Knowledge and Reasoning under Uncertainty
COURSE 2025/2026

Apparent Temperature using a Fuzzy Logic System

Master in Artificial Intelligence

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Contents

1. Introduction

The objective of this practice is to develop, from the ground up, a Fuzzy Inference System that models apparent temperature, which is the way a human body perceives thermal conditions.

While actual temperature is measured using devices like sensors or thermometers, the actual ''feel like'' temperature or apparent temperature, is influenced by several environmental factors. For example, a cold might feel colder if there is wind. Or, a hot day might feel hotter when humidity is high. These interactions represent the foundation of the fuzzy inference system to be discussed.

2. System Description

The model uses three inputs: actual temperature, humidity, and wind speed. And a single output, the apparent temperature.

2.1. Inputs

Temperature

Is an objective measure. It is modeled from -10°C to 40°C, which covers almost everything from freezing cold temperatures that can occur in winter to extreme hot conditions in summer heat.

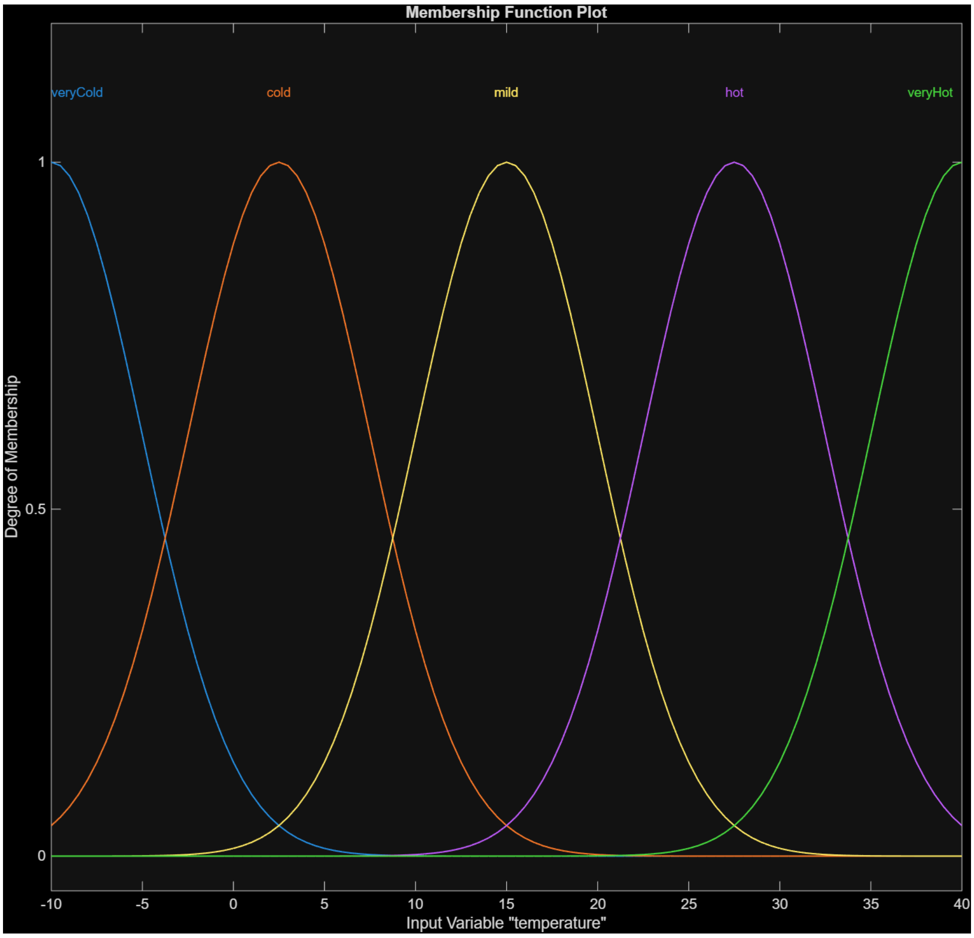

Figura 1.1: Temperature Membership Functions

Figure 1.1 shows the membership functions for the temperature input. As we can see, the temperature is divided into 5: very cold, cold, mild, hot, and very hot. These 5 functions perfectly describe the different ranges that we can experience with an objective temperature measure.

Humidity

Modeled from 0 % to 100 %, which represents its entire spectrum from dry to air to total saturation.

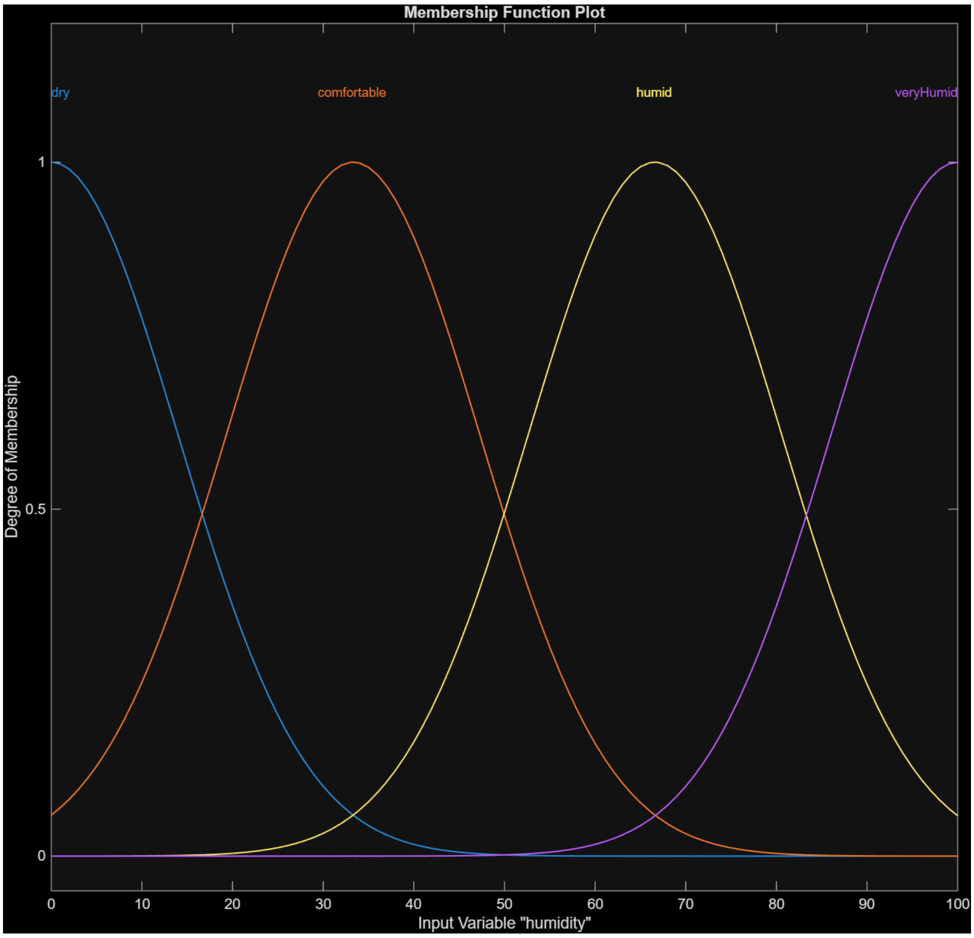

Figura 1.2: Humidity Membership Functions

Figure 1.2 shows the 4 membership functions for humidity: dry, comfortable, humid and very humid. This are enough to model the different scenarios that might affect the temperature.

Wind

Modeled in the range of 0 to 100 km/h, to capture the cooling effect that air movement provokes.

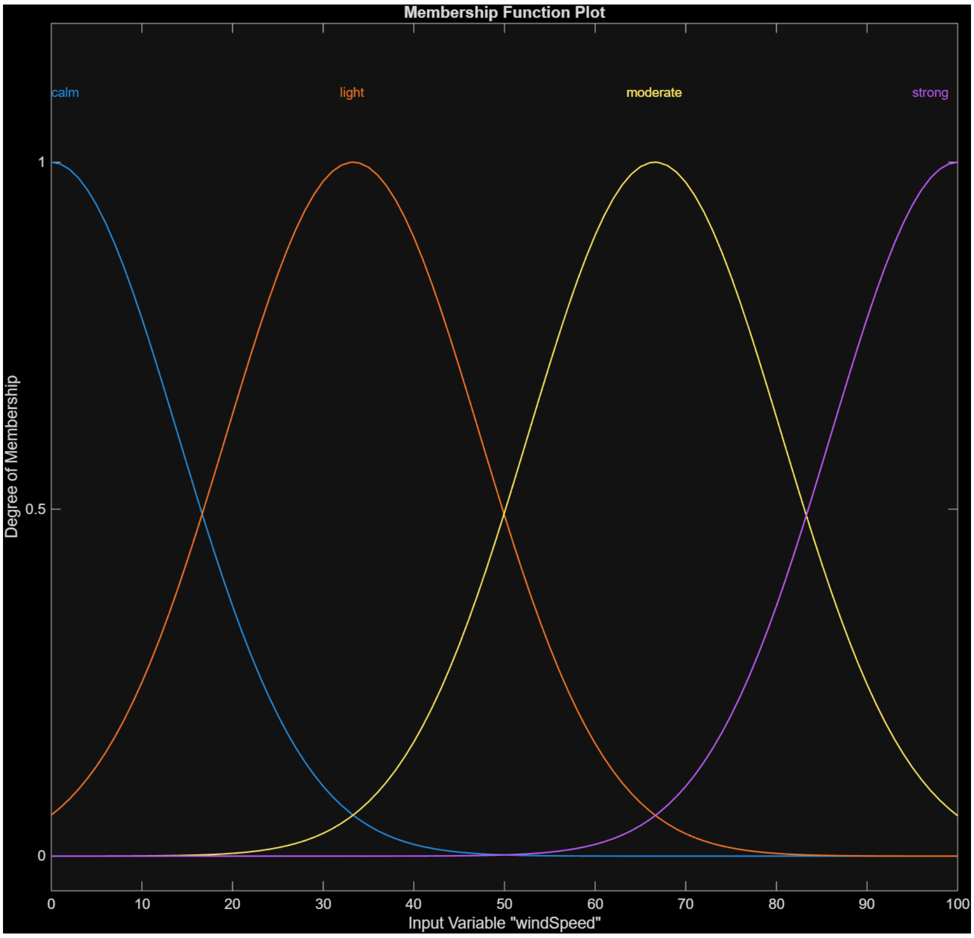

Figura 1.3: Wind Membership Functions

Lastly, figure 1.3 shows the 4 levels of wind: calm, light, moderate, and strong. Similarly to the previous cases, the 4 levels of wind perfectly model the possible effect of wind in the temperature.

2.2. Outputs

Apparent Temperature

Modeled in the range of -20$^{\circ}\mathrm{C}$ to 50$^{\circ}\mathrm{C}$. The output universe of this variable is intentionally increased beyond the input temperature range. This is because the system can model extreme conditions caused by the interaction of humidity and wind with the objective variable (temperature).

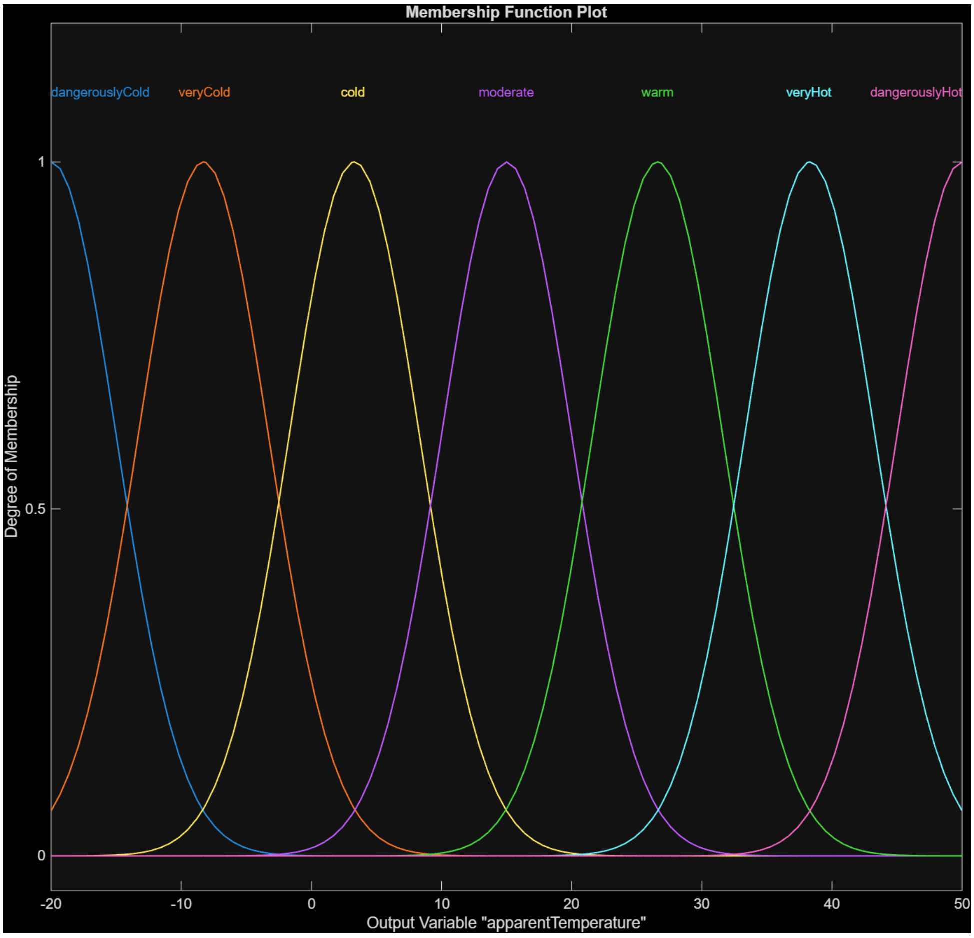

Figura 1.4: Apparent Temperature Membership Functions

Figure 1.4 shows the seven different membership functions for the apparent temperature: dangerously cold, very cold, cold, moderate, warm, very hot, and dangerously hot. The apparent temperature is divided into seven to accommodate the nuisance of humidity and wind interacting with the actual temperature. For example, a very hot temperature, such as $40\,^{\circ}\mathrm{C}$, when there is high humidity, goes above the very hot label to the dangerously hot level. Conversely, a very low temperature, with high wind, would drop to dangerously cold. It also makes other transitions possible, like warm to very hot or moderate to cold.

3. Design Justifications

3.1. Membership Functions: Gaussian

All input and output variables utilize Gaussian membership functions as opposed to standard triangles or trapezoidal forms.

Triangular functions usually lead to wrong linguistic classifications, especially at boundary zones due to their sharp transitions. In this scenario, Gaussian functions provide smooth and differentiable curves. Moreover, this approach better models the behavior of these environmental conditions in the real world. Usually, changes in their magnitude are proportional and continuous, not abrupt changes Ajofoyinbo (Dr.), Olunloyo e ibidapo-obe (2011)

3.2. Rule Base

The following table summarizes the rules that define both the inference system and the resulting surfaces described previously in 2.1.

ID	Fuzzy Logical Rule
1.	If (**temp** is veryCold) and (**wind** is strong) then (**app_temp** is dangerouslyCold) (1)
2.	If (**temp** is veryCold) and (**wind** is moderate) then (**app_temp** is dangerouslyCold) (1)
3.	If (**temp** is veryCold) and (**wind** is calm) then (**app_temp** is veryCold) (1)
4.	If (**temp** is cold) and (**wind** is strong) then (**app_temp** is veryCold) (1)
5.	If (**temp** is cold) and (**wind** is moderate) then (**app_temp** is veryCold) (1)
6.	If (**temp** is cold) and (**wind** is calm) then (**app_temp** is cold) (1)
7.	If (**temp** is mild) then (**app_temp** is moderate) (1)
8.	If (**temp** is cold) and (**wind** is light) then (**app_temp** is cold) (1)
9.	If (**temp** is hot) and (**humidity** is comfortable) then (**app_temp** is warm) (1)
10.	If (**temp** is veryHot) and (**humidity** is veryHumid) then (**app_temp** is dangerouslyHot) (1)
11.	If (**temp** is veryHot) and (**humidity** is humid) then (**app_temp** is dangerouslyHot) (1)
12.	If (**temp** is veryHot) and (**humidity** is dry) then (**app_temp** is veryHot) (1)
13.	If (**temp** is hot) and (**humidity** is veryHumid) then (**app_temp** is veryHot) (1)
14.	If (**temp** is hot) and (**humidity** is humid) then (**app_temp** is veryHot) (1)
15.	If (**temp** is hot) and (**humidity** is dry) then (**app_temp** is warm) (1)
16.	If (**temp** is mild) and (**wind** is strong) then (**app_temp** is cold) (1)
17.	If (**temp** is mild) and (**humidity** is veryHumid) then (**app_temp** is warm) (1)
18.	If (**temp** is veryHot) and (**wind** is strong) then (**app_temp** is veryHot) (1)
19.	If (**temp** is cold) and (**wind** is light) then (**app_temp** is cold) (1)
20.	If (**temp** is veryCold) and (**wind** is light) then (**app_temp** is veryCold) (1)
21.	If (**temp** is veryHot) and (**humidity** is comfortable) then (**app_temp** is veryHot) (1)

Tabla 1.1: Fuzzy Rule Base for Apparent Temperature Inference.

3.3. Apparent Temperature Logic

The rule base described above 1.1 was constructed to model two behaviors that contradict each other in their given contexts, formalized as follows:

- **Cold Index (Wind Chill Effect):** in colder zones of the temperature spectrum ($-10\,^{\circ}\mathrm{C}$ to $0\,^{\circ}\mathrm{C}$ for instance) the presence of wind shifts the apparent temperature down, essentially capturing the fact that when there is wind and it is cold the temperature feeling is lower. As an example, rules 1,2, and 4 map *veryCold* temperature combined with the presence of wind to *dangerouslyCold* output.

- **Heat Index:** for hot regions, the logic for humidity is inverted. The presence of humidity in hot environments shifts the apparent temperature higher than the real temperature. For example, a measured temperature can increase from $40\,^{\circ}\mathrm{C}$ to $45\,^{\circ}\mathrm{C}$ in apparent temperature. In the rule base, rules 10 and 11 map *veryHot* temperatures combined with humidity to *dangerouslyHot* apparent temperatures.

- **Stability Zone:** in the middle range of temperature (about $20\,^{\circ}\mathrm{C}$), the effect of humidity or wind do not create a big penalty. Rule 7 is an example of this mapping *mild* temperatures to *moderate* apparent temperatures, modeling a near 1:1 relationship in this region

4. Visual Validation

The system was validated by looking at the control surfaces, which plot two input variables against the apparent temperature.

4.1. Temperature vs. Humidity

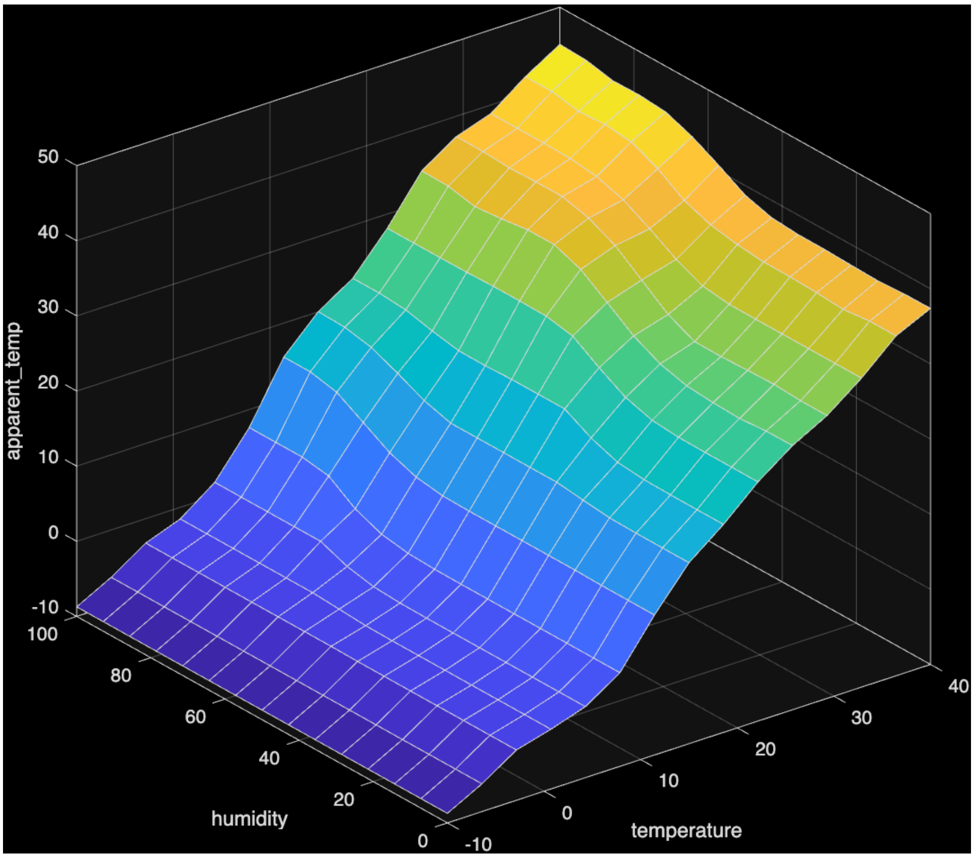

Figura 1.5: Control Surface: Temperature vs. Humidity

The surface in 1.5 represents the influence that humidity has on the actual temperature when measuring the apparent temperature. As seen in it, the more humid the environment, the higher the perceived temperature is. This effectively models the effect captured in the Heat Index. Also, it is worth noting that temperatures in the middle are not affected much by humidity and that low temperatures are unbothered.

4.2. Temperature vs. Wind

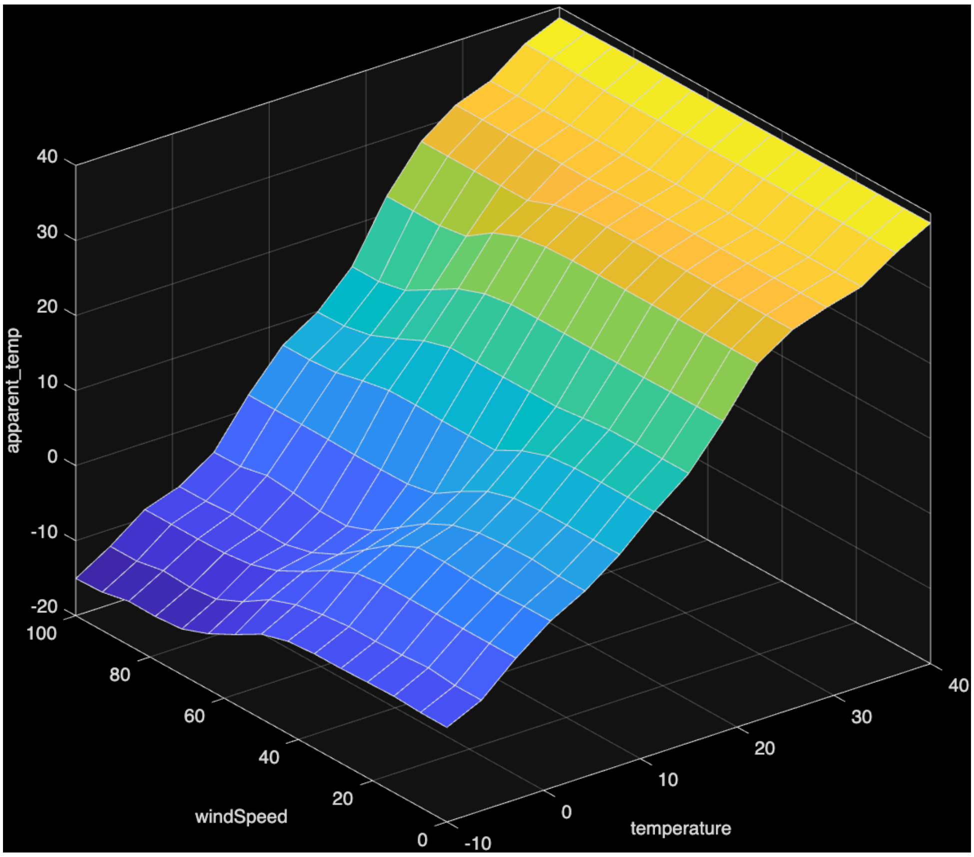

Figura 1.6: Control Surface: Temperature vs. Wind

As seen in 1.6 at low temperatures, increasing the wind speed causes a drop in the apparent temperature. Temperatures of $-10\,^{\circ}\mathrm{C}$, which is the minimum modeled in the actual temperature input, drop to around $-15\,^{\circ}\mathrm{C}$. However, as the temperature increases, this effect is minimized. Therefore, this relationship captures what the Cold Index describes, wind has more effect the lower the temperature is.

5. Test Cases (Inference)

To further verify the accuracy and behavior of the system, some test cases were created and proved using rule inference.

5.1. Case 1: Low Temperature & Wind

In this first example, the inputs are: a temperature of $-5\,^{\circ}\mathrm{C}$, wind_speed of 80 km/h and 5 % humidity.

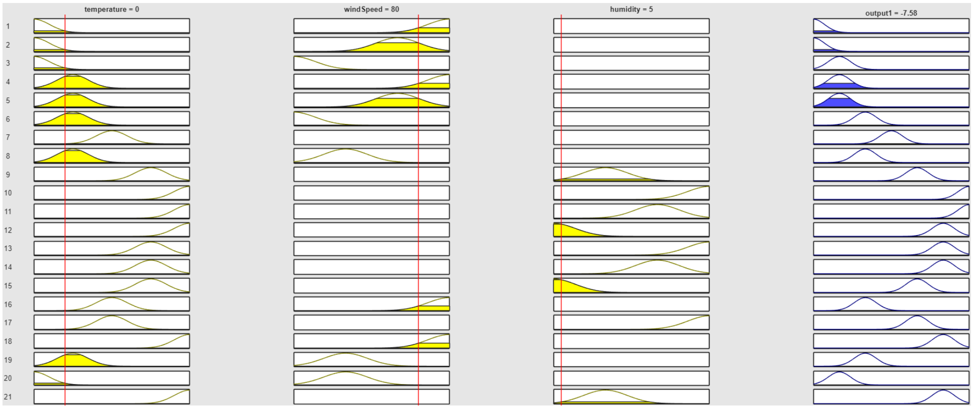

Figura 1.7: Fired rules for low temperature

Figure 1.7, shows the rules that were fired with those inputs. A total of four rules were fired:

- Rule 1: If (**temp** is veryCold) and (**wind** is strong) then (**app_temp** is dangerouslyCold)
- Rule 2: If (**temp** is veryCold) and (**wind** is moderate) then (**app_temp** is dangerously-Cold)
- Rule 4: If (**temp** is cold) and (**wind** is strong) then (**app_temp** is veryCold)
- Rule 5: If (**temp** is cold) and (**wind** is moderate) then (**app_temp** is veryCold)

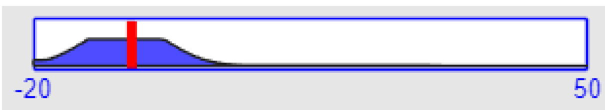

Figura 1.8: Result of inference with low temperature

The result is shown in figure 1.8. The final apparent temperature is $-7.58\,°\mathrm{C}$. This makes sense, the rules fired contain low and very low temperatures and moderate and strong winds. Both map the apparent temperature to dangerously cold, so the actual temperature drops.

5.2. Case 2: Moderate Temperature

In this example with moderate temperature, the inputs are: a temperature of $17\,°\mathrm{C}$, a wind speed of 25 km/h, and a 30 % humidity.

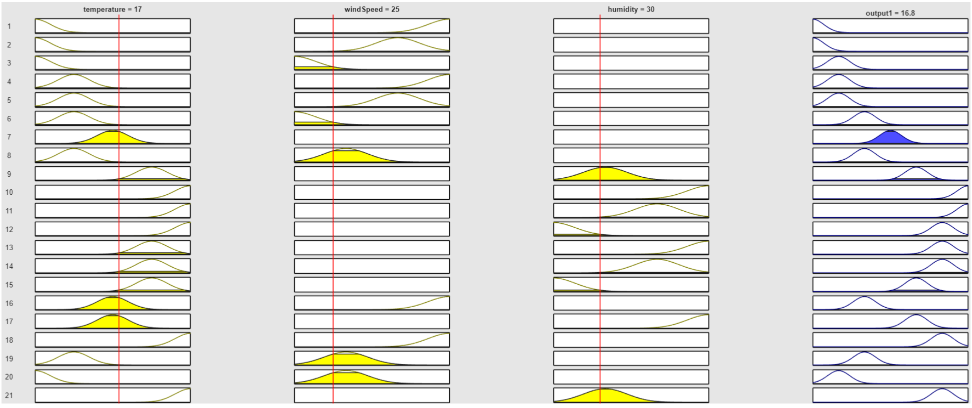

Figura 1.9: Fired rules for moderate temperature

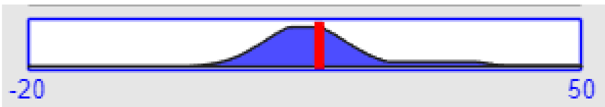

Figura 1.10: Result of inference with moderate temperature

Figure 1.10 shows the rules that fired. The apparent temperature is $16.8\,^{\circ}\mathrm{C}$, almost identical to the real temperature. The activated rules in this case are:

- Rule 7: If (**temp** is mild) then (**app_temp** is moderate)
- Rule 16: If (**temp** is mild) and (**wind** is strong) then (**app_temp** is cold)
- Rule 9: If (**temp** is hot) and (**humidity** is comfortable) then (**app_temp** is warm)

As seen in the figure, rule 7 dominates, which makes the temperature stay consistent with the input temperature. This is due to the rule logic, since for mid temperature neither wind nor humidity have a great impact on it.

The last two rules were active because the wind speed (25 km/h) slightly overlaps with the *strong* membership function. This makes the apparent tempeture slightly lower than the measured one.

5.3. Case 3: High Temperature & Humidity

In this example with moderate temperature, the inputs are: a temperature of $35\,^{\circ}\mathrm{C}$, a wind speed of 10 km/h, and a 70 % humidity.

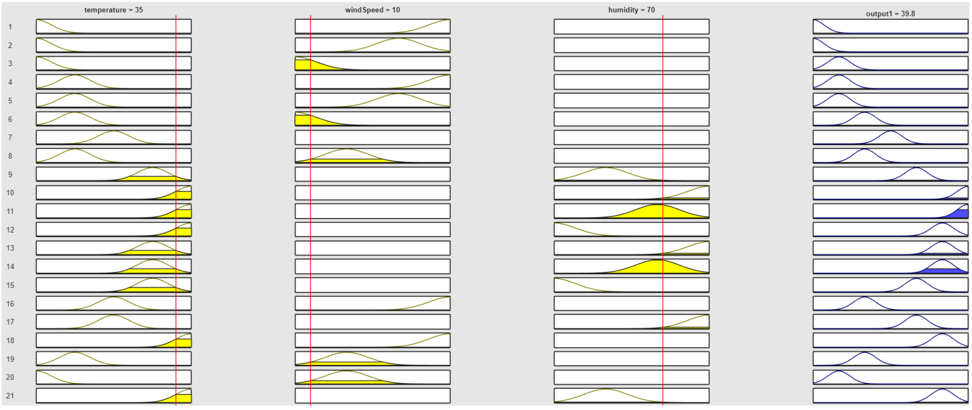

Figura 1.11: Fired rules for high temperature

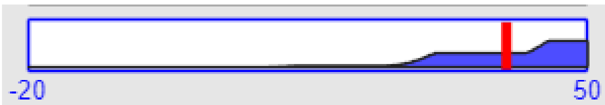

Figura 1.12: Result of inference with high temperature

Figure 1.11 shows that the combination of high heat with humidity have an impact of increasing the apparent temperature, capturing the essence of the Heat Index described in Section 3.3. The rules are:

- Rule 10: If (**temp** is veryHot) and (**humidity** is veryHumid) then (**app_temp** is dangerouslyHot)
- Rule 11: If (**temp** is veryHot) and (**humidity** is humid) then (**app_temp** is dangerouslyHot)
- Rule 13: If (**temp** is hot) and (**humidity** is veryHumid) then (**app_temp** is veryHot) If (**temp** is hot) and (**humidity** is humid) then (**app_temp** is veryHot)

The result is shown in figure 1.12. The final apparent temperature is $39.8\,°\mathrm{C}$, as previously stated, high temperatures with high humidity results in higher apparent temperature, so the results are consistent.

Bibliografía

Ajofoyinbo (Dr.), Abayomi, Vincent Olunloyo y Oye ibidapo-obe (ene. de 2011). "On Development of Fuzzy Controller: The Case of Gaussian and Triangular Membership Functions". En: *Journal of Signal and Information Processing* 2, págs. 257-265. DOI: 10.4236/jsip.2011.24036.