<u>TRC4901 Artificial Intelligence for Engineers</u>

<u>Lab-1 Fuzzy Logic System : Weather forecast Simulation</u>

Resources: MATLAB, Fuzzy Logic Toolbox
Compatible with previous version. No new features or commands added in the new release.

Experiment Description:
This lab assignment consists of two parts. First, you are required to go through the Help documentation for the Fuzzy Logic Toolbox to familiarize yourself with the toolbox referring the week2 workshop demonstration (*Tutor will help you*). Once you have done, secondly, you are required to use fuzzy logic to solve one of the problems given in the problem data set. Each student must choose a different data set for the same problem and confirm your selection with the tutor.

Fuzzy Logic Toolbox Tutorial

"Fuzzy Inference Systems" and its subtopics (highlighted in red) discuss theoretical aspects about Fuzzy Inferences Systems (FIS). "Building Systems with Fuzzy Logic Toolbox Software" and its subtopics (highlighted in yellow) contains a tutorial to creating a simple FIS, using the Risk analysis (week 2 workshop demonstration) problem. You are required to go through the material to learn and understand how fuzzy logic can be used to solve a problem. This is part of your lab work, but ***not*** a gradable part of the subject. In other words, you should do it, but no marks are allocated for it either in your demonstration or in the submitted report. The aim is for you to be proficient in building a fuzzy logic system with the help of the GUI tools provided by the Fuzzy Logic toolbox (the FIS editor, the Membership Function Editor, the Rule Editor, the Rule Viewer, and the Surface Viewer).

Problem Solving Using Fuzzy Logic

Once you are able to implement the Risk analysis problem successfully, choose a problem of medium complexity (2 inputs and 1 output) from the available data set. If you choose to use a 2-input controller, each input/output must have at least **FIVE (5)** membership functions. Practically speaking, you may need more than this minimum to achieve the desired result. Use the Fuzzy Logic Toolbox to solve the problem.

Available Number	Titles
26	Weather Prediction - UK
5	Weather Prediction - Sweden
2	Weather Prediction - Norway
3	Weather Prediction - Mexico
19	Weather Prediction - Asia
4	Weather Prediction - Africa
7	Weather Prediction – South America
18	Weather Prediction – USA
1	Prediction of Body Fat Percentage
1	House Price Prediction
1	Staff Hiring System
87	

Note: Plotting the input-output relationships of the selected data may help with designing a suitable membership function.

Laboratory Activities

Week 3: Practice with FL Toolbox, specifically by completing the tutorial in "Building Systems with Fuzzy Logic Toolbox Software". Start working on the lab assignment. Finalize the data set used and confirm with the lab Tutors. Continue working on the lab assignment.

Week 4: Continue working on the lab assignment. Demonstrate your fuzzy logic system and prepare the Lab Report.

Resources

You are strongly recommended to go through the help documentation for the Fuzzy Logic Toolbox, especially the topics previously highlighted. The sub-topic "FIS Evaluation" under "Working from the Command Line" may also prove useful in your lab session. For report preparation, the other topics may prove useful. Please take note that this doesn't mean that copying and pasting directly from the help file is allowed. This documentation is available at Help >> Product Help >> Fuzzy Logic Toolbox.

Questions:

(a) Demonstrate the relationship between inputs and output using the preliminary studies before the simulations by showing the graphical evidences. (refer sample experiment and results).

(b) Simulate the data using fuzzy logic system show the rule viewer & surface viewer and demonstrate the output with respect to inputs. The evalfis command may prove useful for calculating the output of the fuzzy logic system.

(c) Demonstrate two cases as below

i. Dew point and Dry bulb temperatures are as inputs and Relative humidity as an output
ii. Relative humidity and Dry bulb Temperature are as inputs and Dew point Temperature as an output.

(d) Evaluate the results by plotting the real relative humidity and estimated relative humidity to show the percentage error and mean error between them. (refer sample code available in the sample report).

Report Format

Please make sure that your name and Student ID are included in the first page of your softcopy report. Your report will be assessed based on the demonstration done and how the work done has been documented. However, the following aspects are essential:

1. Assumptions made (if any).
2. Details of the fuzzy system setup, including inputs, output(s), linguistic terms, membership functions, input/output range, controller type, defuzzification method, etc.
3. How the rules are designed.
4. Simulation of your fuzzy logic system and results.
5. Comment on the simulation results with 2 case studies.
6. Addressing questions (a) to (d)
7. Maximum page limit: 5 pages. You can add rest of the materials in the appendix.

Report Submission

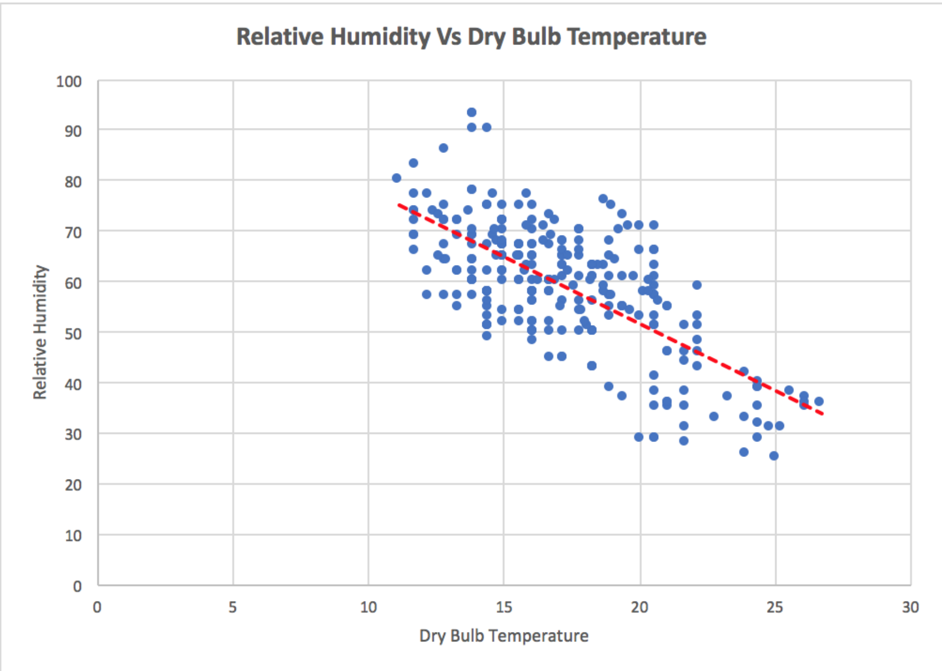
Demonstration and report carries marks as indicated in the Assessment details. Submission is via Moodle page.

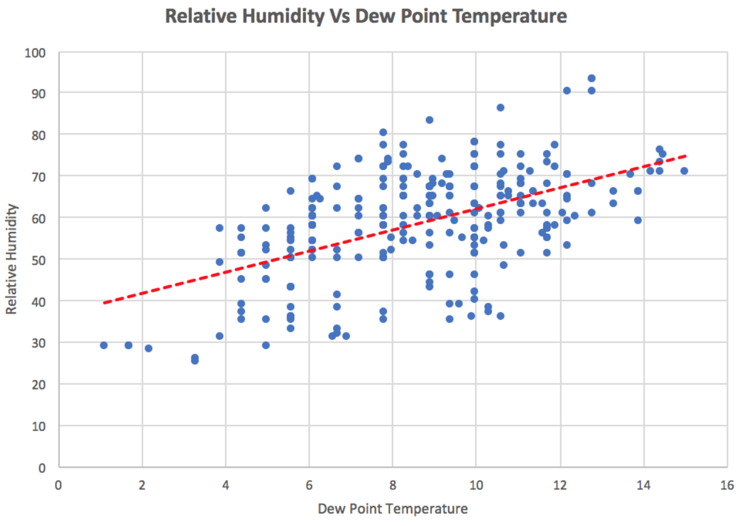
Sample Experiment and Results

The objective of this experiment is to predict the Relative humidity of a particular city.

Step-1. Preliminary studies:

- Study the data provided about the variables such as temperature, relative humidity, wind speed and accordingly design a Fuzzy Logic system using two or three inputs and one output.
- Relative Humidity is the amount of water vapor in the air, expressed as a percentage of the maximum amount that the air could hold at the given temperature. Relative humidity is proportional to rain, therefore the higher the Relative humidity, the higher are the chances of raining.
- Dry Bulb Temperature refers basically to the ambient air temperature. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air.
- Dew Point Temperature is the temperature where water vapor starts to condense out of the air (the temperature at which air becomes completely saturated). Above this temperature, the moisture stays in the air.
- If the Dew Point Temperature is close to the Dry Bulb Temperature - the relative humidity is high [1].
- If the Dew Point Temperature is well below the Dry Bulb Temperature - the relative humidity is low [1].
- The Dew Point temperature is always lower than the Dry Bulb temperature [1].
- Relative humidity of 100% indicates the dew point is equal to the current temperature and that the air is maximally saturated with water [1].





Data Set: San Francisco, USA.

Dry Bulb Temperature	Dew Point Temperature	Relative Humidity
13.9	12.8	93
14.4	12.8	90
13.9	12.8	93
13.9	6.1	60
13.9	6.1	60
13.9	6.1	60
13.3	5	57
14.4	4.4	51
14.4	5.6	55
13.3	7.8	69
15	7.8	62
16.1	7.8	58
14.4	3.9	49
12.8	10.6	86
13.9	12.2	90
14.4	6.1	58
15	7.2	60
16.1	7.2	56
16.1	5.6	50
17.2	5	45
18.3	5.6	43
15	8.3	65
15	8.9	67
13.9	8.3	69
11.7	7.2	74
12.8	6.7	67
13.3	6.1	62
13.9	5.6	57
14.4	5	53

14.4	6.1	58
17.2	10.6	65
16.1	10	67
17.2	10	63
18.3	5.6	43
20.6	4.4	35
21.7	2.2	28
20	1.1	29
20.6	1.7	29
20.6	1.7	29
21.1	5	35
21.1	5.6	36
21.7	5.6	35
14.4	6.1	58
14.4	7.2	62
14.4	6.1	58
17.2	10	63
20	10	53
21.1	8.9	46
12.2	8.3	77
12.8	8.3	75
13.9	8.3	69
11.7	7.8	77
11.1	7.8	80
11.7	7.2	74
13.9	6.7	62
13.9	6.1	60
14.4	6.1	58
15	8.3	65
16.1	7.8	58
16.1	8.3	60
13.9	10	78
15	10	72
15	10	72
12.8	7.8	72
13.9	7.8	67
13.9	7.2	64
11.7	6.1	69
11.7	5.6	66
12.2	5	62
12.8	6.1	64
12.8	4.4	57
13.3	4.4	55

12.2	3.9	57
14.4	4.4	51
14.4	4.4	51
11.7	8.9	83
13.3	8.3	72
13.9	7.2	64
15.6	8.9	65
16.1	9.4	65
15.6	8.9	65
19.4	10	55
21.7	9.4	46
21.1	8.9	46
22.2	10	46
23.9	6.7	33
24.4	9.4	39
13.9	10	78
14.4	10	75
14.4	10	75
15	8.9	67
17.2	8.3	56
18.3	7.8	50
18.3	11.1	63
18.9	11.1	61
18.3	10.6	61
16.1	10	67
16.7	8.9	60
16.7	8.3	58
16.1	7.8	58
18.3	7.8	50
18.3	7.8	50
15	7.8	62
15	8.3	65
15.6	7.8	60
11.7	6.1	69
14.4	5.6	56
11.7	6.7	72
15.6	6.1	54
16.1	9.4	65
16.7	6.1	50
18.9	8.9	53
20.6	6.7	41
21.7	6.7	38
23.9	3.3	26

25	3.3	25
23.3	7.8	37
15	5.6	54
16.1	5	48
15	5	52
17.2	5	45
18.3	5.6	43
18.9	4.4	39
21.1	5.6	36
22.8	5.6	33
22.2	8.9	43
17.2	9.4	61
21.7	8.9	44
20.6	10	51
16.1	7.8	58
16.1	7.2	56
17.2	6.7	50
15.6	6.1	54
16.1	6.1	52
16.7	6.7	52
21.7	11.1	51
24.4	7.8	35
24.4	5	29
22.2	11.7	51
22.2	12.2	53
24.4	10	40
15	8.9	67
16.7	8.9	60
16.7	8.9	60
15	9.4	70
15.6	9.4	67
15.6	9.4	67
16.1	11.1	72
16.1	11.7	75
16.7	11.7	73
16.1	5.6	50
16.7	4.4	45
15.6	5.6	52
19.4	4.4	37
20.6	5.6	38
21.7	3.9	31
16.1	5.6	50
15.6	7.8	60

16.1	6.1	52
18.9	12.2	65
20.6	11.7	57
20.6	11.7	57
20.6	12.8	61
20.6	15	71
20	13.3	66
20.6	13.9	66
20.6	13.9	66
22.2	13.9	59
15.6	11.1	75
15	10.6	75
16.1	10.6	70
15	10	72
17.8	10	61
18.9	10	57
17.8	12.2	70
18.9	12.8	68
21.1	11.7	55
17.8	12.2	70
19.4	11.7	61
20.6	12.2	59
17.2	11.1	68
18.3	11.1	63
17.8	11.1	65
12.6	6.2	65
12.9	6.3	64
13.3	6.1	62
14.8	8.3	65
15.8	8.6	62
16.7	8.3	58
12.4	7.9	74
12.6	7.9	73
12.8	7.8	72
14.6	9	69
14.8	9	68
15	8.9	67
18.7	11.6	63
18.5	11.4	63
18.3	11.1	63
15.9	8.9	63
16.9	9.1	60
17.8	8.9	56

13.7	9.2	74
14.7	9.3	70
15.6	9.4	67
13.3	8.4	72
13.9	8.6	70
14.4	8.3	67
14.6	10.6	77
15.9	10.7	71
17.2	10.6	65
17.8	11.4	66
17.2	10.8	66
16.7	10.6	67
17.4	10.1	62
18.2	10.3	60
18.9	10	57
15	9.2	68
15.5	9	65
16.1	8.9	63
18.3	9.4	56
18.9	9.7	55
19.4	10	55
20.6	10.7	53
22.2	10.7	48
23.9	10	42
24.4	9.6	39
25.6	10.3	38
26.7	10.6	36
26.1	10.3	37
26.1	9.9	36
26.1	9.4	35
25.2	6.9	31
24.8	6.6	31
24.4	6.7	32
20.2	11.7	58
20.4	12.4	60
20.6	13.3	63
19.1	12.2	64
19.8	12.1	61
20.6	11.7	57
16.5	10.6	68
17.4	10.8	65
18.3	10.6	61
20.4	11.9	58

20.7	11.6	56
21.1	11.7	55
16.5	11.3	71
16.8	11.1	69
17.2	11.1	68
15.9	11.9	77
16.9	11.9	72
17.8	11.7	68
16.3	8.6	60
17.1	8	55
17.8	7.2	50
19.3	13.7	70
19.6	14.2	71
20	14.4	71
18.7	14.4	76
19	14.5	75
19.4	14.4	73
17.6	9.5	59
17.9	8.5	54
18.3	7.8	50
18.1	7.8	51
18	8	52
17.8	8.3	54
18.7	10.3	58
19.7	10.2	54
20.6	10	51
18.7	10.6	59
19	10.3	57
19.4	10	55

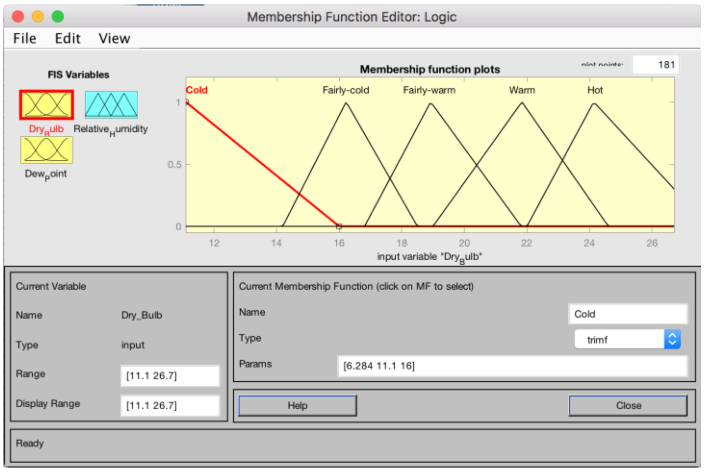
	Dry Bulb	Dew point	Relative Humidity
Max	26.7	15	93
Min	11.1	1.1	25

[1] *Dry bulb -, wet bulb - and dew point temperatures", engineeringtoolbox.com, 2017. [online]. available: http://www.engineeringtoolbox.com/dry-wet-bulb-dew-point-air-d_682.html. [accessed: 01-apr- 2017].*

Step-2: Fuzzifications: Fuzzy Inputs/ Output/Membership function

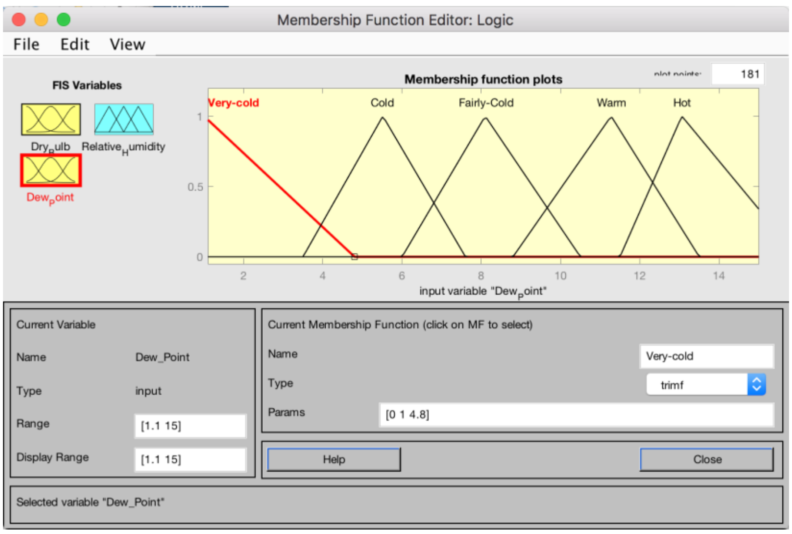
Membership functions for input, Dry Bulb Temperature.

INPUT-1		
Linguistic Variable	**Linguistic Value**	**Numerical Range**
Dry Bulb Temperature	Cold	6.28°C - 16°C [6.284 11.1 16]
	Fairly Cold	14.2°C – 18.5°C [14.2 16.23 18.5]
	Fairly Warm	16.81°C – 21.81°C [16.81 18.92 21.81]
	Warm	19°C – 24.6°C [19 21.84 24.6]
	Hot	22°C – 27.8°C [22 24.13 27.8]



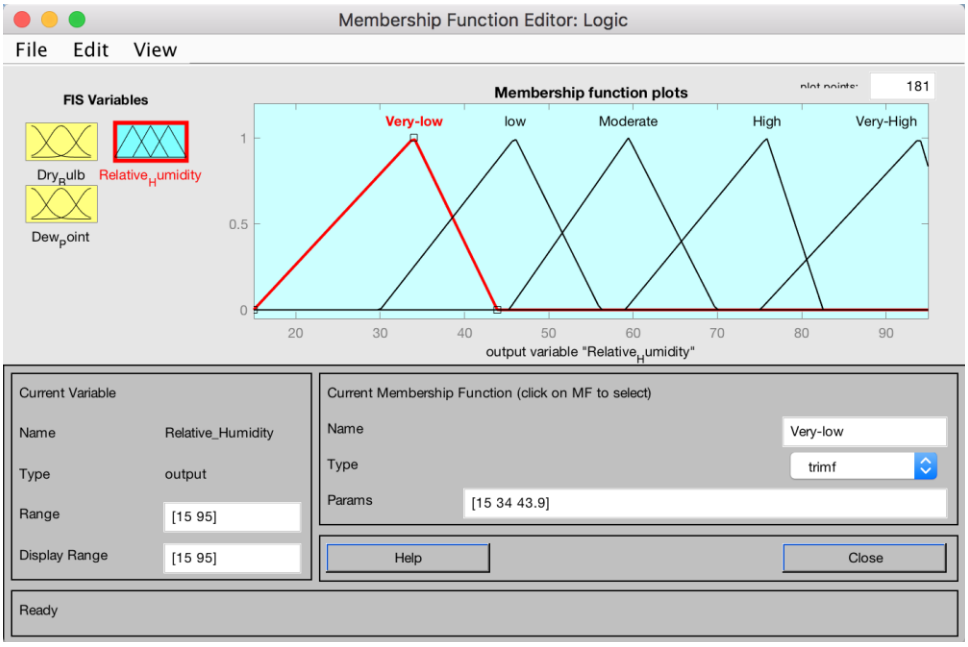
Membership functions for input, Dew Point Temperature

INPUT-2		
Linguistic Variable	**Linguistic Value**	**Numerical Range**
Dew Point Temperature	Very Cold	0°C – 4.8°C [0 1 4.8]
	Cold	3.5°C – 7.6°C [3.5 5.515 7.6]
	Fairly Cold	6°C – 10.5°C [6 8.098 10.5]
	Warm	8.8°C – 13.5°C [8.8 11.28 13.5]
	Hot	11.5°C – 16°C [11.5 13.06 16]



Membership functions for output, Relative Humidity

OUTPUT		
Linguistic Variable	**Linguistic Value**	**Numerical Range**
Relative Humidity	Very Low	15% -44% [15 34 43.9]
	Low	30% -56% [30 46 56.14]
	Moderate	45% -70% [45.26 59.46 69.86]
	High	59% -82.5% [59.05 75.85 82.55]
	Very High	75% -100% [75.06 94 00]



Step-3 Rule Evaluation:

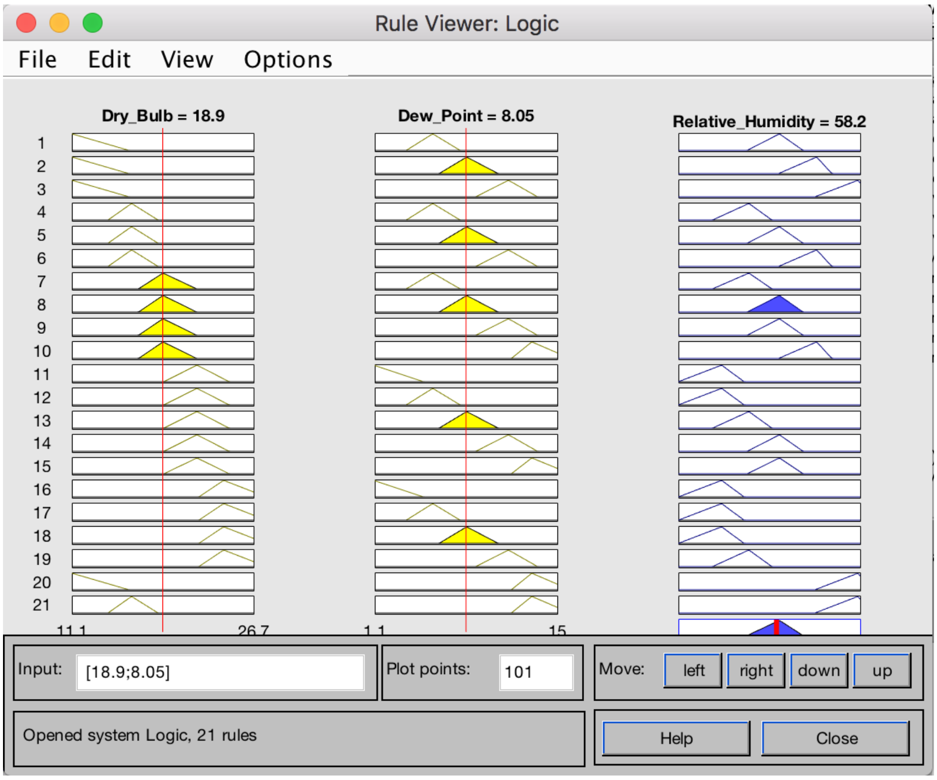
As there are two inputs and one output selected, there are twenty-five possible rules combinations suggested. However, after analyzing the relationship between Dry Bulb Temperature, Dew Point Temperature and Relative Humidity, we are able to conclude that only 21 rules were enough to simulate an acceptable range of relative humidity.

A	B	C	D	E	F
Dry Bulb Temperature	Dew Point Temperature	Relative Humidity	Dry Bulb Temperature	Dew Point Temperature	Relative Humidity
13.9	12.8	93	Cold	Hot	Very-High
14.4	12.8	90	Fairly-Cold	Hot	Very-High
13.9	12.8	93	Cold	Hot	Very-High
13.9	6.1	60	Cold	Cold	Moderate
13.9	6.1	60	Cold	Cold	Moderate
13.9	6.1	60	Cold	Cold	Moderate
13.3	5	57	Cold	Cold	Moderate
14.4	4.4	51	Fairly-Cold	Cold	Low
14.4	5.6	55	Fairly-Cold	Cold	Moderate
13.3	7.8	69	Cold	Fairly-Cold	High
15	7.8	62	Fairly-Cold	Fairly-Cold	Moderate

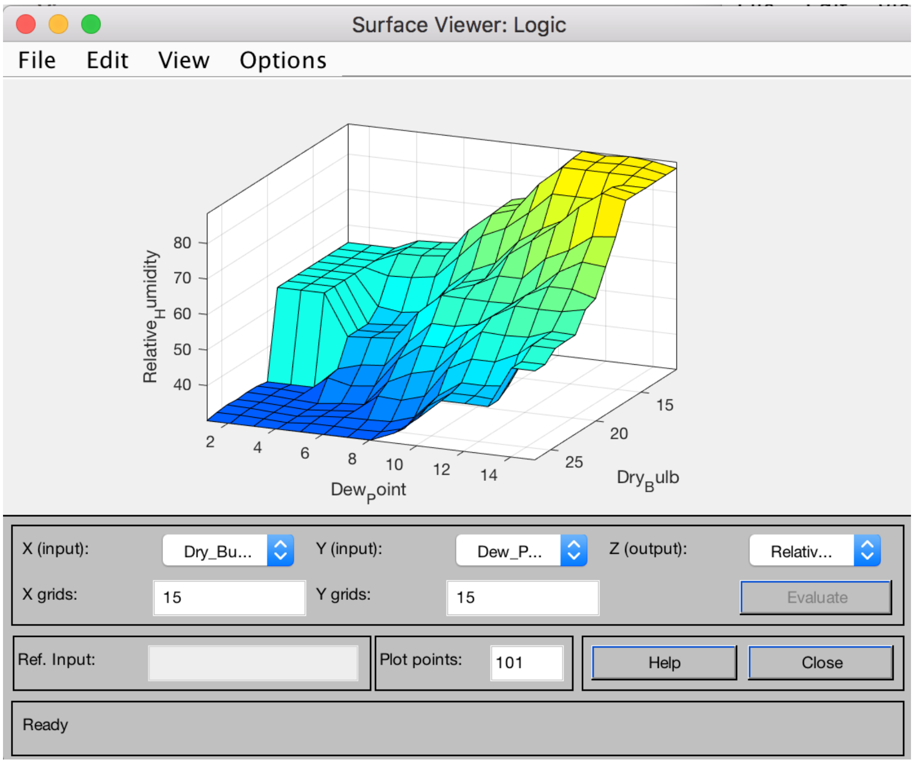
Dew Point \ Dry Bulb	Cold	Fairly Cold	Fairly Warm	Warm	Hot
Very Cold				Very Low	Very Low
Cold	Moderate	Low	Low	Very Low	Very Low
Fairly Cold	High	Moderate	Moderate	Low	Very Low
Warm	Very High	High	Moderate	Moderate	Low
Hot	Very High	Very High	High	Moderate	Very High

1. If (Dry_Bulb is Cold) and (Dew_Point is Cold) then (Relative_Humidity is Moderate) (1)
2. If (Dry_Bulb is Cold) and (Dew_Point is Fairly-Cold) then (Relative_Humidity is High) (1)
3. If (Dry_Bulb is Cold) and (Dew_Point is Warm) then (Relative_Humidity is Very-High) (1)
4. If (Dry_Bulb is Fairly-cold) and (Dew_Point is Cold) then (Relative_Humidity is low) (1)
5. If (Dry_Bulb is Fairly-cold) and (Dew_Point is Fairly-Cold) then (Relative_Humidity is Moderate) (1)
6. If (Dry_Bulb is Fairly-cold) and (Dew_Point is Warm) then (Relative_Humidity is High) (1)
7. If (Dry_Bulb is Fairly-warm) and (Dew_Point is Cold) then (Relative_Humidity is low) (1)
8. If (Dry_Bulb is Fairly-warm) and (Dew_Point is Fairly-Cold) then (Relative_Humidity is Moderate) (1)
9. If (Dry_Bulb is Fairly-warm) and (Dew_Point is Warm) then (Relative_Humidity is Moderate) (1)
10. If (Dry_Bulb is Fairly-warm) and (Dew_Point is Hot) then (Relative_Humidity is High) (1)
11. If (Dry_Bulb is Warm) and (Dew_Point is Very-cold) then (Relative_Humidity is Very-low) (1)
12. If (Dry_Bulb is Warm) and (Dew_Point is Cold) then (Relative_Humidity is Very-low) (1)
13. If (Dry_Bulb is Warm) and (Dew_Point is Fairly-Cold) then (Relative_Humidity is low) (1)
14. If (Dry_Bulb is Warm) and (Dew_Point is Warm) then (Relative_Humidity is Moderate) (1)
15. If (Dry_Bulb is Warm) and (Dew_Point is Hot) then (Relative_Humidity is Moderate) (1)
16. If (Dry_Bulb is Hot) and (Dew_Point is Very-cold) then (Relative_Humidity is Very-low) (1)
17. If (Dry_Bulb is Hot) and (Dew_Point is Cold) then (Relative_Humidity is Very-low) (1)
18. If (Dry_Bulb is Hot) and (Dew_Point is Fairly-Cold) then (Relative_Humidity is Very-low) (1)
19. If (Dry_Bulb is Hot) and (Dew_Point is Warm) then (Relative_Humidity is low) (1)
20. If (Dry_Bulb is Cold) and (Dew_Point is Hot) then (Relative_Humidity is Very-High) (1)
21. If (Dry_Bulb is Fairly-cold) and (Dew_Point is Hot) then (Relative_Humidity is Very-High) (1)

Step-4 Aggregation & Defuzzifiction.



Step-5: Output of a particular case study.



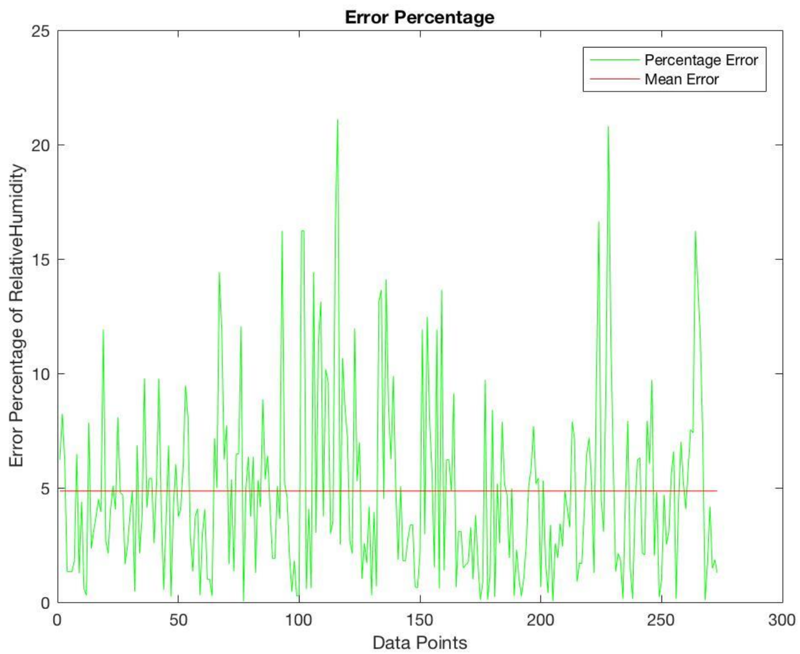
Step- 6: Results Evaluation.

After the design of the fuzzy logic system, relative humidity for the city of San Fransicso can be determined based on the sampled data. The simulated relative humidity is compared with the real relative humidity data and the accuracy of the fuzzy system is computed. Furthermore, a graph is plotted for comparison between the real relative humidity and the estimated relative humidity to show the percentage error and mean error between them. The MATLAB m-file was written to perform these functions as shown below.

```
%Tidying up the workplace
clc;
clear all;
close all;

%% Developing a Fuzzy Logic Controller for Weather Prediction

%Importing the relevant data from the data sheet provided

sanfrancisco='data_sanfrancisco.xlsx'; %Importing data from the excel file

Dry_Bulb_Temp = xlsread(sanfrancisco,'A:A');
Dew_Point_Temp = xlsread(sanfrancisco,'B:B');
Relative_Humidity=xlsread(sanfrancisco,'C:C');
fuzzy_set= readfis('Logic.fis');

%Using fuzzy logic to simulate data
Output=evalfis([Dry_Bulb_Temp Dew_Point_Temp],fuzzy_set);
deviation=abs(Output-Relative_Humidity);
max_deviation=max(deviation);
error= deviation./Relative_Humidity*100;
min_error=min(error)
max_error=max(error)
average_error=mean(error)
```

```
%Graph plotted to compare Actual and Simulated Relative Humidity
figure(1)
plot(1:length(Relative_Humidity),Relative_Humidity,'b',1:length(Relative_Humidity),Output,'r
*-')
title('Comparison of Simulated and Actual Relative Humidity')
xlabel('Data Points')
ylabel('Relative Humidity')
legend('Actual Relative Humidity','Simulated Relative Humidity')

%Graph plotted for percentage error and mean error
figure(2)
plot(1:length(Relative_Humidity),error,'g', [1,length(Relative_Humidity)],
[average_error,average_error], 'r')
title('Error Percentage')
xlabel('Data Points')
ylabel('Error Percentage of RelativeHumidity')
legend ('Percentage Error', 'Mean Error')
```

Initially, a higher average error of 8.5% was obtained. Aequate modifications are then made to the limits of the membership fuctions and also to the Fuzzy Rules. Some rules are modified to optimize the fuzzy controller further and as a result the final percentage error reduced to 4.857%.



Step-7: Students need to discuss and demonstrate at least three (3) cases.