.00039
58	10	3	20	0.000332
59	10	3	20	0.000284
60	10	3	20	0.000244
61	10	3	20	0.00021
62	10	3	20	0.000182
63	10	3	20	0.000158
64	10	3	20	0.000138
65	10	3	20	0.00012
66	10	3	20	0.000106
67	10	3	20	9.28E-05
68	10	3	20	8.18E-05
69	10	3	20	7.22E-05
70	10	3	20	0.000064
71	10	3	20	5.68E-05
72	10	3	20	5.06E-05
73	10	3	20	4.51E-05
74	10	3	20	4.03E-05
75	10	3	20	3.61E-05
76	10	3	20	3.24E-05
77	10	3	20	2.92E-05
78	10	3	20	2.63E-05
79	10	3	20	2.37E-05
80	10	3	20	2.14E-05
81	10	3	20	1.94E-05
82	10	3	20	1.76E-05
83	10	3	20	0.000016
84	10	3	20	1.46E-05
85	10	3	20	1.33E-05
86	10	3	20	1.21E-05
87	10	3	20	1.11E-05
88	10	3	20	1.01E-05
89	10	3	20	9.27E-06
90	10	3	20	8.5E-06

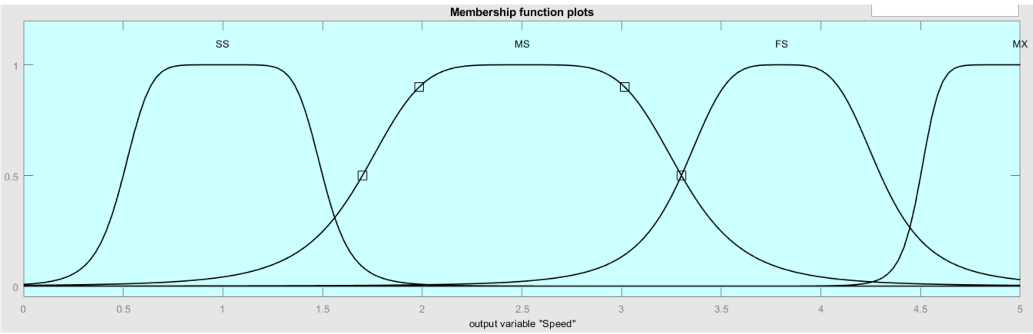
Medium Fuzzy Set (M)				
x	a	b	c	µ(x)
0	10	1.5	45	0.010855
1	10	1.5	45	0.011603
2	10	1.5	45	0.012421
3	10	1.5	45	0.013318
4	10	1.5	45	0.014302
5	10	1.5	45	0.015385
6	10	1.5	45	0.016579
7	10	1.5	45	0.017898
8	10	1.5	45	0.01936
9	10	1.5	45	0.020984
10	10	1.5	45	0.022792
11	10	1.5	45	0.024811
12	10	1.5	45	0.027073
13	10	1.5	45	0.029614
14	10	1.5	45	0.032477
15	10	1.5	45	0.035714
16	10	1.5	45	0.039387
17	10	1.5	45	0.043569
18	10	1.5	45	0.048349
19	10	1.5	45	0.053833
20	10	1.5	45	0.06015
21	10	1.5	45	0.067458
22	10	1.5	45	0.075947
23	10	1.5	45	0.085852
24	10	1.5	45	0.097456
25	10	1.5	45	0.111111
26	10	1.5	45	0.127243
27	10	1.5	45	0.14637
28	10	1.5	45	0.169119
29	10	1.5	45	0.196232
30	10	1.5	45	0.228571
31	10	1.5	45	0.267094
32	10	1.5	45	0.312793
33	10	1.5	45	0.366569
34	10	1.5	45	0.429
35	10	1.5	45	0.5
36	10	1.5	45	0.578369
37	10	1.5	45	0.661376
38	10	1.5	45	0.744602
39	10	1.5	45	0.822368
40	10	1.5	45	0.888889
41	10	1.5	45	0.93985
42	10	1.5	45	0.97371
43	10	1.5	45	0.992063
44	10	1.5	45	0.999001
45	10	1.5	45	1
46	10	1.5	45	0.999001
47	10	1.5	45	0.992063
48	10	1.5	45	0.97371
49	10	1.5	45	0.93985
50	10	1.5	45	0.888889
51	10	1.5	45	0.822368
52	10	1.5	45	0.744602
53	10	1.5	45	0.661376
54	10	1.5	45	0.578369
55	10	1.5	45	0.5
56	10	1.5	45	0.429
57	10	1.5	45	0.366569
58	10	1.5	45	0.312793
59	10	1.5	45	0.267094
60	10	1.5	45	0.228571
61	10	1.5	45	0.196232
62	10	1.5	45	0.169119
63	10	1.5	45	0.14637
64	10	1.5	45	0.127243
65	10	1.5	45	0.111111
66	10	1.5	45	0.097456
67	10	1.5	45	0.085852
68	10	1.5	45	0.075947
69	10	1.5	45	0.067458
70	10	1.5	45	0.06015
71	10	1.5	45	0.053833
72	10	1.5	45	0.048349
73	10	1.5	45	0.043569
74	10	1.5	45	0.039387
75	10	1.5	45	0.035714
76	10	1.5	45	0.032477
77	10	1.5	45	0.029614
78	10	1.5	45	0.027073
79	10	1.5	45	0.024811
80	10	1.5	45	0.022792
81	10	1.5	45	0.020984
82	10	1.5	45	0.01936
83	10	1.5	45	0.017898
84	10	1.5	45	0.016579
85	10	1.5	45	0.015385
86	10	1.5	45	0.014302
87	10	1.5	45	0.013318
88	10	1.5	45	0.012421
89	10	1.5	45	0.011603
90	10	1.5	45	0.010855

Large Fuzzy Set (L)				
x	a	b	c	µ(x)
0	15	3	80	4.34499E-05
1	15	3	80	4.68559E-05
2	15	3	80	5.05776E-05
3	15	3	80	5.46487E-05
4	15	3	80	5.91072E-05
5	15	3	80	6.39959E-05
6	15	3	80	6.93629E-05
7	15	3	80	7.52623E-05
8	15	3	80	8.17555E-05
9	15	3	80	8.89117E-05
10	15	3	80	9.68093E-05
11	15	3	80	0.000105538
12	15	3	80	0.000115198
13	15	3	80	0.000125905
14	15	3	80	0.000137792
15	15	3	80	0.000151009
16	15	3	80	0.000165728
17	15	3	80	0.000182148
18	15	3	80	0.000200498
19	15	3	80	0.000221041
20	15	3	80	0.000244081
21	15	3	80	0.000269972
22	15	3	80	0.000299123
23	15	3	80	0.000332012
24	15	3	80	0.000369198
25	15	3	80	0.000411332
26	15	3	80	0.000459183
27	15	3	80	0.000513652
28	15	3	80	0.000575808
29	15	3	80	0.000646912
30	15	3	80	0.000728469
31	15	3	80	0.000822269
32	15	3	80	0.000930456
33	15	3	80	0.001055606
34	15	3	80	0.001200822
35	15	3	80	0.001369863
36	15	3	80	0.001567293
37	15	3	80	0.001798684
38	15	3	80	0.002070864
39	15	3	80	0.002392237
40	15	3	80	0.002773202
41	15	3	80	0.003226683
42	15	3	80	0.003768826
43	15	3	80	0.00441991
44	15	3	80	0.005205541
45	15	3	80	0.006158239
46	15	3	80	0.007319536
47	15	3	80	0.008742795
48	15	3	80	0.01049699
49	15	3	80	0.012671818
50	15	3	80	0.015384615
51	15	3	80	0.018789777
52	15	3	80	0.023091558
53	15	3	80	0.028561453
54	15	3	80	0.035561653
55	15	3	80	0.04457625
56	15	3	80	0.056251778
57	15	3	80	0.071447495
58	15	3	80	0.091292592
59	15	3	80	0.117239672
60	15	3	80	0.151088083
61	15	3	80	0.194923102
62	15	3	80	0.25087908
63	15	3	80	0.32060805
64	15	3	80	0.404384028
65	15	3	80	0.5
66	15	3	80	0.602036367
67	15	3	80	0.702369129
68	15	3	80	0.792302622
69	15	3	80	0.86540526
70	15	3	80	0.919293821
71	15	3	80	0.95542375
72	15	3	80	0.977503716
73	15	3	80	0.989777007
74	15	3	80	0.995920709
75	15	3	80	0.998630137
76	15	3	80	0.999640535
77	15	3	80	0.999936004
78	15	3	80	0.999994381
79	15	3	80	0.999999912
80	15	3	80	1
81	15	3	80	0.999999912
82	15	3	80	0.999994381
83	15	3	80	0.999936004
84	15	3	80	0.999640535
85	15	3	80	0.998630137
86	15	3	80	0.995920709
87	15	3	80	0.989777007
88	15	3	80	0.977503716
89	15	3	80	0.95542375
90	15	3	80	0.919293821

Speed : Minimum value: 0 ; Maximum value: 5 ; Step: 0.2

$$\mu_{SS}(x) = \frac{1}{1 + \left|\frac{x-1}{0.5}\right|^{7}} \qquad \mu_{MS}(x) = \frac{1}{1 + \left|\frac{x-2.5}{0.8}\right|^{5}} \qquad \mu_{FS}(x) = \frac{1}{1 + \left|\frac{x-3.8}{0.5}\right|^{4}} \qquad \mu_{MX}(x) = \frac{1}{1 + \left|\frac{x-5}{0.5}\right|^{10}}$$

Where, $0 \le x \le 5$.



Slow Speed (SS)				
x	a	b	c	μ(x)
0	0.5	3.5	1	0.007751938
0.2	0.5	3.5	1	0.035914966
0.4	0.5	3.5	1	0.21818908
0.6	0.5	3.5	1	0.826640849
0.8	0.5	3.5	1	0.99836428
1	0.5	3.5	1	1
1.2	0.5	3.5	1	0.99836428
1.4	0.5	3.5	1	0.826640849
1.6	0.5	3.5	1	0.21818908
1.8	0.5	3.5	1	0.035914966
2	0.5	3.5	1	0.007751938
2.2	0.5	3.5	1	0.002175582
2.4	0.5	3.5	1	0.00074058
2.6	0.5	3.5	1	0.000290954
2.8	0.5	3.5	1	0.000127593
3	0.5	3.5	1	6.10314E-05
3.2	0.5	3.5	1	3.13197E-05
3.4	0.5	3.5	1	1.70335E-05
3.6	0.5	3.5	1	9.72685E-06
3.8	0.5	3.5	1	5.79004E-06
4	0.5	3.5	1	3.57223E-06
4.2	0.5	3.5	1	2.27373E-06
4.4	0.5	3.5	1	1.48743E-06
4.6	0.5	3.5	1	9.96947E-07
4.8	0.5	3.5	1	6.82817E-07
5	0.5	3.5	1	4.76837E-07

Medium Speed (MS)				
x	a	b	c	μ(x)
0	0.8	2.5	2.5	0.003344
0.2	0.8	2.5	2.5	0.005065
0.4	0.8	2.5	2.5	0.007959
0.6	0.8	2.5	2.5	0.013061
0.8	0.8	2.5	2.5	0.022558
1	0.8	2.5	2.5	0.041366
1.2	0.8	2.5	2.5	0.081097
1.4	0.8	2.5	2.5	0.169065
1.6	0.8	2.5	2.5	0.356884
1.8	0.8	2.5	2.5	0.660978
2	0.8	2.5	2.5	0.912936
2.2	0.8	2.5	2.5	0.992639
2.4	0.8	2.5	2.5	0.999969
2.6	0.8	2.5	2.5	0.999969
2.8	0.8	2.5	2.5	0.992639
3	0.8	2.5	2.5	0.912936
3.2	0.8	2.5	2.5	0.660978
3.4	0.8	2.5	2.5	0.356884
3.6	0.8	2.5	2.5	0.169065
3.8	0.8	2.5	2.5	0.081097
4	0.8	2.5	2.5	0.041366
4.2	0.8	2.5	2.5	0.022558
4.4	0.8	2.5	2.5	0.013061
4.6	0.8	2.5	2.5	0.007959
4.8	0.8	2.5	2.5	0.005065
5	0.8	2.5	2.5	0.003344

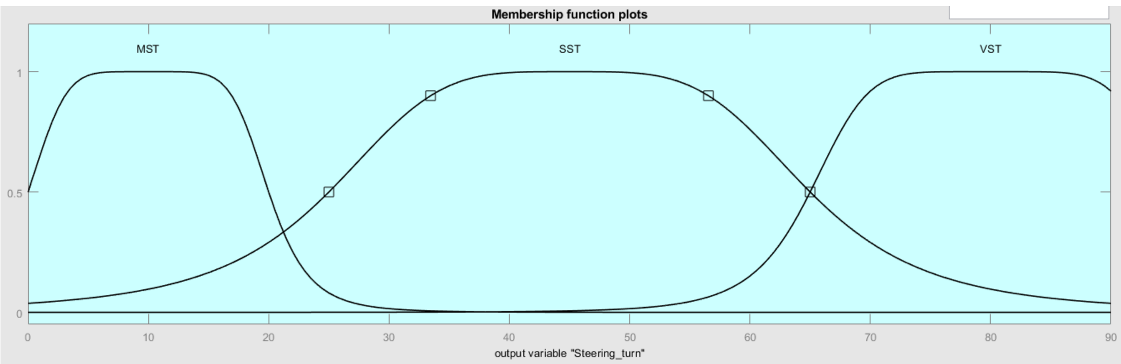
Fast Speed (FS)				
x	a	b	c	μ(x)
0	0.5	2	3.8	0.0003
0.2	0.5	2	3.8	0.000372
0.4	0.5	2	3.8	0.000467
0.6	0.5	2	3.8	0.000596
0.8	0.5	2	3.8	0.000771
1	0.5	2	3.8	0.001016
1.2	0.5	2	3.8	0.001366
1.4	0.5	2	3.8	0.00188
1.6	0.5	2	3.8	0.002661
1.8	0.5	2	3.8	0.003891
2	0.5	2	3.8	0.005919
2.2	0.5	2	3.8	0.009447
2.4	0.5	2	3.8	0.016009
2.6	0.5	2	3.8	0.029259
2.8	0.5	2	3.8	0.058824
3	0.5	2	3.8	0.132387
3.2	0.5	2	3.8	0.325351
3.4	0.5	2	3.8	0.709421
3.6	0.5	2	3.8	0.975039
3.8	0.5	2	3.8	1
4	0.5	2	3.8	0.975039
4.2	0.5	2	3.8	0.709421
4.4	0.5	2	3.8	0.325351
4.6	0.5	2	3.8	0.132387
4.8	0.5	2	3.8	0.058824
5	0.5	2	3.8	0.029259

Maximum Speed (MX)				
x	a	b	c	μ(x)
0	0.5	5	5	1E-10
0.2	0.5	5	5	1.50414E-10
0.4	0.5	5	5	2.30209E-10
0.6	0.5	5	5	3.59065E-10
0.8	0.5	5	5	5.71751E-10
1	0.5	5	5	9.31323E-10
1.2	0.5	5	5	1.55548E-09
1.4	0.5	5	5	2.67101E-09
1.6	0.5	5	5	4.73054E-09
1.8	0.5	5	5	8.67362E-09
2	0.5	5	5	1.65382E-08
2.2	0.5	5	5	3.29701E-08
2.4	0.5	5	5	6.91778E-08
2.6	0.5	5	5	1.54024E-07
2.8	0.5	5	5	3.67683E-07
3	0.5	5	5	9.53673E-07
3.2	0.5	5	5	2.7351E-06
3.4	0.5	5	5	8.88171E-06
3.6	0.5	5	5	3.37602E-05
3.8	0.5	5	5	0.000157695
4	0.5	5	5	0.00097561
4.2	0.5	5	5	0.009012974
4.4	0.5	5	5	0.139048477
4.6	0.5	5	5	0.903037127
4.8	0.5	5	5	0.999895153
5	0.5	5	5	1

Steering Turn: Minimum value: 0 ; Maximum value: 90 ; Step: 1

$$\mu_{SS}(x) = \frac{1}{1 + \left|\frac{x-10}{10}\right|^{6}} \qquad \mu_{MS}(x) = \frac{1}{1 + \left|\frac{x-45}{20}\right|^{4}} \qquad \mu_{FS}(x) = \frac{1}{1 + \left|\frac{x-80}{15}\right|^{6}}$$

Where, $0 \le x \le 90$.



Mild Turn (MST)				
x	a	b	c	μ(x)
0	10	3	10	0.5
1	10	3	10	0.6529798
2	10	3	10	0.7923026
3	10	3	10	0.8947353
4	10	3	10	0.9554237
5	10	3	10	0.9846154
6	10	3	10	0.9959207
7	10	3	10	0.9992715
8	10	3	10	0.999936
9	10	3	10	0.999999
10	10	3	10	1
11	10	3	10	0.999999
12	10	3	10	0.999936
13	10	3	10	0.9992715
14	10	3	10	0.9959207
15	10	3	10	0.9846154
16	10	3	10	0.9554237
17	10	3	10	0.8947353
18	10	3	10	0.7923026
19	10	3	10	0.6529798
20	10	3	10	0.5
21	10	3	10	0.3608075
22	10	3	10	0.2508791
23	10	3	10	0.1716205
24	10	3	10	0.1172397
25	10	3	10	0.0807062
26	10	3	10	0.0562518
27	10	3	10	0.0397811
28	10	3	10	0.0285615
29	10	3	10	0.0208134
30	10	3	10	0.0153846
31	10	3	10	0.0115252
32	10	3	10	0.0087428
33	10	3	10	0.0067098
34	10	3	10	0.0052055
35	10	3	10	0.0040793
36	10	3	10	0.0032267
37	10	3	10	0.0025745
38	10	3	10	0.0020709
39	10	3	10	0.0016783
40	10	3	10	0.0013699
41	10	3	10	0.0011255
42	10	3	10	0.0009305
43	10	3	10	0.0007737
44	10	3	10	0.0006469
45	10	3	10	0.0005437
46	10	3	10	0.0004592
47	10	3	10	0.0003896
48	10	3	10	0.000332
49	10	3	10	0.0002841
50	10	3	10	0.0002441
51	10	3	10	0.0002105
52	10	3	10	0.0001821
53	10	3	10	0.0001582
54	10	3	10	0.0001378
55	10	3	10	0.0001204
56	10	3	10	0.0001055
57	10	3	10	9.276E-05
58	10	3	10	8.176E-05
59	10	3	10	7.224E-05
60	10	3	10	0.000064
61	10	3	10	5.683E-05
62	10	3	10	5.058E-05
63	10	3	10	4.512E-05
64	10	3	10	4.033E-05
65	10	3	10	3.613E-05
66	10	3	10	3.242E-05
67	10	3	10	2.916E-05
68	10	3	10	2.627E-05
69	10	3	10	2.371E-05
70	10	3	10	2.143E-05
71	10	3	10	1.941E-05
72	10	3	10	1.761E-05
73	10	3	10	1.599E-05
74	10	3	10	1.455E-05
75	10	3	10	1.326E-05
76	10	3	10	0.0000121
77	10	3	10	1.105E-05
78	10	3	10	1.011E-05
79	10	3	10	9.266E-06
80	10	3	10	0.0000085
81	10	3	10	7.806E-06
82	10	3	10	7.178E-06
83	10	3	10	6.608E-06
84	10	3	10	6.09E-06
85	10	3	10	5.619E-06
86	10	3	10	5.189E-06
87	10	3	10	4.798E-06
88	10	3	10	4.44E-06
89	10	3	10	4.114E-06
90	10	3	10	3.815E-06

Sharp Turn (SST)				
x	a	b	c	μ(x)
0	20	2	45	0.037553
1	20	2	45	0.040941
2	20	2	45	0.044708
3	20	2	45	0.048904
4	20	2	45	0.053588
5	20	2	45	0.058824
6	20	2	45	0.064687
7	20	2	45	0.071265
8	20	2	45	0.078657
9	20	2	45	0.086975
10	20	2	45	0.096349
11	20	2	45	0.106928
12	20	2	45	0.118878
13	20	2	45	0.132387
14	20	2	45	0.147667
15	20	2	45	0.164948
16	20	2	45	0.184485
17	20	2	45	0.206543
18	20	2	45	0.231401
19	20	2	45	0.259329
20	20	2	45	0.290579
21	20	2	45	0.325351
22	20	2	45	0.363768
23	20	2	45	0.405828
24	20	2	45	0.451364
25	20	2	45	0.5
26	20	2	45	0.551114
27	20	2	45	0.603828
28	20	2	45	0.657028
29	20	2	45	0.709421
30	20	2	45	0.759644
31	20	2	45	0.806387
32	20	2	45	0.848532
33	20	2	45	0.885269
34	20	2	45	0.916165
35	20	2	45	0.941176
36	20	2	45	0.960609
37	20	2	45	0.975039
38	20	2	45	0.985216
39	20	2	45	0.991965
40	20	2	45	0.996109
41	20	2	45	0.998403
42	20	2	45	0.999494
43	20	2	45	0.9999
44	20	2	45	0.999994
45	20	2	45	1
46	20	2	45	0.999994
47	20	2	45	0.9999
48	20	2	45	0.999494
49	20	2	45	0.998403
50	20	2	45	0.996109
51	20	2	45	0.991965
52	20	2	45	0.985216
53	20	2	45	0.975039
54	20	2	45	0.960609
55	20	2	45	0.941176
56	20	2	45	0.916165
57	20	2	45	0.885269
58	20	2	45	0.848532
59	20	2	45	0.806387
60	20	2	45	0.759644
61	20	2	45	0.709421
62	20	2	45	0.657028
63	20	2	45	0.603828
64	20	2	45	0.551114
65	20	2	45	0.5
66	20	2	45	0.451364
67	20	2	45	0.405828
68	20	2	45	0.363768
69	20	2	45	0.325351
70	20	2	45	0.290579
71	20	2	45	0.259329
72	20	2	45	0.231401
73	20	2	45	0.206543
74	20	2	45	0.184485
75	20	2	45	0.164948
76	20	2	45	0.147667
77	20	2	45	0.132387
78	20	2	45	0.118878
79	20	2	45	0.106928
80	20	2	45	0.096349
81	20	2	45	0.086975
82	20	2	45	0.078657
83	20	2	45	0.071265
84	20	2	45	0.064687
85	20	2	45	0.058824
86	20	2	45	0.053588
87	20	2	45	0.048904
88	20	2	45	0.044708
89	20	2	45	0.040941
90	20	2	45	0.037553

Very Sharp Turn (VST)				
x	a	b	c	μ(x)
0	15	3	80	4.34499E-05
1	15	3	80	4.68559E-05
2	15	3	80	5.05776E-05
3	15	3	80	5.46487E-05
4	15	3	80	5.91072E-05
5	15	3	80	6.39959E-05
6	15	3	80	6.93629E-05
7	15	3	80	7.52623E-05
8	15	3	80	8.17555E-05
9	15	3	80	8.89117E-05
10	15	3	80	9.68093E-05
11	15	3	80	0.000105538
12	15	3	80	0.000115198
13	15	3	80	0.000125905
14	15	3	80	0.000137792
15	15	3	80	0.000151009
16	15	3	80	0.000165728
17	15	3	80	0.000182148
18	15	3	80	0.000200498
19	15	3	80	0.000221041
20	15	3	80	0.000244081
21	15	3	80	0.000269972
22	15	3	80	0.000299123
23	15	3	80	0.000332012
24	15	3	80	0.000369198
25	15	3	80	0.000411332
26	15	3	80	0.000459183
27	15	3	80	0.000513652
28	15	3	80	0.000575808
29	15	3	80	0.000646912
30	15	3	80	0.000728469
31	15	3	80	0.000822269
32	15	3	80	0.000930456
33	15	3	80	0.001055606
34	15	3	80	0.001200822
35	15	3	80	0.001369863
36	15	3	80	0.001567293
37	15	3	80	0.001798684
38	15	3	80	0.002070864
39	15	3	80	0.002392237
40	15	3	80	0.002773202
41	15	3	80	0.003226683
42	15	3	80	0.003768826
43	15	3	80	0.00441991
44	15	3	80	0.005205541
45	15	3	80	0.006158239
46	15	3	80	0.007319536
47	15	3	80	0.008742795
48	15	3	80	0.01049699
49	15	3	80	0.012671818
50	15	3	80	0.015384615
51	15	3	80	0.018789777
52	15	3	80	0.023091558
53	15	3	80	0.028561453
54	15	3	80	0.035561653
55	15	3	80	0.04457625
56	15	3	80	0.056251778
57	15	3	80	0.071447495
58	15	3	80	0.091292592
59	15	3	80	0.117239672
60	15	3	80	0.151088083
61	15	3	80	0.194923102
62	15	3	80	0.25087908
63	15	3	80	0.32060805
64	15	3	80	0.404384028
65	15	3	80	0.5
66	15	3	80	0.602036367
67	15	3	80	0.702369129
68	15	3	80	0.792302622
69	15	3	80	0.86540526
70	15	3	80	0.919293821
71	15	3	80	0.95542375
72	15	3	80	0.977503716
73	15	3	80	0.989777007
74	15	3	80	0.995920709
75	15	3	80	0.998630137
76	15	3	80	0.999640535
77	15	3	80	0.999936004
78	15	3	80	0.999994381
79	15	3	80	0.999999912
80	15	3	80	1
81	15	3	80	0.999999912
82	15	3	80	0.999994381
83	15	3	80	0.999936004
84	15	3	80	0.999640535
85	15	3	80	0.998630137
86	15	3	80	0.995920709
87	15	3	80	0.989777007
88	15	3	80	0.977503716
89	15	3	80	0.95542375
90	15	3	80	0.919293821

B. THE RULE BASE THAT WILL BE USED FOR INFERENCING

There are 7 rules which covers all possibilities:

1. If (Distance is N) and (Angle is S) then (Speed is SS)(Steering_turn is VST)

This rule says that if the distance is less (means around 0 to 4) and angle of the obstacle is less (means around 0 to 35) then the robot should take the very sharp turn(VST) and speed should be decreased (SS) while turning.

2. If (Distance is N) and (Angle is M) then (Speed is SS)(Steering_turn is VST)

3. If (Distance is F) and (Angle is S) then (Speed is MS)(Steering_turn is SST)

4. If (Distance is F) and (Angle is M) then (Speed is FS)(Steering_turn is MST)

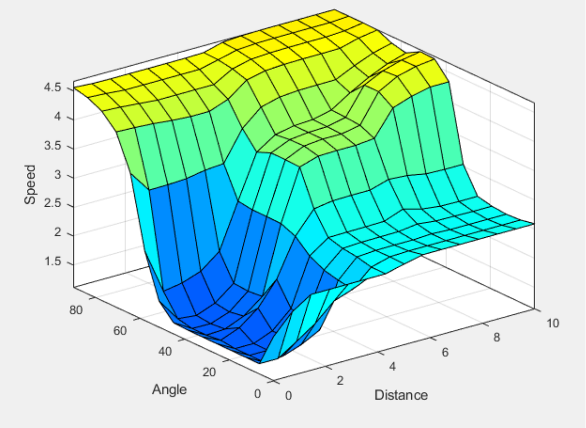
5. If (Distance is VF) and (Angle is S) then (Speed is MS)(Steering_turn is SST)

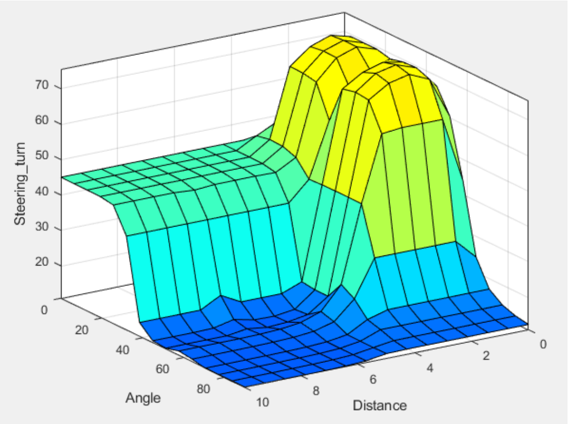
6. If (Distance is VF) and (Angle is M) then (Speed is MX)(Steering_turn is MST)

7. If (Angle is L) then (Speed is MX)(Steering_turn is MST)

This rule says that if the angle is Large (around 70 to 90) then does not matter distance is less or more because the obstacle is not in the way of robot. If there is no obstacle than speed of robot should be increased and robot can take mild turn (around at angle 0 to 20). I have to specify the steering turn because if I don't specify it the Steering turn value will be surprise or unwanted.

The figures below specifies how the system will behave in every situation.

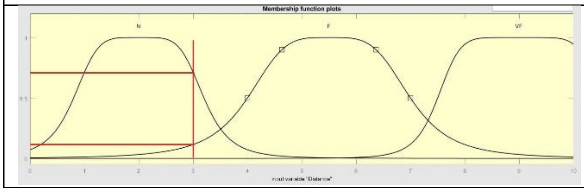
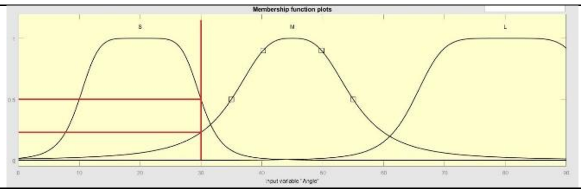




C. THE INFERENCING SYSTEM THAT WILL BE USED

I have used Mamdani inferencing system.

Let's consider the input values such as, Distance is 3 and Angle is 30. Firstly, lets calculate the membership value of input values

Distance	Angle
$\mu_N(3) = \dfrac{1}{1 + \left\lvert\dfrac{3-2}{1.2}\right\rvert^5} = 0.71$	$\mu_S(30) = \dfrac{1}{1 + \left\lvert\dfrac{30-20}{10}\right\rvert^6} = 0.5$
$\mu_F(3) = \dfrac{1}{1 + \left\lvert\dfrac{3-5.5}{1.5}\right\rvert^4} = 0.11$	$\mu_M(30) = \dfrac{1}{1 + \left\lvert\dfrac{30-45}{10}\right\rvert^3} = 0.22$
	

The four out of seven rules will be affected by this values. Firstly, T-norm will be applied to antecedents which are distance and angle in this example. Then I will apply S-norm(union) to all results. That four rules which are affected are below:

1. If distance is near and angle is small then speed is slow and steering turn is very sharp.

$$\mu(z) = \min\big(\mu_N(3), \mu_S(30)\big)$$

$$\mu(z) = \min(0.71, 0.5)$$

$$\mu(z) = 0.5$$

$$SS' = \left[\frac{0.21}{0.4} + \frac{0.5}{0.6} + \frac{0.5}{0.8} + \frac{0.5}{1} + \frac{0.5}{1.2} + \frac{0.5}{1.4} + \frac{0.21}{1.6}\right]$$

$$VST' = \left[\frac{0.11}{59} + \frac{0.15}{60} + \frac{0.19}{61} + \frac{0.25}{62} + \frac{0.32}{63} + \frac{0.4}{64} + \frac{0.5}{65} + \frac{0.5}{66} + \frac{0.5}{67} + \cdots + \frac{0.5}{90}\right]$$

2. If distance is near and angle is medium then speed is slow and steering turn is very sharp.

$$\mu(z) = \min\big(\mu_N(3), \mu_M(30)\big)$$

$$\mu(z) = \min(0.71, 0.22)$$

$$\mu(z) = 0.22$$

$$SS' = \left[\frac{0.21}{0.4} + \frac{0.22}{0.6} + \frac{0.22}{0.8} + \frac{0.22}{1} + \frac{0.22}{1.2} + \frac{0.22}{1.4} + \frac{0.21}{1.6}\right]$$

$$VST' = \left[\frac{0.11}{59} + \frac{0.15}{60} + \frac{0.19}{61} + \frac{0.22}{62} + \frac{0.22}{63} + \frac{0.22}{64} + \frac{0.22}{65} + \frac{0.22}{66} + \frac{0.22}{67} + \cdots + \frac{0.22}{90}\right]$$

3. If distance is far and angle is small then speed is medium and steering turn is sharp.

$$\mu(z) = \min\left(\mu_F(3), \mu_S(30)\right)$$

$$\mu(z) = \min(0.11, 0.5)$$

$$\mu(z) = 0.11$$

$$MS' = \left[\frac{0.11}{1.4} + \frac{0.11}{1.6} + \frac{0.11}{1.8} + \frac{0.11}{2} + \frac{0.11}{2.2} + \frac{0.11}{2.4} + \cdots + \frac{0.11}{3.6}\right]$$

$$SST' = \left[\frac{0.1}{11} + \frac{0.11}{12} + \frac{0.11}{13} + \frac{0.11}{14} + \cdots + \frac{0.11}{78} + \frac{0.1}{79}\right]$$

4. If distance is far and angle is medium then speed is fast and steering turn is mild.

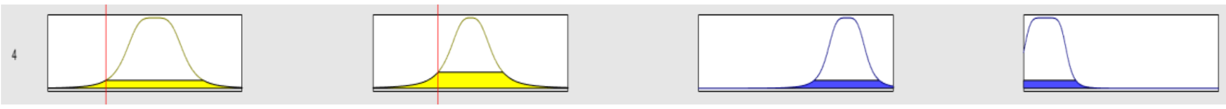
$$\mu(z) = \min\left(\mu_F(3), \mu_M(30)\right)$$

$$\mu(z) = \min(0.11, 0.22)$$

$$\mu(z) = 0.11$$

$$FS' = \left[\frac{0.11}{3} + \frac{0.11}{3.2} + \frac{0.11}{3.4} + \cdots + \frac{0.11}{4.6} + \frac{0.11}{4.8} + \frac{0.11}{5}\right]$$

$$MST' = \left[\frac{0.11}{0} + \frac{0.11}{1} + \frac{0.11}{2} + \cdots + \frac{0.11}{24} + \frac{0.08}{25}\right]$$

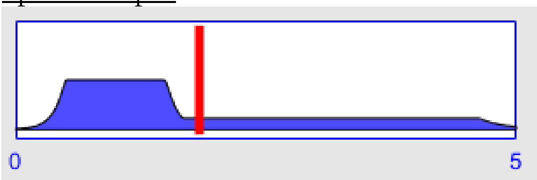


Now, we will apply union operation on all 4 speed universe fuzzy sets and all 4 steering turn universe fuzzy sets which I obtained above. The output will be:

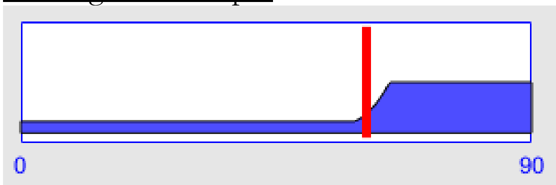
$$Speed = \left[\frac{0.21}{0.4} + \frac{0.5}{0.6} + \frac{0.5}{0.8} + \frac{0.5}{1} + \frac{0.5}{1.2} + \frac{0.11}{1.4} + \frac{0.11}{1.6} + \frac{0.11}{1.8} + \cdots + \frac{0.11}{4.6} + \frac{0.05}{4.8} + \frac{0.02}{5}\right]$$

$$Steering = \left[\frac{0.11}{0} + \cdots + \frac{0.11}{59} + \frac{0.15}{60} + \frac{0.19}{61} + \frac{0.25}{62} + \frac{0.32}{63} + \frac{0.4}{64} + \frac{0.5}{65} + \frac{0.5}{66} + \cdots + \frac{0.5}{90}\right]$$

Speed Output



Steering Turn Output



These two fuzzy sets are the output I received.

D. THE DEFUZZIFICATION METHOD

x	μ(x)	x * μ(x)
0.2	0.03	0.006
0.4	0.21	0.084
0.6	0.5	0.3
0.8	0.5	0.4
1	0.5	0.5
1.2	0.5	0.6
1.4	0.11	0.154
1.6	0.11	0.176
1.8	0.11	0.198
2	0.11	0.22
2.2	0.11	0.242
2.4	0.11	0.264
2.6	0.11	0.286
2.8	0.11	0.308
3	0.11	0.33
3.2	0.11	0.352
3.4	0.11	0.374
3.6	0.11	0.396
3.8	0.11	0.418
4	0.11	0.44
4.2	0.11	0.462
4.4	0.11	0.484
4.6	0.11	0.506
4.8	0.05	0.24
5	0.02	0.1
Summation	**4.18**	**7.84**

I have used centroid defuzzification method.

$$Centroid = \frac{\sum_i \mu(x_i)x_i}{\sum \mu(x_i)}$$

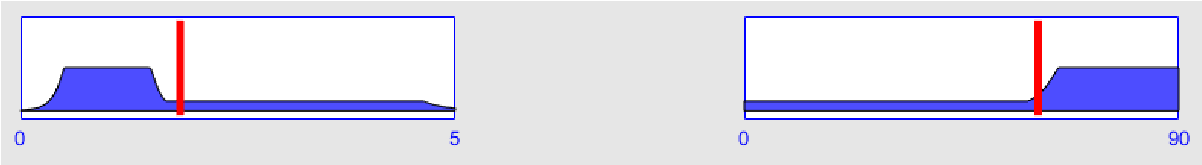
$$Speed\ Centroid\ value = \frac{7.84}{4.18} = 1.87$$

Steering Turn Output

x	μ(x)	x * μ(x)
0	0.11	0
1	0.11	0.11
2	0.11	0.22
3	0.11	0.33
4	0.11	0.44
5	0.11	0.55
6	0.11	0.66
7	0.11	0.77
8	0.11	0.88
9	0.11	0.99
10	0.11	1.1
11	0.11	1.21
12	0.11	1.32
13	0.11	1.43
14	0.11	1.54
15	0.11	1.65
16	0.11	1.76
17	0.11	1.87
18	0.11	1.98
19	0.11	2.09
20	0.11	2.2
21	0.11	2.31
22	0.11	2.42
23	0.11	2.53
24	0.11	2.64
25	0.11	2.75
26	0.11	2.86
27	0.11	2.97
28	0.11	3.08
29	0.11	3.19
30	0.11	3.3
31	0.11	3.41
32	0.11	3.52
33	0.11	3.63
34	0.11	3.74
35	0.11	3.85
36	0.11	3.96
37	0.11	4.07
38	0.11	4.18
39	0.11	4.29
40	0.11	4.4
41	0.11	4.51
42	0.11	4.62
43	0.11	4.73
44	0.11	4.84
45	0.11	4.95
46	0.11	5.06
47	0.11	5.17
48	0.11	5.28
49	0.11	5.39
50	0.11	5.5
51	0.11	5.61
52	0.11	5.72
53	0.11	5.83
54	0.11	5.94
55	0.11	6.05
56	0.11	6.16
57	0.11	6.27
58	0.11	6.38
59	0.11	6.49
60	0.15	9
61	0.19	11.59
62	0.25	15.5
63	0.32	20.16
64	0.4	25.6
65	0.5	32.5
66	0.5	33
67	0.5	33.5
68	0.5	34
69	0.5	34.5
70	0.5	35
71	0.5	35.5
72	0.5	36
73	0.5	36.5
74	0.5	37
75	0.5	37.5
76	0.5	38
77	0.5	38.5
78	0.5	39
79	0.5	39.5
80	0.5	40
81	0.5	40.5
82	0.5	41
83	0.5	41.5
84	0.5	42
85	0.5	42.5
86	0.5	43
87	0.5	43.5
88	0.5	44
89	0.5	44.5
90	0.5	45
Summation	**20.91**	**1284.05**

$$Centroid = \frac{\sum_i \mu(x_i)x_i}{\sum \mu(x_i)}$$

$$Steering\ Turn\ Centroid\ value = \frac{1284.05}{20.91} = 61$$



2. EXPLAIN YOUR CHOICES IN 1-C AND 1-D.

Mamdani because it gives output in fuzzy set. It gives intuitive output. Whereas Sugeno five output as linear or constant. In this question, I needed output to be in fuzzy set and should be intuitive output based on rules to whatever input value is insert.

Mamdani is more beneficial when human input is needed. Apparently, Sugeno is better with mathematical analysis.

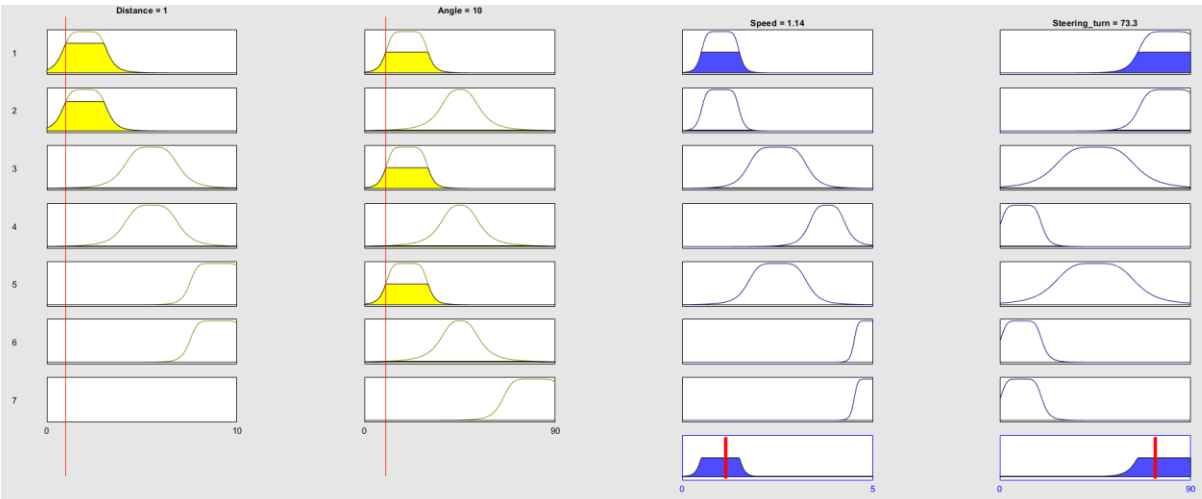
In mamdani, the rules are provided from expert human operators. It is rule based system means interpretability is more.

Centroid defuzzification method is used because I needed center point of my whole output rather than SOM, LOM, MOM which considers only largest plague. I consider the whole area of output is equally important and I needed the center of gravity of my whole output.

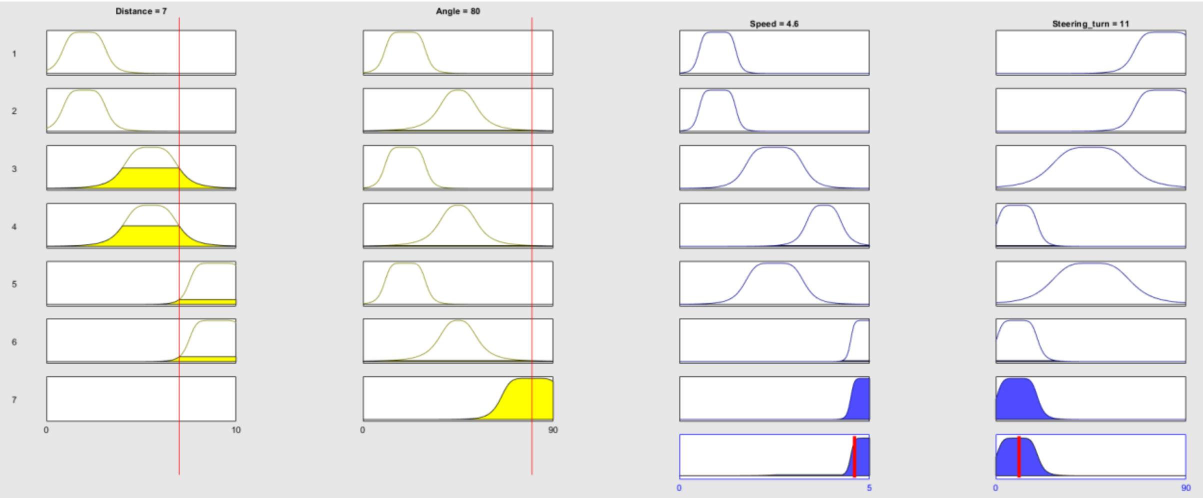
I have tried different defuzzification methods but most reliable output from any input entered is acquired by Centroid defuzzification method.

3. PROVIDE AT LEAST 2 EXAMPLES OF INPUTS AND SHOW YOUR SYSTEM'S OUTPUT CONTROL COMMAND.

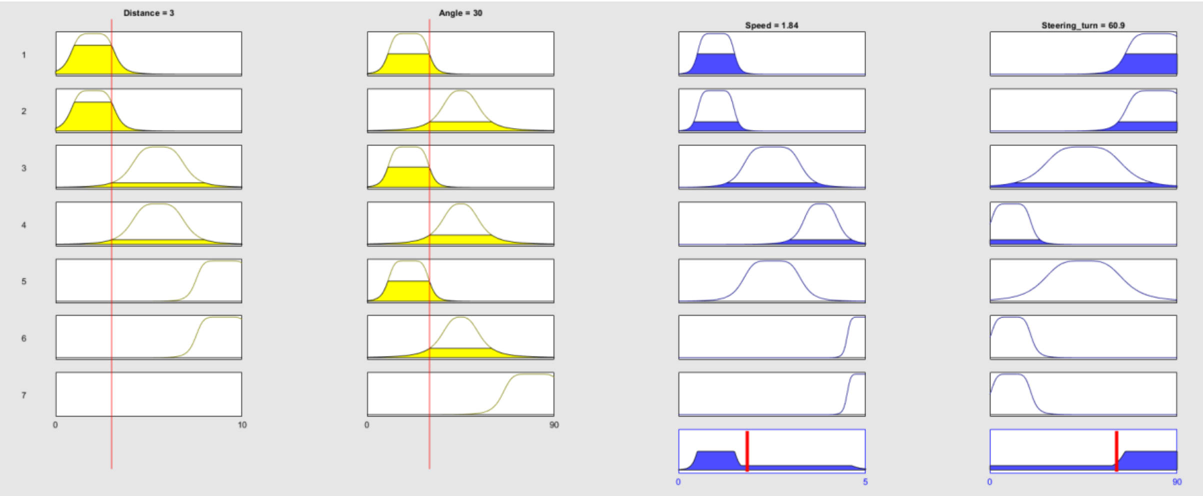
Example 1: Distance is 1 and Angle is 10. Then the final output we got is Speed is 1.14 and Steering Turn is 73.3. In this example there is obstacle, so speed is decreased and took the very sharp turn.



Example 2: Distance is 7 and Angle is 80. Then the final output we got is Speed is 4.6 and Steering Turn is 11. In this example, there will be no obstacle because angle is too high. So robot will not meet an obstacle. So Speed is increased to 4.6 and Steering turn is 11.



Example 3: Distance is 3 and Angle is 30. Then the final output we got is Speed is 1.84 and Steering Turn is 60.9



<u>.fis file</u>

```
[System]
Name='Trying_fuzzy'
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=2
NumRules=7
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'
```

```
[Input1]
Name='Distance'
Range=[0 10]
NumMFs=3
MF1='N':'gbellmf',[1.2 2.5 2]
MF2='F':'gbellmf',[1.5 2 5.5]
MF3='VF':'gbellmf',[1.5 3.5 9]

[Input2]
Name='Angle'
Range=[0 90]
NumMFs=3
MF1='S':'gbellmf',[10 3 20]
MF2='M':'gbellmf',[10 1.5 45]
MF3='L':'gbellmf',[15 3 80]

[Output1]
Name='Speed'
Range=[0 5]
NumMFs=4
MF1='MS':'gbellmf',[0.8 2.5 2.5]
MF2='FS':'gbellmf',[0.5 2 3.8]
MF3='MX':'gbellmf',[0.5 5 5]
MF4='SS':'gbellmf',[0.5 3.5 1]

[Output2]
Name='Steering_turn'
Range=[0 90]
NumMFs=3
MF1='MST':'gbellmf',[10 3 10]
MF2='SST':'gbellmf',[20 2 45]
MF3='VST':'gbellmf',[15 3 80]

[Rules]
1 1, 4 3 (1) : 1
1 2, 4 3 (1) : 1
2 1, 1 2 (1) : 1
2 2, 2 1 (1) : 1
3 1, 1 2 (1) : 1
3 2, 3 1 (1) : 1
0 3, 3 1 (1) : 1
```