Fuzzy logic : principles and applications

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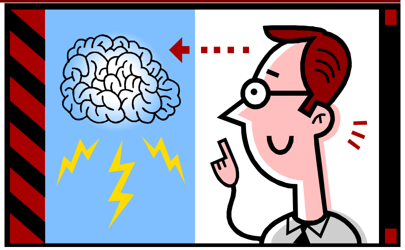
Fuzzy Logic

What is Fuzzy Logic?



A computational paradigm that is based on how humans think

Fuzzy Logic looks at the world in imprecise terms, in much the same way that our brain takes in information (e.g. temperature is hot, speed is slow), then responds with precise actions.

The human brain can reason with uncertainties, vagueness, and judgments. Computers can only manipulate precise valuations. Fuzzy logic is an attempt to combine the two techniques.

“Fuzzy” – a misnomer, has resulted in the mistaken suspicion that FL is somehow less exact than traditional logic

Fuzzy logic

What is Fuzzy Logic?

FL is in fact, **a precise problem-solving methodology**.

It is able to simultaneously handle numerical data and linguistic knowledge.

A technique that facilitates the control of a complicated system without knowledge of its mathematical description.

Fuzzy logic differs from classical logic in that statements are no longer black or white, true or false, on or off.
In traditional logic an object takes on a value of either zero or one.
In fuzzy logic, a statement can assume any real value between 0 and 1, representing the degree to which an element belongs to a given set.

Fuzzy Logic

History of Fuzzy Logic

Professor Lotfi A. Zadeh

http://www.cs.berkeley.edu/~zadeh/

In **1965**, **Lotfi A. Zadeh** of the University of California at Berkeley published "Fuzzy Sets," which laid out the mathematics of fuzzy set theory and, by extension, fuzzy logic. Zadeh had observed that conventional computer logic couldn't manipulate data that represented subjective or vague ideas, so he created fuzzy logic to allow computers to determine the distinctions among data with shades of gray, similar to the process of human reasoning.

Source: August 30, 2004 (Computerworld) http://www.computerworld.com/news/2004/story/0,11280,95282,00.html

Task 1

1) What is the principle of fuzzy logic? Explain the distinction between it and classical logic.

2) What is the main difference between the probability and fuzzy logic?

Task 1

3) What is the reasons that fuzzy logic has rapidly become one of the most successful technology for developing sophisticated control systems?

Task 1

4) When not to use fuzzy logic?

5) Give at least 3 famous applications of fuzzy logic.

Fuzzy Logic Explained

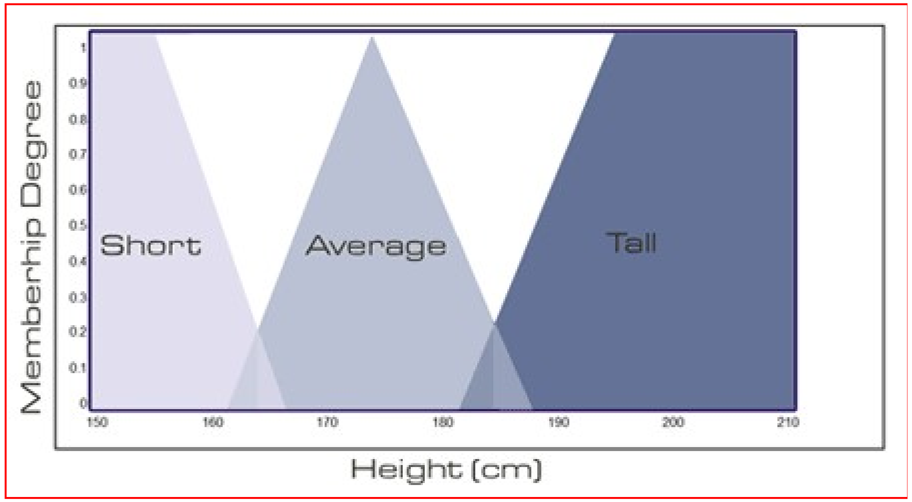
Fuzzy Set Theory

Is a man whose height is 180 cm average or tall?

A fuzzy system might say that he is partly medium and partly tall.

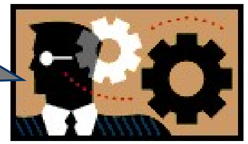
Boolean representation

Fuzzy representation



http://blog.peltarion.com/2006/10/25/fuzzy-math-part-1-the-theory/

In fuzzy terms, the height of the man would be classified within a range of [0, 1] as average to a degree of 0.6, and tall to a degree of 0.4.



Fuzzy Inference Process

- What are the steps involved in creating a Fuzzy Control System?

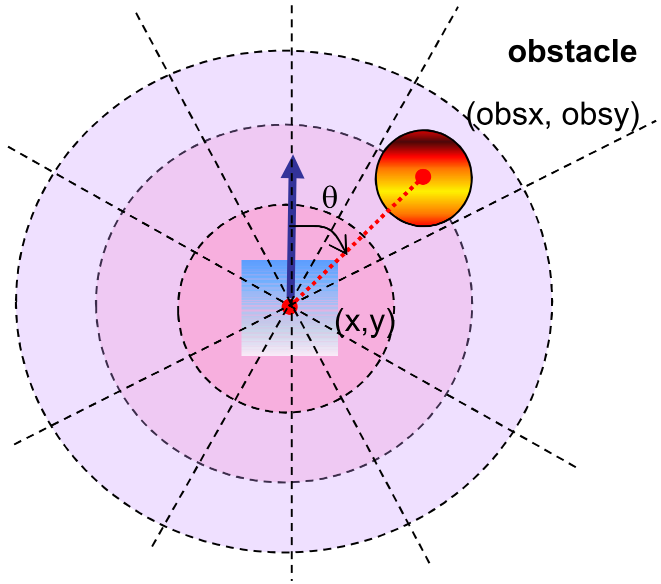
Fuzzy Inference Process

Fuzzy Inference Process

Fuzzification: Translate input into truth values
Rule Evaluation: Compute output truth values
Defuzzification: Transfer truth values into output

Example 1 : Obstacle Avoidance Problem

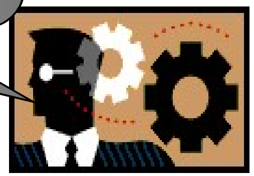
Robot Navigation



Obstacle Avoidance & Target Pursuit

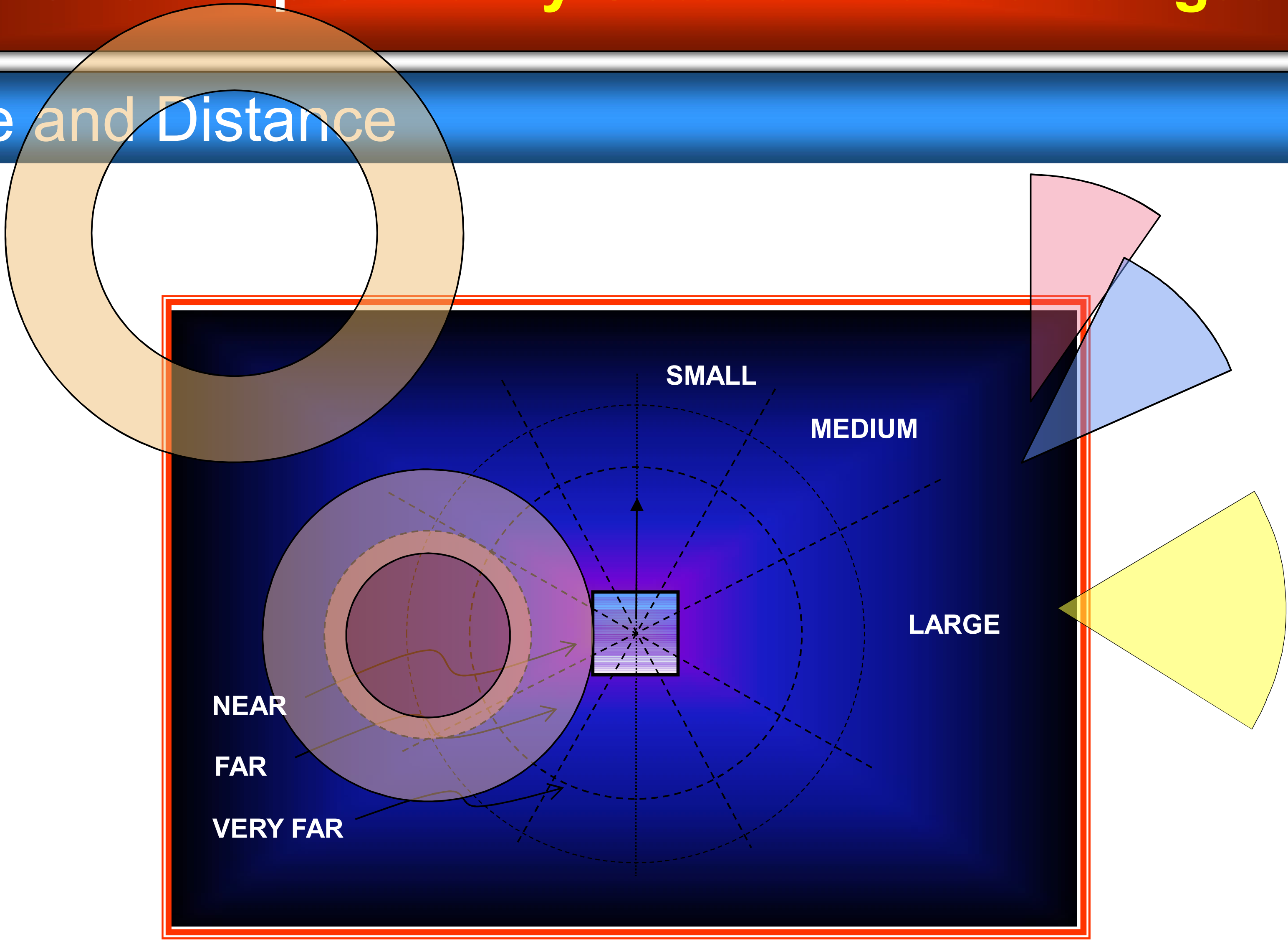
Demonstration

Can you describe how the robot should turn based on the position and angle of the obstacle?



Another example: Fuzzy Sets for Robot Navigation

Angle and Distance



* Sub ranges for angles & distances overlap

Fuzzy Systems *for* Obstacle Avoidance

Vision System

Nearest Obstacle (Distance and Angle)

Fuzzy System 3 (Steering)

	NEAR	*FAR*	*VERY FAR*
SMALL	Very Sharp	Sharp Turn	Med Turn
MEDIUM	Sharp Turn	Med Turn	Mild Turn
LARGE	Med Turn	Mild Turn	Zero Turn

e.g. If the *Distance* from the Obstacle is *NEAR* and the *Angle* from the Obstacle is *SMALL* **Then** turn *Very Sharply*.

Angle

Fuzzy System 4 (Speed Adjustment)

	NEAR	*FAR*	*VERY FAR*
SMALL	Very Slow	Slow Speed	Fast Fast
MEDIUM	Slow Speed	Fast Speed	Very Fast
LARGE	Fast Speed	Very Fast	Top Speed

e.g. **If** the *Distance* from the Obstacle is *NEAR* and the *Angle* from the Obstacle is *SMALL* **Then** move *Very Slowly.*

Speed

Summary of Steps

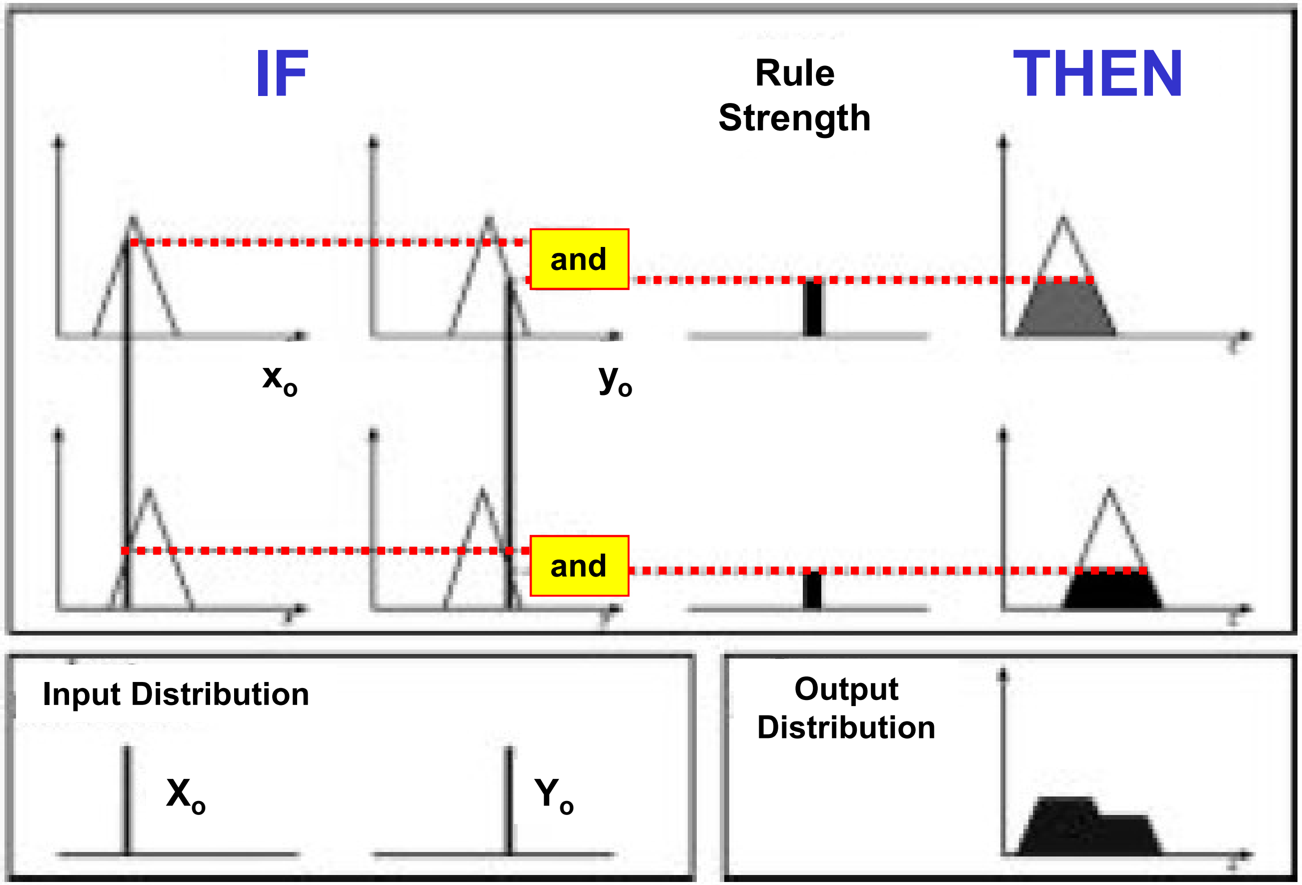
1. determining a set of fuzzy rules
2. fuzzifying the inputs using the input membership functions,
3. combining the fuzzified inputs according to the fuzzy rules to establish a rule strength,
4. finding the consequence of the rule by combining the rule strength and the output membership function (if it's a mamdani FIS),
5. combining the consequences to get an output distribution, and
6. defuzzifying the output distribution (this step applies only if a crisp output (class) is needed).

Fuzzy Inference

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves : Membership Functions, Logical Operations, and If-Then Rules.

Mamdani Inference System

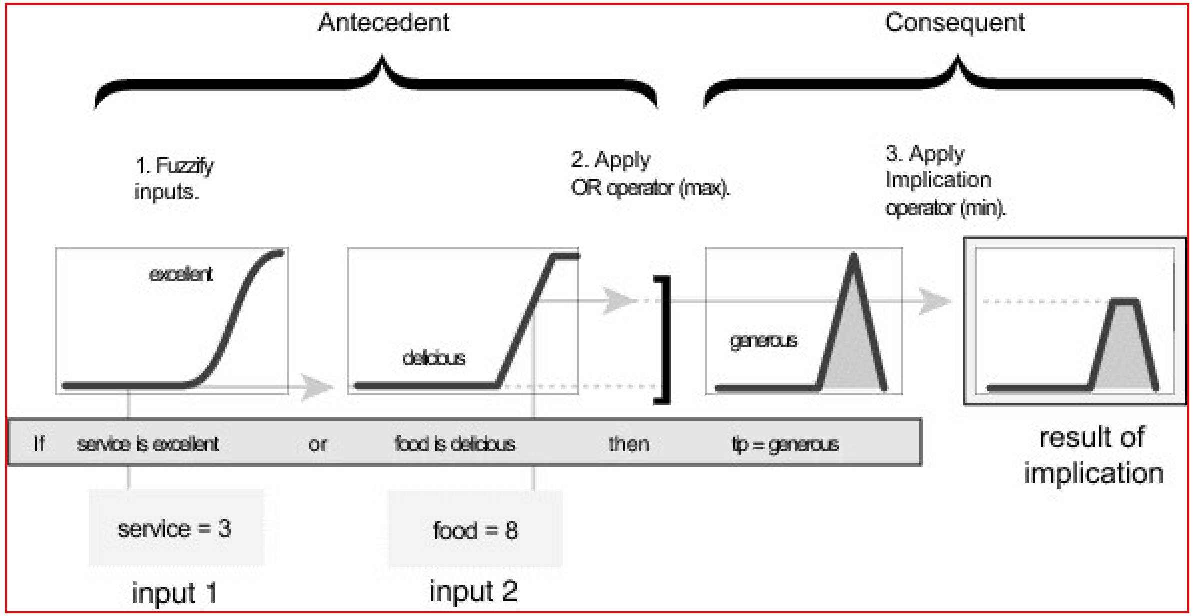
Two input, two rule Mamdani FIS with crisp inputs



Fuzzy rules are a collection of linguistic statements that describe how the FIS should make a decision regarding classifying an input or controlling an output.

Mamdani FIS

Mamdani-type inference, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification.



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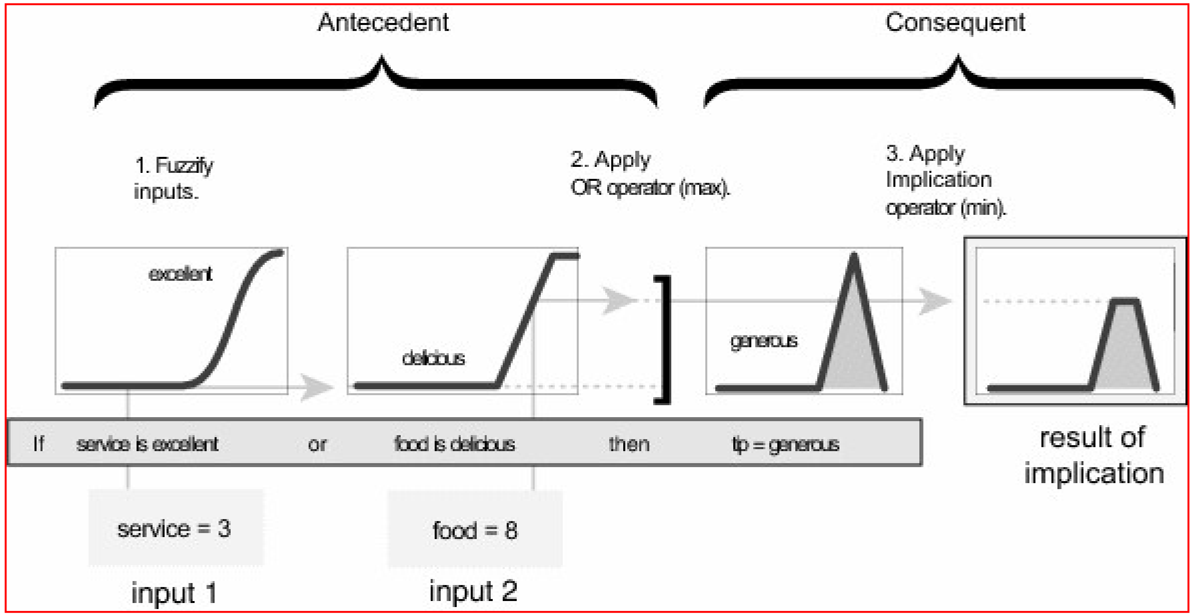

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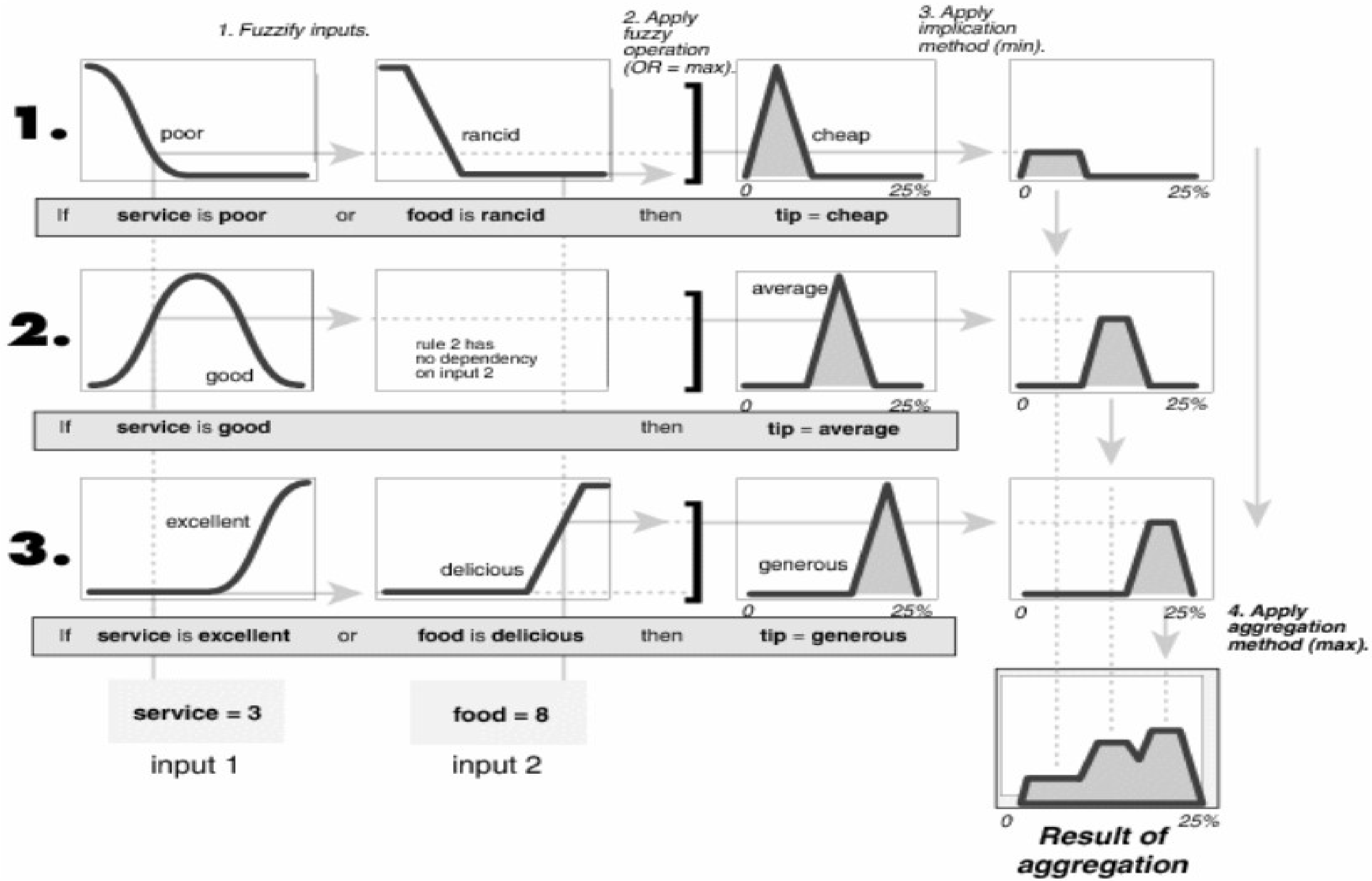
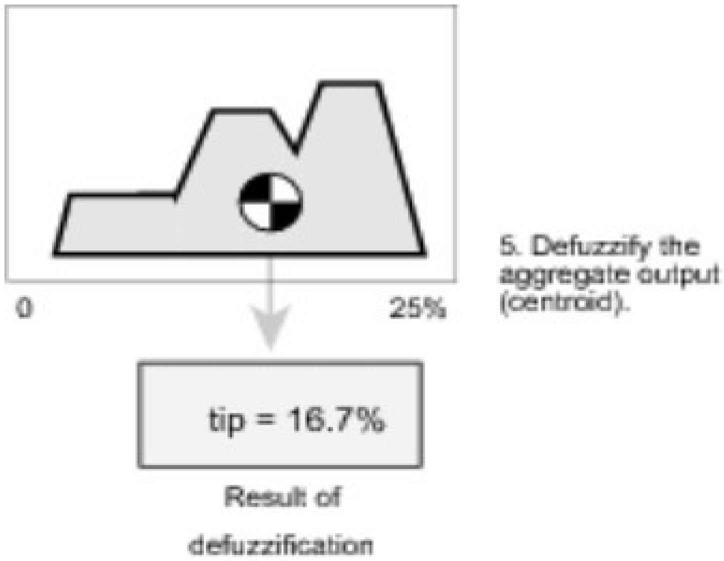
Mamdani FIS



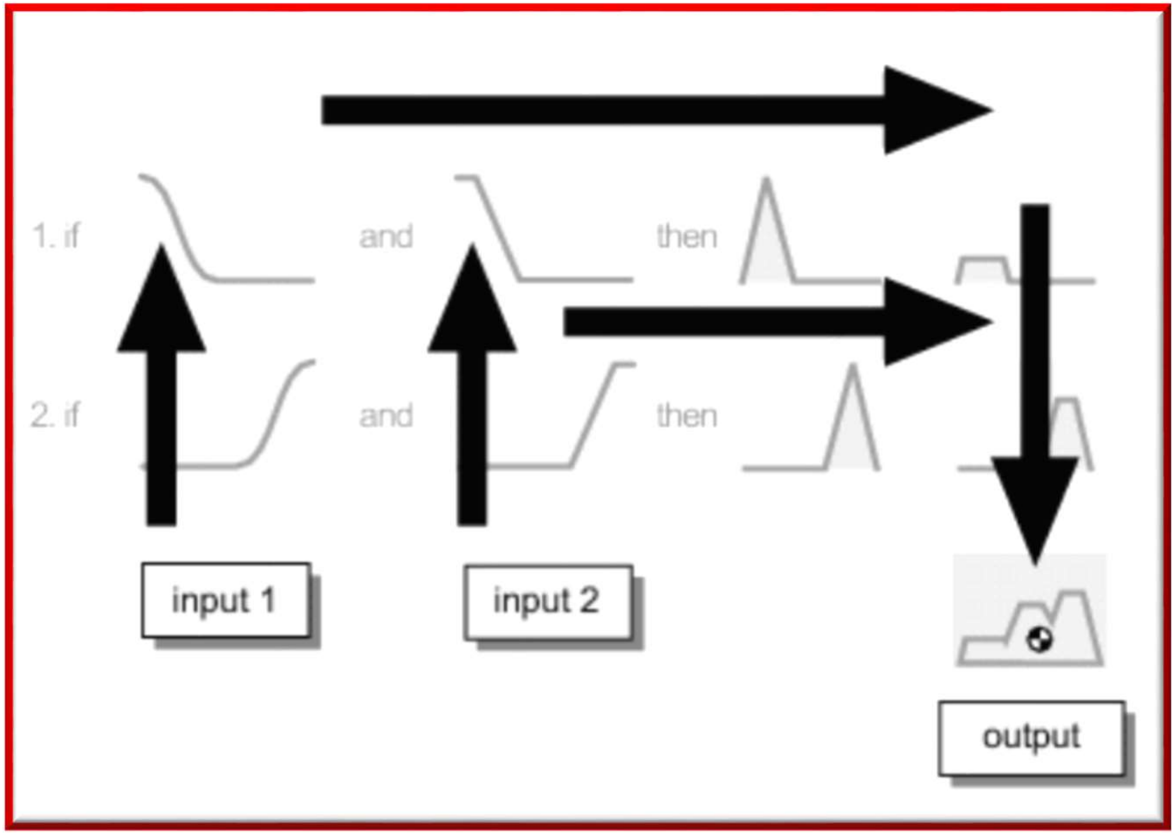
1. Fuzzify inputs.
2. Apply fuzzy operation (OR = max).
3. Apply implication method (min).
1.
poor
rancid
cheap
0
25%
If service is poor or food is rancid then tip = cheap
2.
good
rule 2 has no dependency on input 2
average
If service is good then tip = average
3.
excellent
delicious
generous
4. Apply aggregation method (max).
If service is excellent or food is delicious then tip = generous
service = 3
input 1
food = 8
input 2
Result of aggregation

Mamdani FIS



0
25%
5. Defuzzify the aggregate output (centroid).
tip = 16.7%
Result of defuzzification

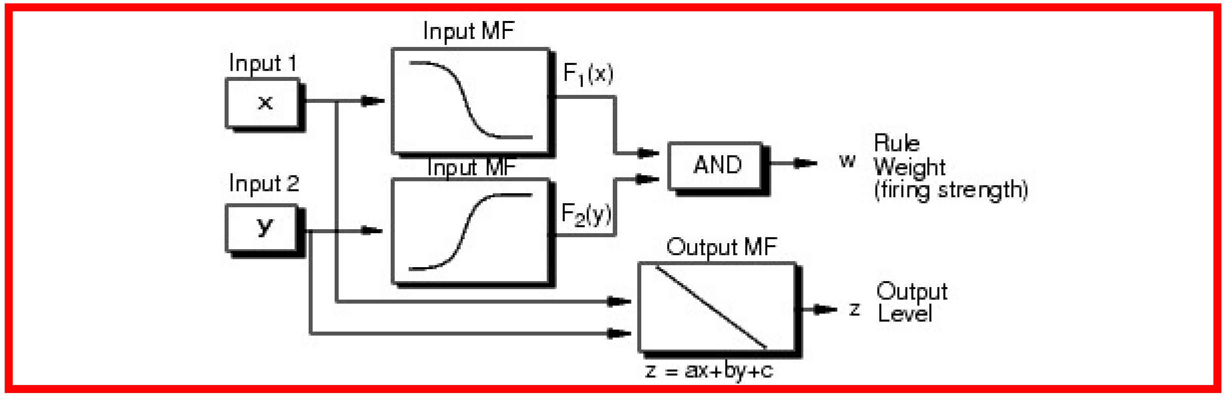
Flow of Fuzzy Inference



In this figure, the flow proceeds up from the inputs in the lower left, then across each row, or rule, and then down the rule outputs to finish in the lower right. This compact flow shows everything at once, from linguistic variable fuzzification all the way through defuzzification of the aggregate output.

Sugeno FIS

Sugeno FIS is similar to the Mamdani method in many respects. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant.

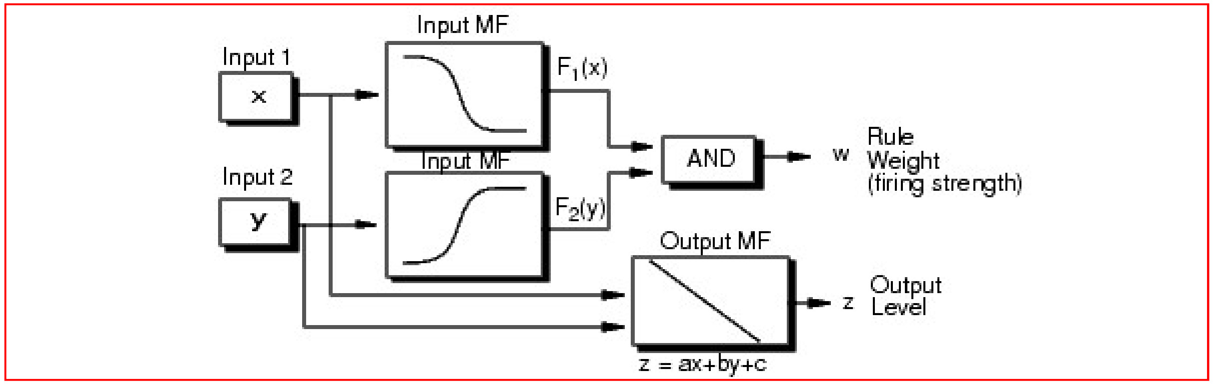


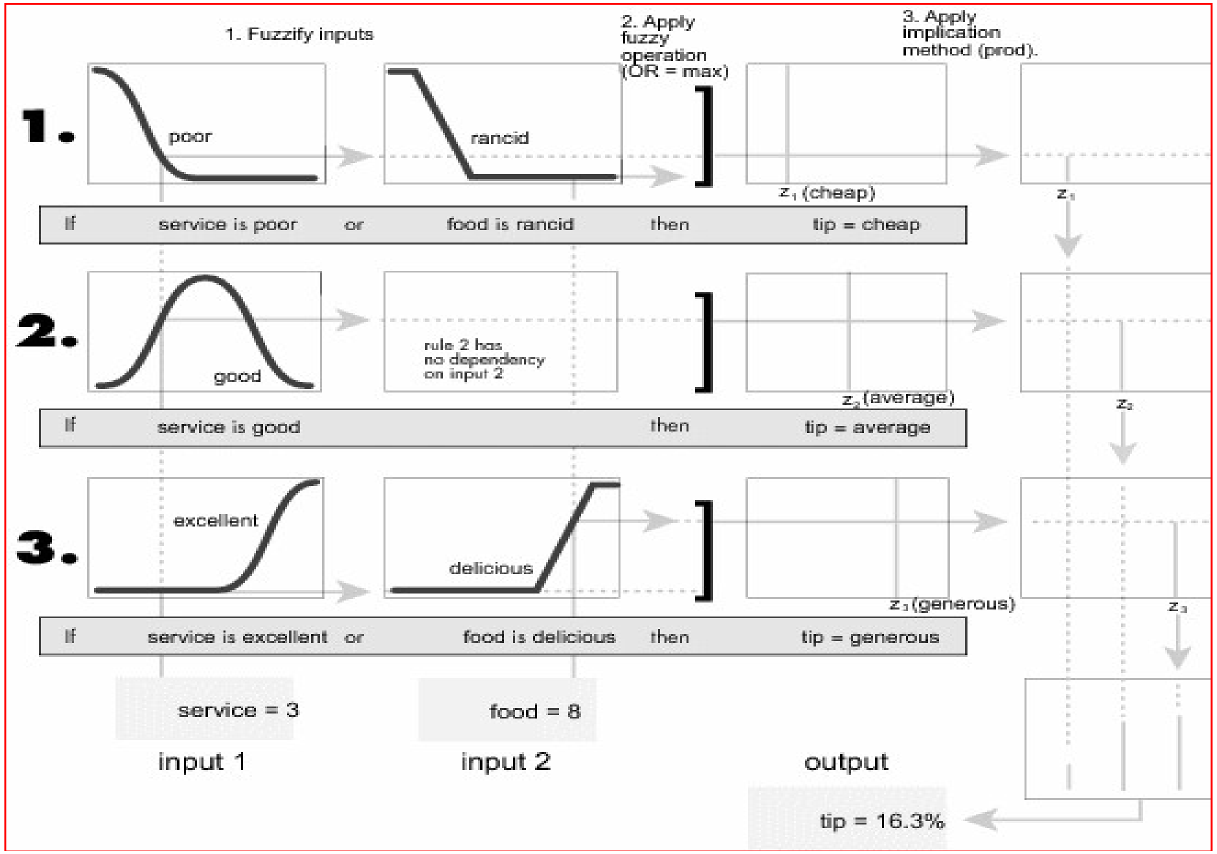
A typical rule in a Sugeno fuzzy model has the form:

If Input 1 = x and Input 2 = y, then Output is **z = ax + by + c**

For a **zero-order Sugeno model**, the output level **z** is a **constant** (a=b =0).

Sugeno FIS





$$\text{Final Output} = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i}$$

FIS: Sugeno vs. Mamdani

Advantages of the Sugeno Method

It is computationally efficient.
It can be used to model any inference system in which the output membership functions are either linear or constant.
It works well with linear techniques (e.g., PID control).
It works well with optimization and adaptive techniques.
It has guaranteed continuity of the output surface.
It is well suited to mathematical analysis.

Advantages of the Mamdani Method

It is intuitive.
It has widespread acceptance.
It is well suited to human input.

Task 2

What is the sequence of steps taken in designing a fuzzy logic controller?

Task 3 : example of control

The objective of this case study is to perform the speed control of a separately excited DC motor (figure 1) using fuzzy logic controller (FLC). The controller will be designed based on the expert knowledge of the system. For the proposed dc motor case, we recommend **7 fuzzy rules** for fuzzy logic controller.

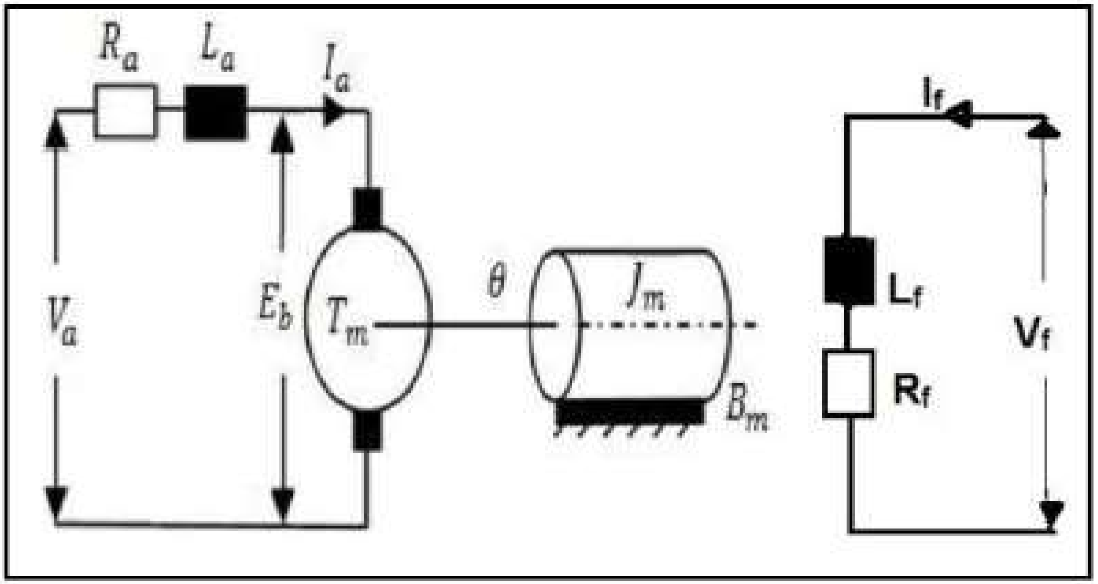


Fig.1 separately excited dc motor model

Task 3 : example of control

Taking field flux as ∅ and Back EMF Constant as K_{φ}.
Equation for back emf of motor will be:

$$E_b = K_{\varphi}\ \omega$$

Torque:

$$T_m = J_m \left(\frac{d\omega}{dt}\right) + T_L$$

$$T_m = K_{\varphi}\ I_a$$

ω is the angular velocity (speed) and friction in rotor of motor is very small (can be neglected) so Bm = 0.
Armature Time Constant:

$$T_a = \frac{L_a}{R_a}$$

Task 3 : example of control

1) Plot the block diagram of separately excited dc motor based on Laplace transformations of the motor's armature voltage and balance torque.

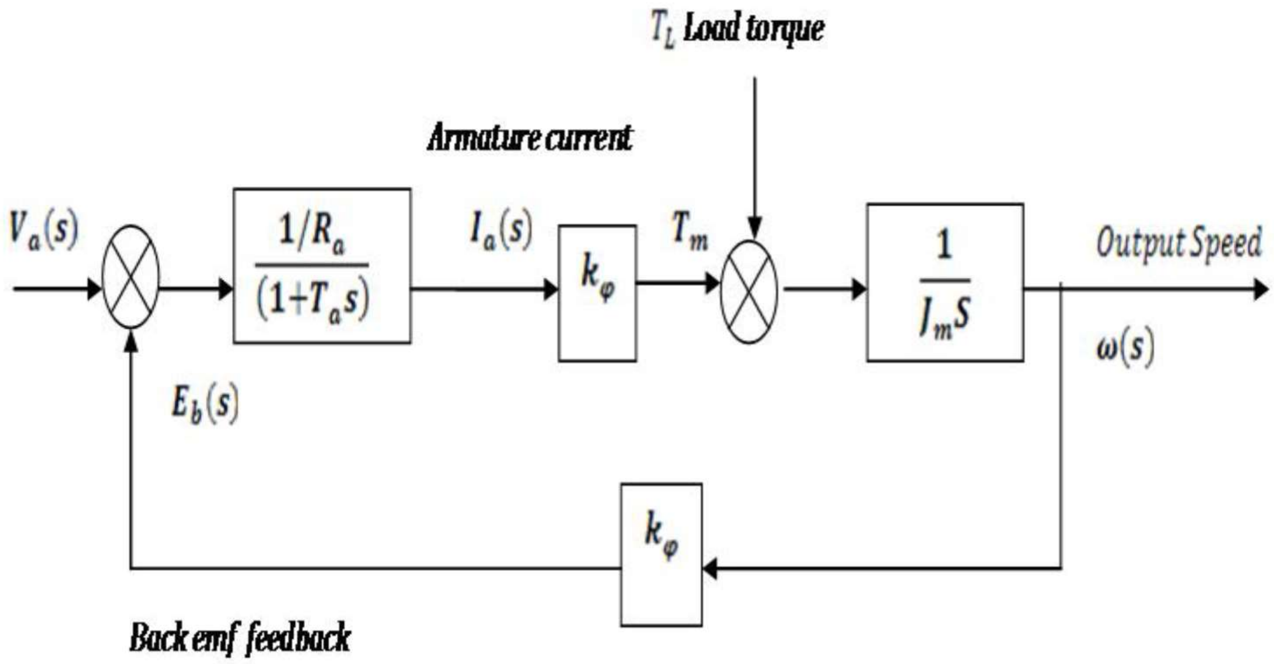


Fig.2 Block diagram of separately excited dc motor

Task 3 : example of control

2) Define the required fuzzy controller inputs and outputs. Then complete this diagram:

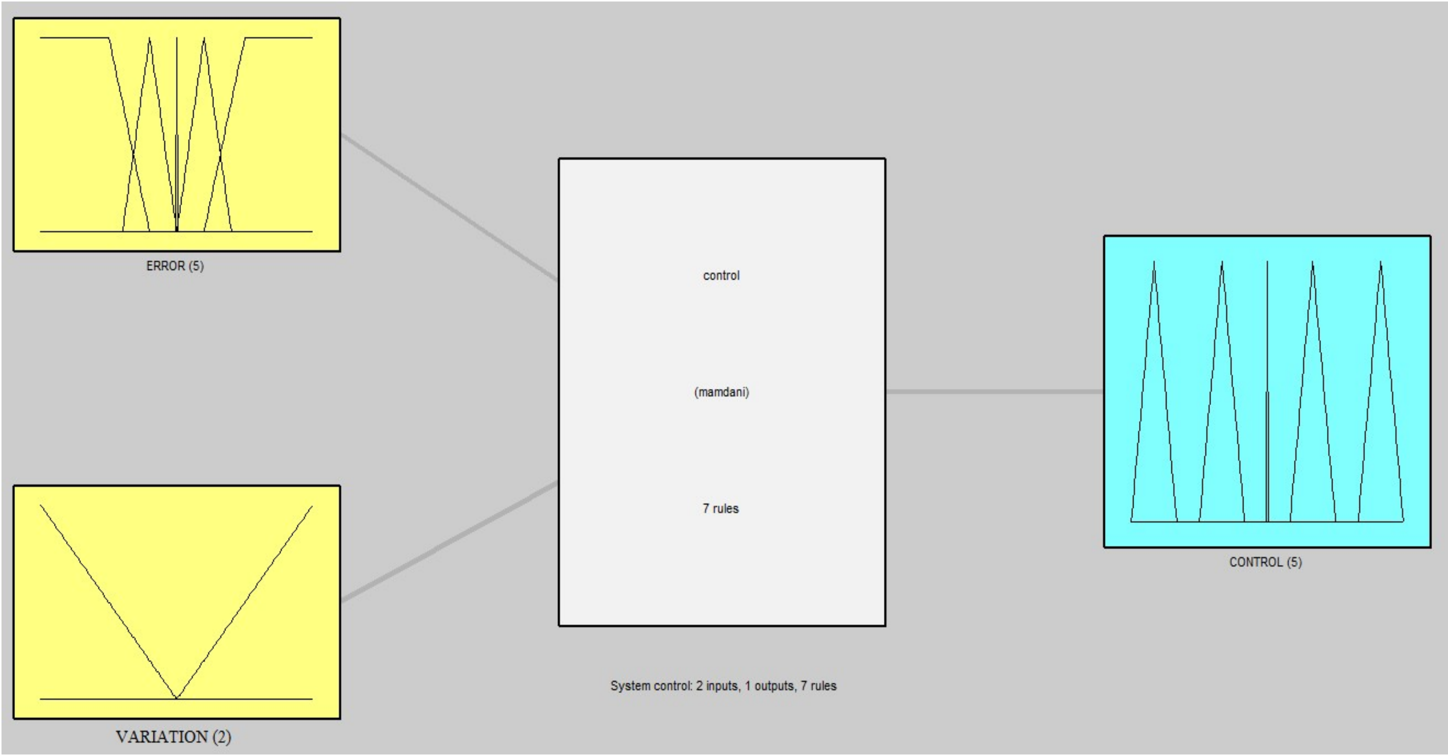


Fig. 3: General structure of the fuzzy controller.

Task 3 : example of control

3) Deduce the structure of the fuzzy logic controller with closed loop (synopsis of all system with fuzzy controller).

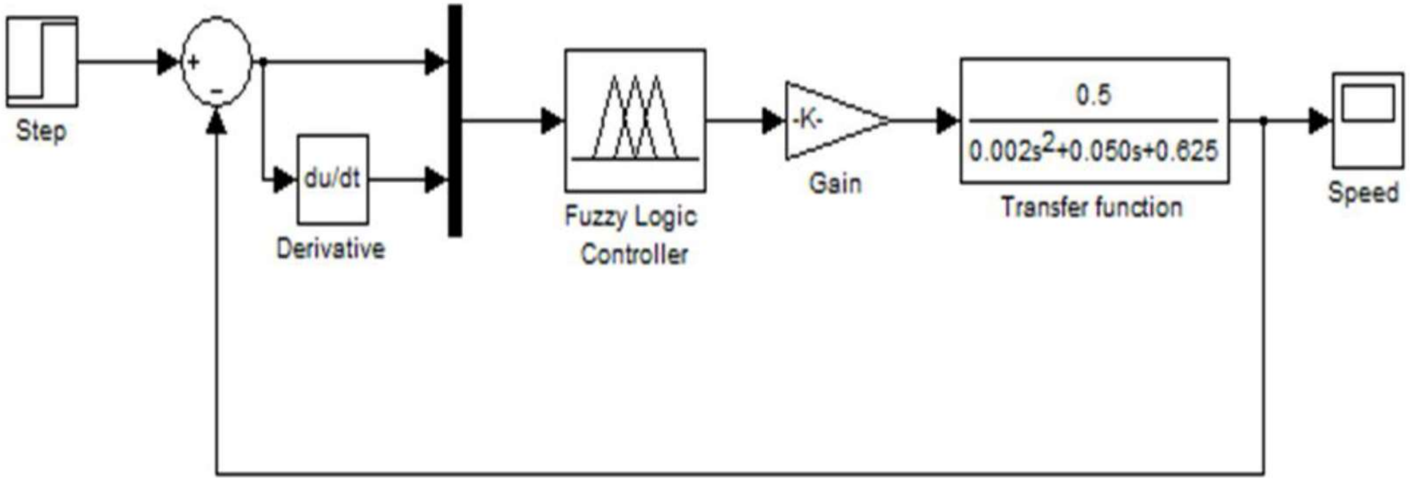


Fig.4 Model of system using fuzzy logic controller

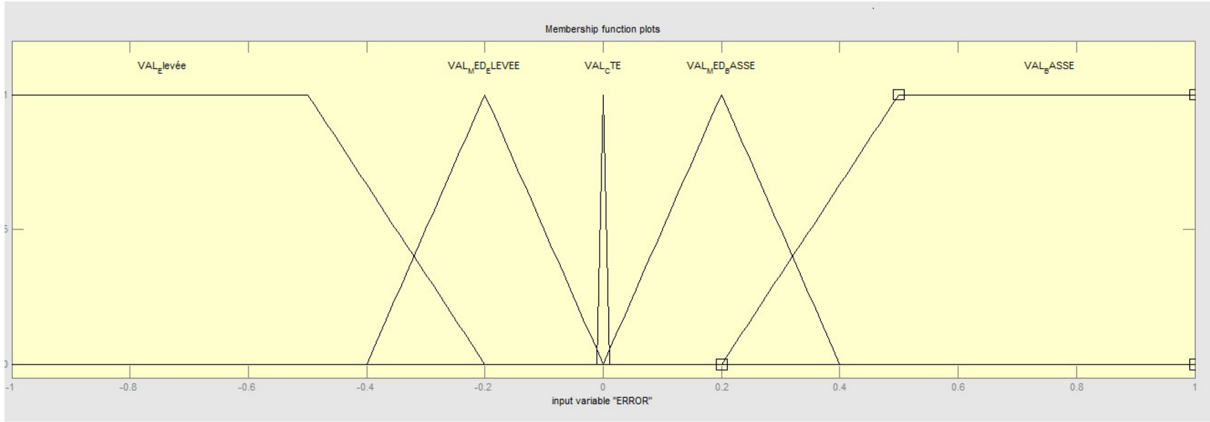
Task 3 : example of control

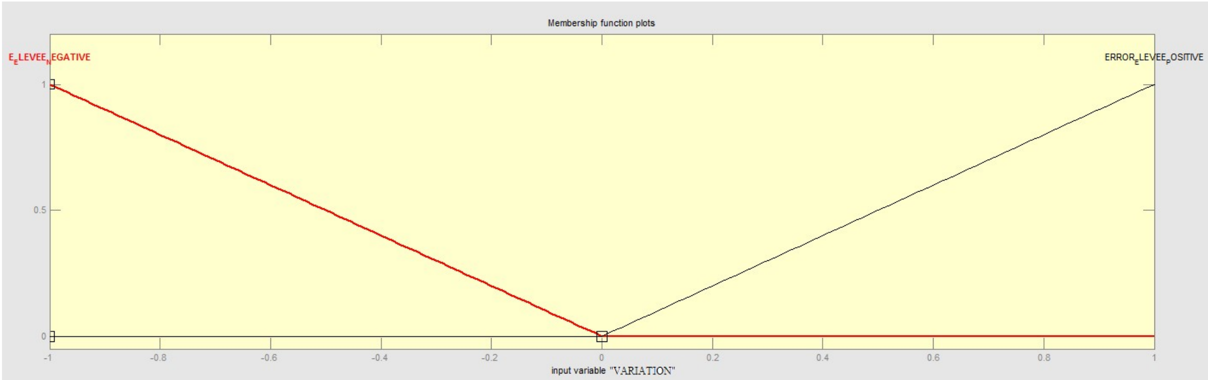
4) Represent membership functions for inputs and output variables.

Input 1 range: [-1 1]

Input 2 range: [- 1 1]

Output range: [-30 30].





Task 3 : example of control

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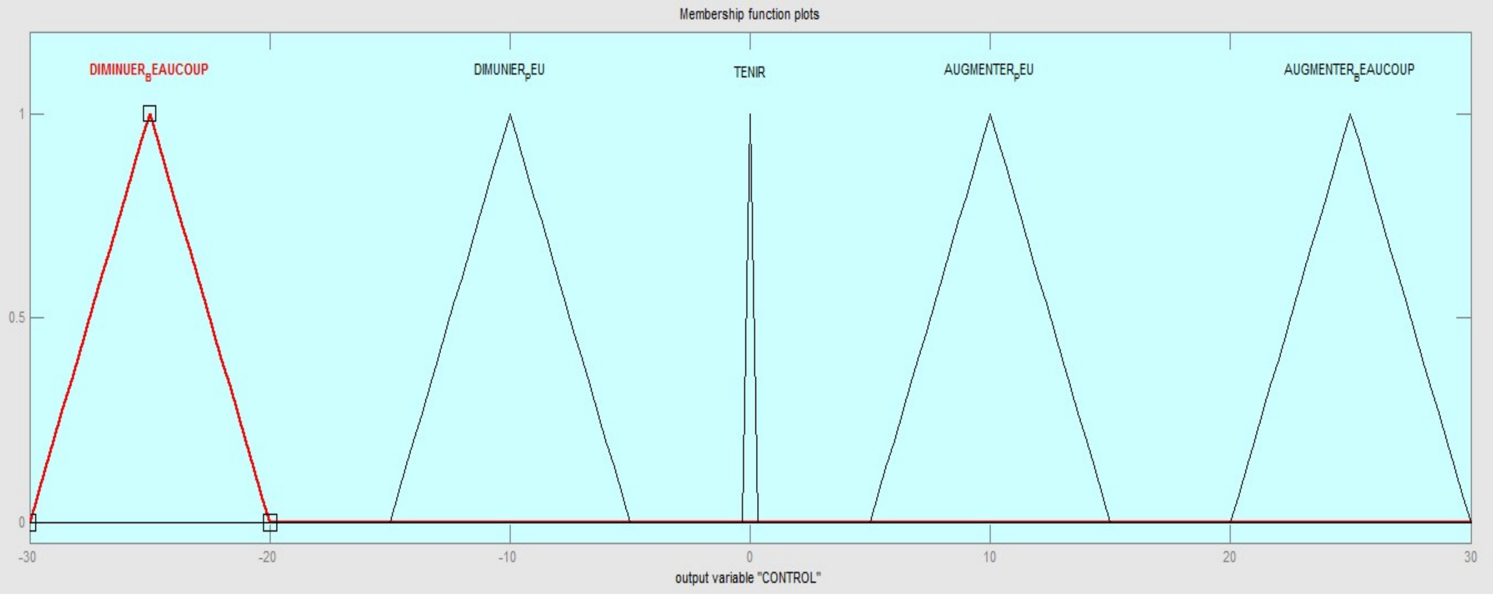


Task 3 : example of control

5) Enunciate the 7 “if-then” rules necessary for separately excited dc motor speed control.

- If (ERROR is VAL_BASSE) then (CONTROL is AUGMENTER_BEAUCOUP)
- If (ERROR is VAL_Elevée) then (CONTROL is DIMINUER_BEAUCOUP)
- If (ERROR is VAL_CTE) and (VARIATION is E_ELEVEE_NEGATIVE) then (CONTROL is DIMUNIER_PEU)
- If (ERROR is VAL_CTE) and (VARIATION is ERROR_ELEVEE_POSITIVE) then (CONTROL is AUGMENTER_PEU)
- If (ERROR is VAL_CTE) and (CAMBIO is ERROR_ELEVEE_POSITIVE) then (CONTROL is AUGMENTER_PEU)
- If (ERROR is VAL_MED_BASSE) then (CONTROL is AUGMENTER_PEU)
- If (ERROR is VAL_CTE) then (CONTROL is TENIR)

6) What is the inference system type used here? Is there another type?

MANDANI. YES SUGENO METHOD.

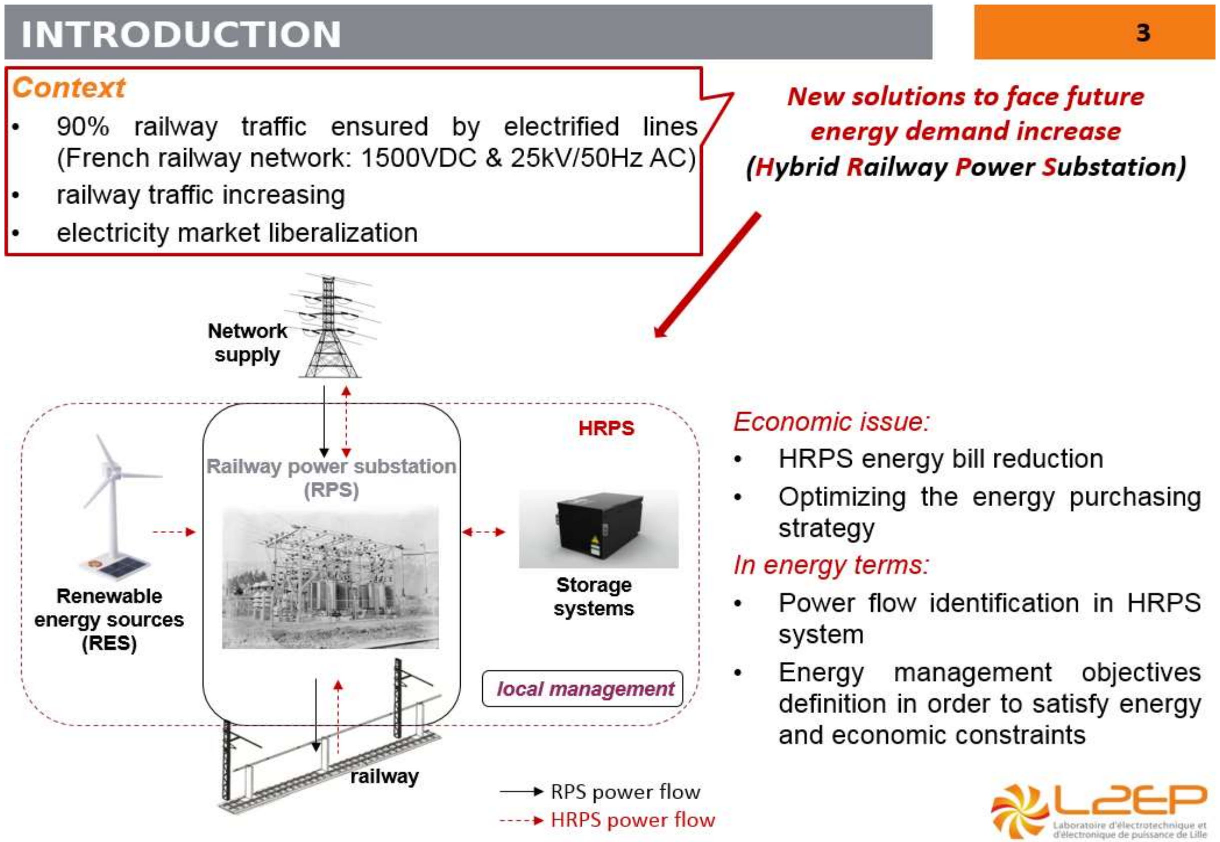
Task 3 : example of control

7) What is the contribution (benefits) of fuzzy logic in comparison with a conventional PID controller for these case study?

The fuzzy logic approach has minimum overshoot, minimum transient and steady state parameters, which shows more effectiveness and efficiency of FLC than conventional PID controller.

Task 4 : Fuzzy logic applied to energy management

You are given 3 slides taken from a power point presentation done by a PhD student from HEI L2EP in ELECTRIMACS conference (Spain 2014). **Well understand the problematic and the objectives then respond to the question**.

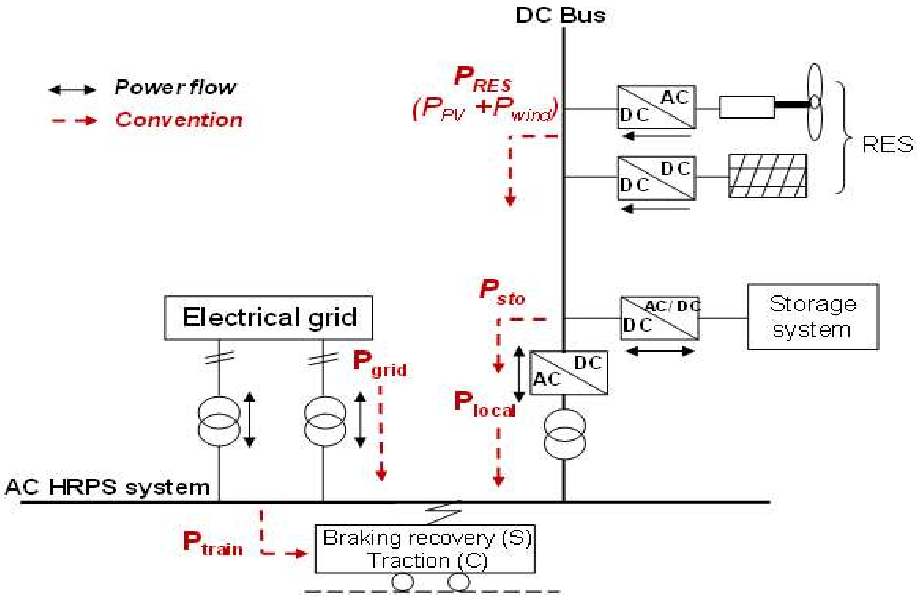


Task 4 : Fuzzy logic applied to energy management

SYSTEM DESCRIPTION & SPECIFICATIONS

5

Hybrid Railway Power Substation architecture



Hybrid system composed of:
→ photovoltaic (PV) units
→ wind turbines
→ storage systems
→ DC-bus interconnection to the power substation (allowing isolation mode if necessary)

➢ *Power flow balance:*

RPS: → $P_{train} = P_{grid}$ $(P_{local} = 0)$
HRPS: → $P_{train} = P_{grid} + P_{local}$
→ $P_{local} = P_{RES} + P_{sto}$

- P_{train} *is the railway power consumption seen by the HRPS*
- P_{grid} *is the power taken from the grid*
- P_{local} *is the local production (PV, wind, thus* P_{RES}*)*
- P_{sto} *is the storage power*

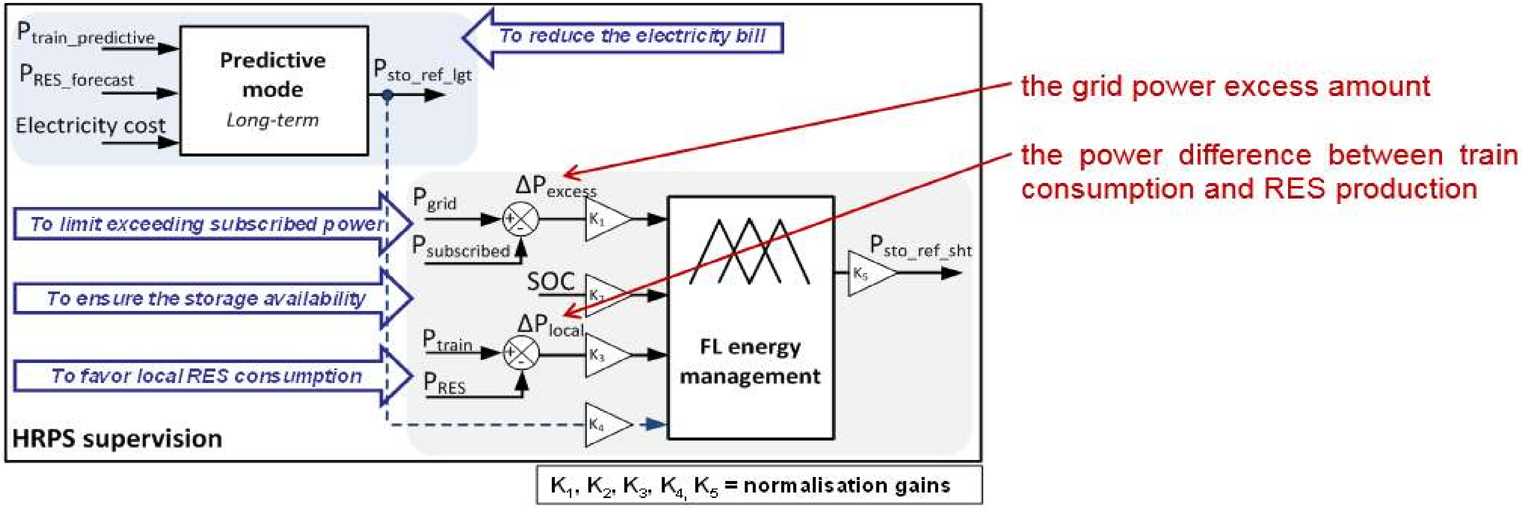
Task 4 : Fuzzy logic applied to energy management

DESIGN OF THE SUPERVISION STRATEGY

10

Methodology for HRPS energy management

STEP 2
Design of the supervisor



Task 4 : Fuzzy logic applied to energy management

Question: Complete this table for work specifications (problem analysis):

Objectives	Constraints	Means of actions
Predictive mode – LONG TERM		
....	....	....
	....	
	....	
Fuzzy Logic energy management – SHORT TERM		
....	....	....
....	....	
....	....	

Task 4 : Fuzzy logic applied to energy management

Objectives	Constraints	Means of actions
Predictive mode – LONGT TERM		
Reducing energy bill (regarding short-term trades)	Trains consumption predictions RES forecast Electricity market fluctuations	Storage power ($P_{sto\text{-}ref\text{-}lgt}$) (Predictive reference power)
Fuzzy Logic energy management – SHORT TERM		
Limitation of subscribed power exceeding Favoring local RES consumption Ensuring storage system availability	Subscribed power Storage limits RES availability	Storage power ($P_{sto\text{-}ref\text{-}sht}$) (Predictive mode adjustment)

Task 4 : Fuzzy logic applied to energy management

DESIGN OF THE SUPERVISION STRATEGY

Methodology for HRPS energy management

STEP 1
Work specifications

STEP 2
Design of the supervisor

STEP 3
Chart representation of operating modes
- Functional graphs -

STEP 4
Determination of the membership functions

STEP 5
Chart representation of fuzzy operating modes
- Operational graphs -

STEP 6
Determination of the fuzzy rules

STEP 7
Determination of indicators to measure the achievement of objectives

Task 4 : Fuzzy logic applied to energy management

Methodology for HRPS energy management

STEP 1
Work specifications

Objectives	Constraints	Means of actions
	Predictive mode – LONGT TERM	
Reducing energy bill (regarding short-term trades)	Trains consumption predictions RES forecast Electricity market fluctuations	Storage power ($P_{sto\text{-}ref\text{-}lgt}$) (Predictive reference power)
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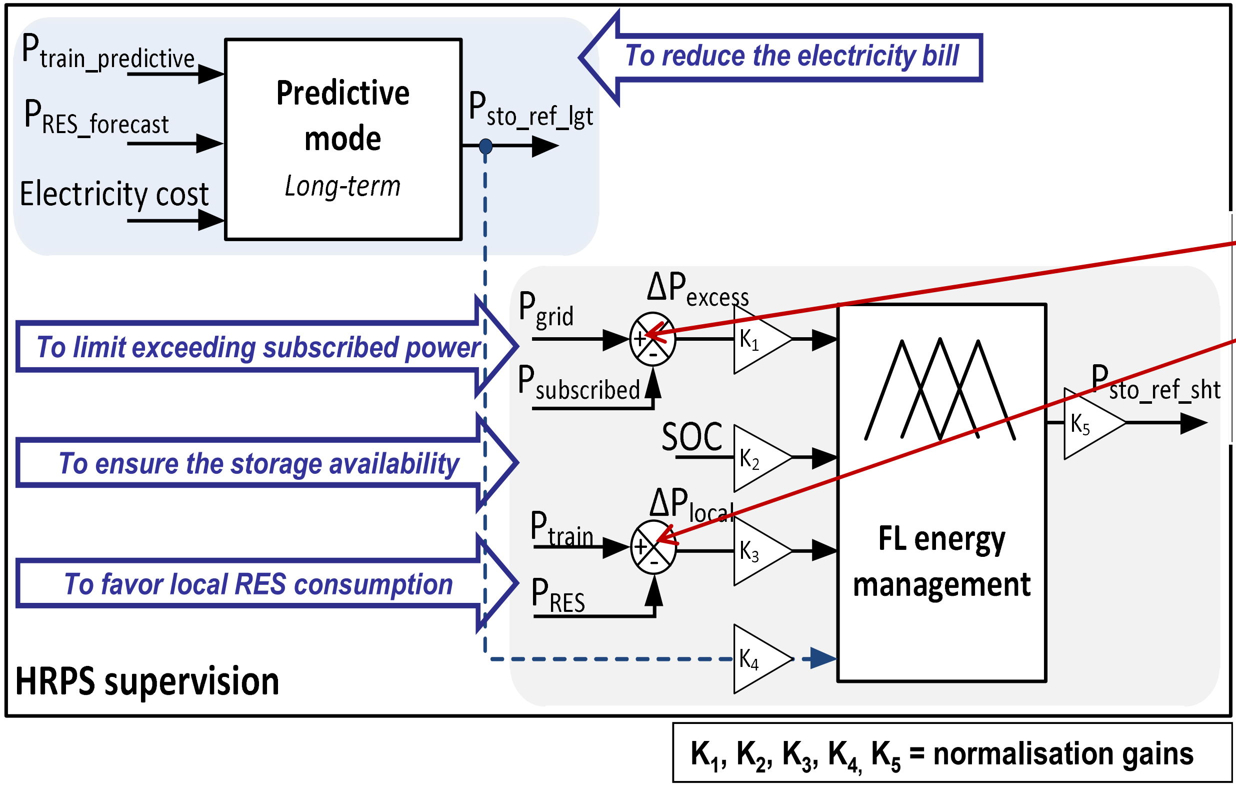
Limitation of subscribed power exceeding Favoring local RES consumption Ensuring storage system availability	Subscribed power Storage limits RES availability	Storage power ($P_{sto\text{-}ref\text{-}sht}$) (Predictive mode adjustment)

Methodology for HRPS energy management

STEP 2
Design of the supervisor



the grid power excess amount

the power difference between train consumption and RES production

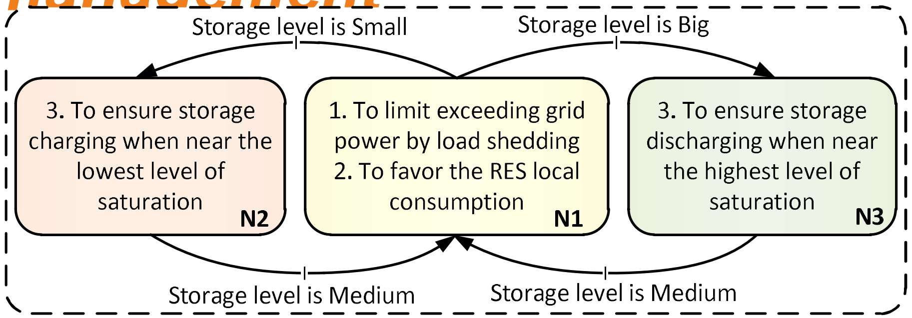
Task 4 : Fuzzy logic applied to energy management

Methodology for HRPS energy management

STEP 3

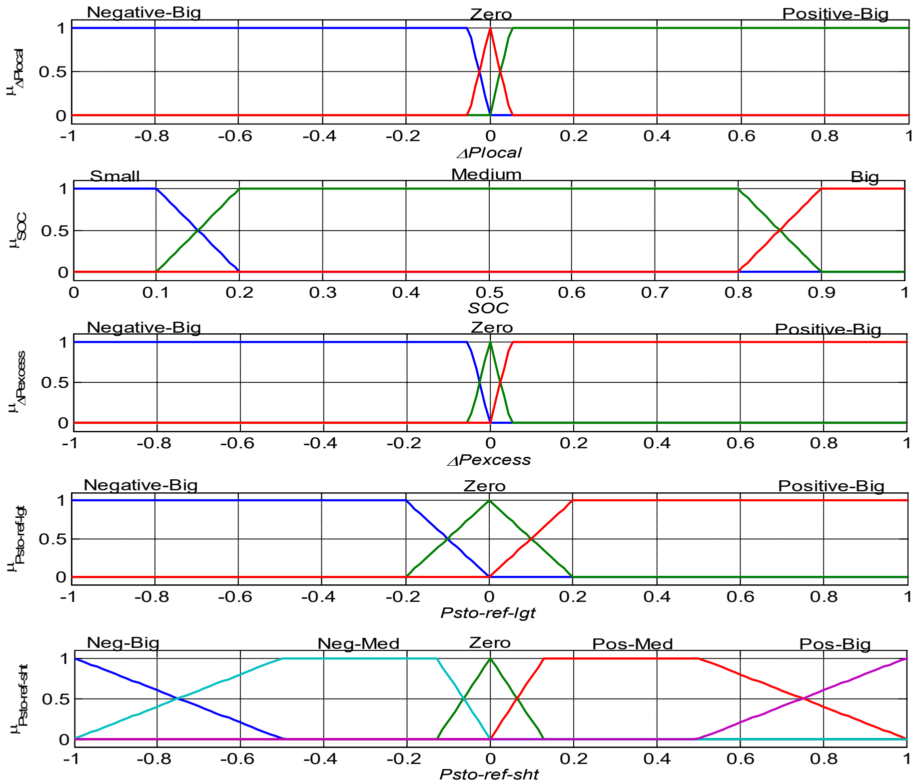
Chart representation of operating modes

- Functional graphs -



STEP 4

Determination of the membership functions



Inputs:

P_{local} *(Negative-Big, Zero, Positive-Big)*

- *SOC (Small, Medium, Big)*
- ΔP_{excess} *(Negative-Big, Zero, Positive-Big)*
- $P_{sto\text{-}ref\text{-}lgt}$ *(Negative-Big, Zero, Positive-Big)*

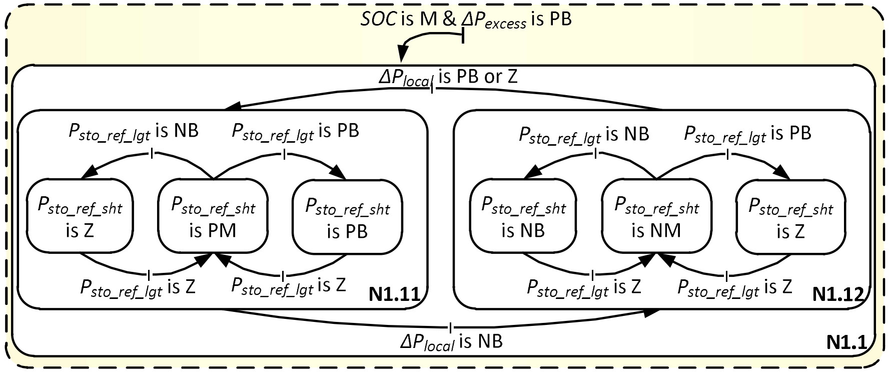
Output:

- $P_{sto\text{-}ref\text{-}sht}$ *(Negative-Big, Zero, Positive-Big)*

Task 4 : Fuzzy logic applied to energy management

Methodology for HRPS energy management

STEP 5
Chart representation of fuzzy operating modes - Operational graphs -



from 81 possible cases, only 30 fuzzy necessary rules

STEP 6
Determination of the fuzzy rules

If *SOC* is M
and $\Delta P_{excess\_p.u.}$ is NB *(P_{grid}<$P_{subscribed}$)*
and $\Delta P_{local\_p.u.}$ is PB (P_{train}>P_{RES})
and $P_{sto\text{-}ref\text{-}lgt\_p.u.}$ is NB *(to charge)*
then $P_{sto\text{-}ref\text{-}sht\_p.u.}$ is NB *(charge reference)*

Mode	*Inputs*				*Output*
	SOC	ΔP_{local}	ΔP_{excess}	$P_{sto\text{-}ref\text{-}lgt}$	$P_{sto\text{-}ref\text{-}sht}$
N1.11	M	not NB	PB	PB	Z
	M	not NB	PB	Z	PB
	M	not NB	PB	PB	PB
N1.12	M	NB	PB	NB	NB
	M	NB	PB	Z	NM
	M	NB	PB	PB	Z
		…			

Task 4 : Fuzzy logic applied to energy management

Methodology for HRPS energy management

STEP 7
Determination of indicators to measure the achievement of objectives

Economic indicator (monthly component of the exceeding subscribed power)

$$CMDPS = \sum_{t \in T} \alpha \cdot k_t \sqrt{\sum_{x \in X_t} \Delta P^2_{excess}(x)}$$

$$\Delta P_{excess} = P_{grid} - P_{subscribed}$$

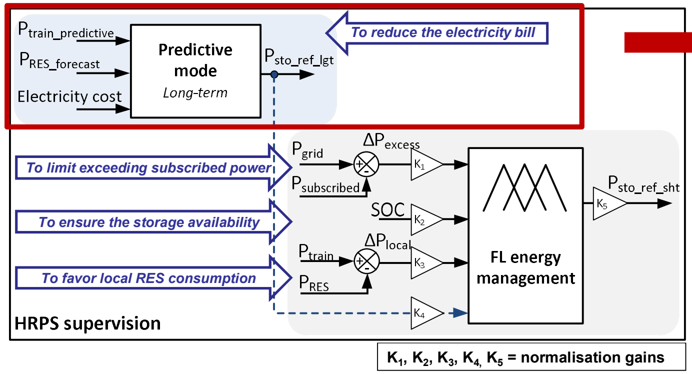
- five tariff time periods *T*
- *α=0.3584€/kW*
- k_t (%) is a power coefficient for each time tariff period *t*
- X_t represents the index set *x* belonging to each time class *t*).

Energy indicator (ratio between the locally consumed energy of RES and the produced one)

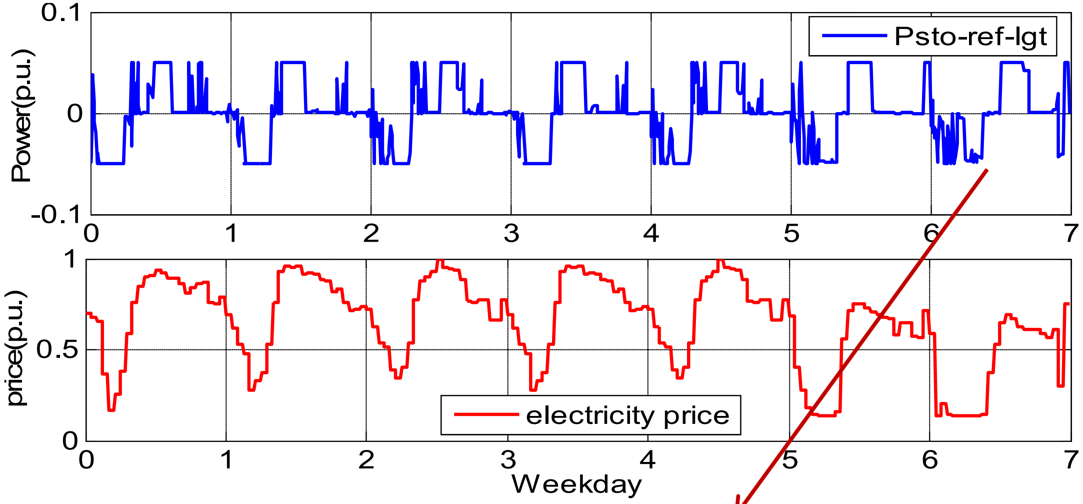
$$I_{RES}(\%) = \frac{E_{RES} - E_{RES\_noncons}}{E_{RES}} \cdot 10($$

Task 4 : Fuzzy logic applied to energy management

Predictive mode storage reference power



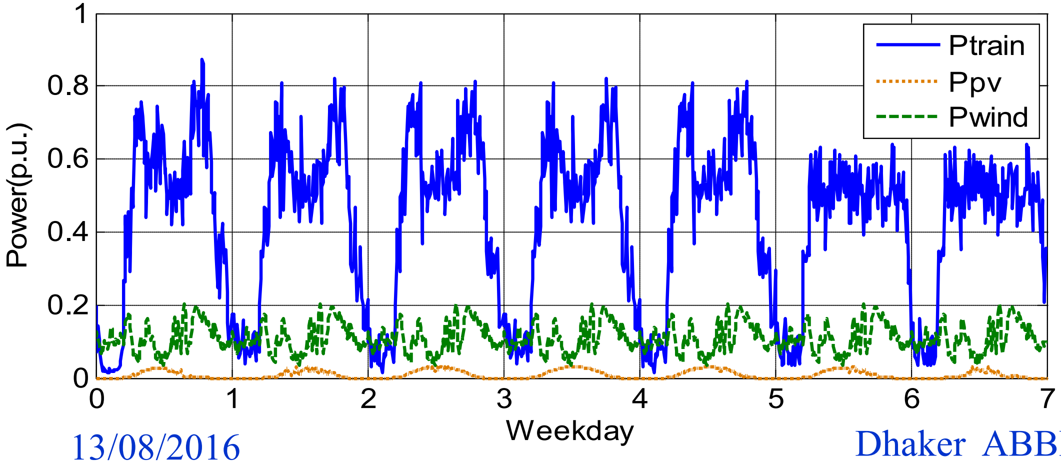
Depends on electricity price in short term trades



Storage system:

- C_{sto} = 5000 kWh
- $P_{sto\text{-}max}$ = 1MW
- η_{charge}=90%, $\eta_{discharge}$=90%
- SOC_{min}, SOC_{max}
- time response constant (τ=0.5s)

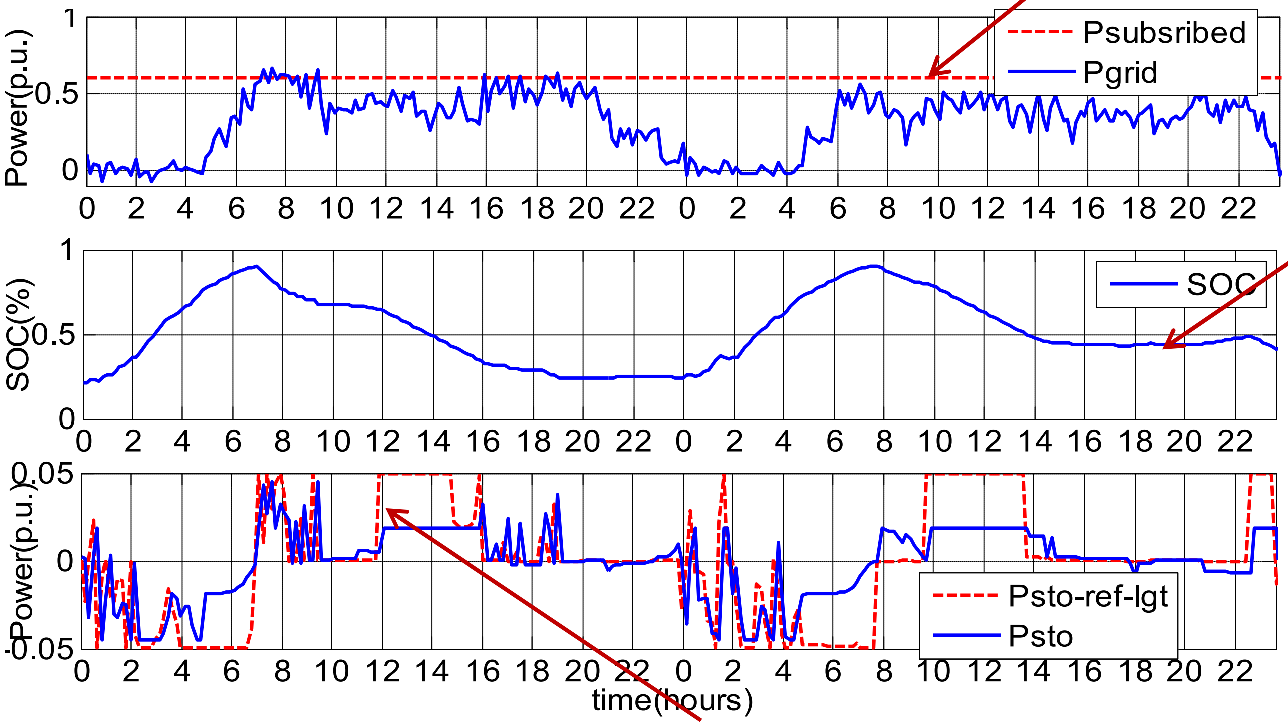
Production and consumption profiles



Task 4 : Fuzzy logic applied to energy management

Case 3: storage power adjustment

the subscribed power is reduced thanks to RES local consumption and storage management



storage system charges when RES exceed train consumption and when economic interesting

adjustment of $P_{sto\text{-}ref\text{-}lgt}$ reference power

Task 4 : Fuzzy logic applied to energy management

Comparison of different supervision cases

Subscribed power is reduced five times in HRPS supervision

Study case	*CMDPS*	I_{RES}
Reference case	5338 €	0%
Case 1 (Predictive mode)	1024 €	96,5%
Case 2 (FLEM strategy)	1036 €	95,5%
Case 3 (Adjustment)	942 €	96,9%

well performance of FLEM strategy compared to predictive mode results

RES is locally consumed almost in totality

References

This first theoric part is extracted from : Fuzzy logic Massey University course.
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Thank you for your attention !