Introduction to Fuzzy Logic

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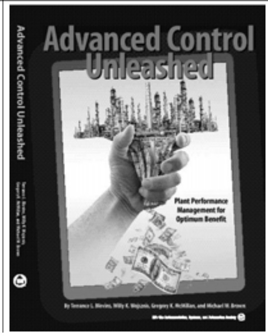
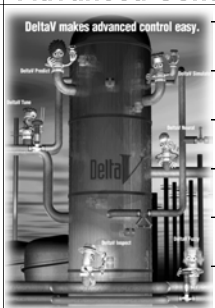
EMERSON. Process Management

Advanced Control



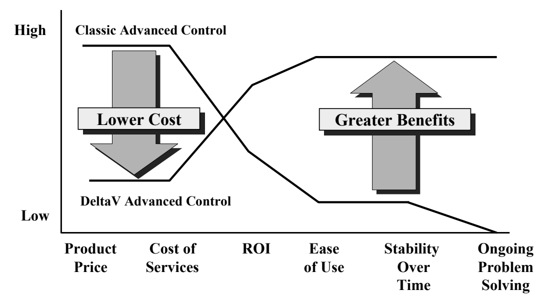
- → Performance Monitoring and optimization
- → Unit and plant-level applications - offer high value to customer operations

Advanced Control



- → **The Control Foundation in DeltaV**
  - Traditional tools e.g. override, cascade, ratio
  - Improvements provided by advanced control
- → **DeltaV Inspect**
  - Detection of abnormal conditions
  - Variability index, utilization
- → **DeltaV Tune**
  - Tuning response, robustness
  - Expert options e.g. Lambda, IMC
- → **DeltaV Fuzzy**
  - Principals of fuzzy logic control
  - FLC function block, tuning
- → **DeltaV Neural**
  - Creation of virtual sensor
  - Data screening, training
- → **DeltaV Predict**
  - MPC for multi-variable control
  - Model identification, data screening
  - Simulation of response, tuning
- → **DeltaV Simulate**
  - Operator training and engineering
  - Using High fidelity process simulation

DeltaV Redefines Advanced Control



DeltaV Fuzzy

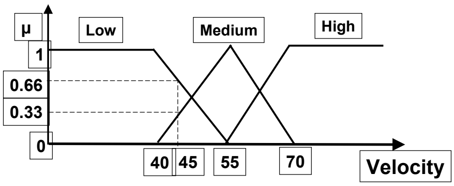
- → Improved response to process disturbances and setpoint changes, especially for loops with long time constants
- → May replace PID for most applications
- → Configuration is Easy - exactly like PID
- → Quick tuning with DeltaV Autotuner

Fuzzy Logic Fundamentals

- → The fuzzy logic associates uncertainty to the data set structure (Zadeh, 1965).
- → The elements of a fuzzy set are order pair data which gives the element value and membership grade

Fuzzy Logic Fundamentals

- Example
  Low: “a velocity around 40 km/h”
  Medium : “a velocity around 55 km/h”
  High: “a velocity over 70 km/h aprox.”

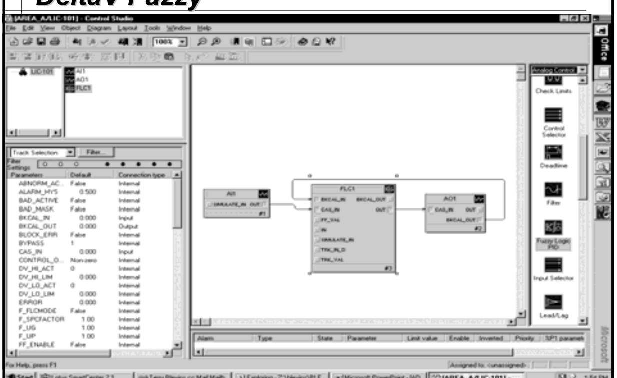


- Thus, if the velocity is 45 km/h, the membership grades are 0, 0.33 and 0.66 belong to the fuzzy sets Low, Medium, High, respectively

Fuzzy Logic Fundamentals

- For a fuzzy set, an element x belong to a set A with a membership grade μ_A (x), which is between 0 and 1
- A variable could be characterized with different linguistic values, each one represents a fuzzy set

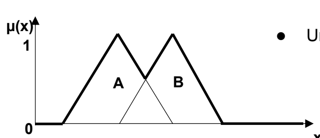
DeltaV Fuzzy



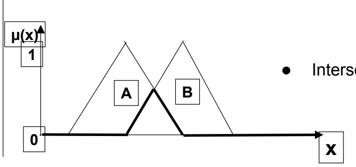
Basic Operations of Fuzzy Logic

- Given two fuzzy sets A and B in the same universe X, with membership functions u_A and u_B respectively, the following basic operations are defined

Basic Operations of Fuzzy Logic



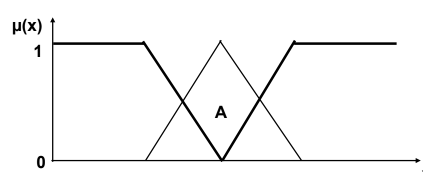
- Union $u_{A\cup B} = \max\{(u_A(x), u_B(x))\}$



- Intersection $u_{A\cap B} = \min\{(u_A(x), u_B(x))\}$

Basic Operations of Fuzzy Logic

- Complement $u_{\bar{A}}(x) = 1 - u_A(x)$



Basic Operations of Fuzzy Logic

- Given the fuzzy sets A1, ..., An with universes X_1, ..., X_n respectively, the product Cartesian is defined as a fuzzy set in $X_1 \cdots X_n$ with the following membership function:

$$u_{A1x..xAn}(x_1,...,x_n) = \min\{u_{A1}(x_1),...,u_{An}(x_n)\}$$

Mamdani (1974)

$$u_{A1x..xAn}(x_1,...,x_n) = u_{A1}(x_1)\cdot u_{A2}(x_2)\cdots u_{An}(x_n)$$

Larsen (1980)

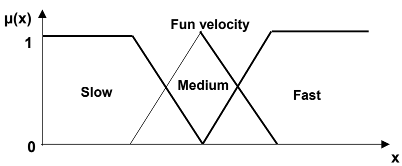
Fuzzy Models

- Linguistic fuzzy models
- Takagi & Sugeno fuzzy models

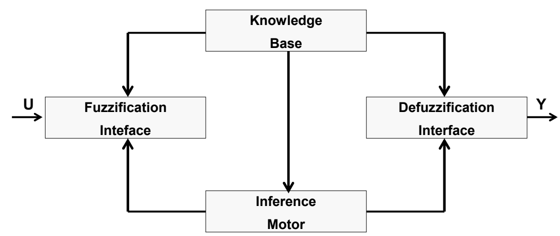
Linguistic Fuzzy models

- The linguistic fuzzy models are based on heuristic rule sets where the input and output linguistic variables are represented by fuzzy sets
- Example

  “If temperature is High then fun velocity is Slow”



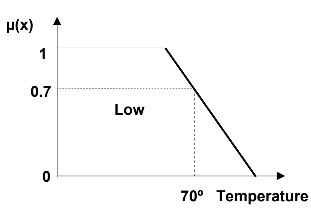
Linguistic Fuzzy models



Fuzzyfication Interface

- This element transform the input variables to fuzzy variables

  Example: 70 º → “Low with membership grade 0.7”



Knowledge base

- It contains the linguistic rules and the membership function information of the fuzzy sets
- Calculates the output variable fuzzy sets from the input variables by using the rules and the fuzzy inference

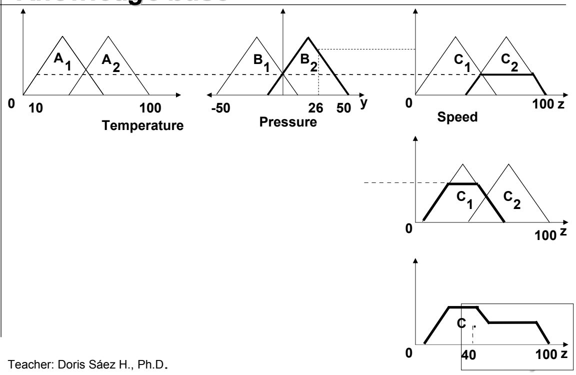
  Example: x1 (temperature) = 10 and

  x_2 (pressure) = 26 → y (speed)?

  R_1: If x_1 is A_1 and x_2 is B_2 then y is C_2

  R_2: If x_1 is A_1 and x_2 is B_1 then y is C_1

Knowledge base



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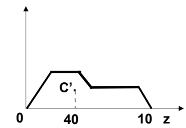
Defuzzification Interface

- From output variable fuzzy sets, obtained by fuzzy inference, provides the non fuzzy output



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Takagi & Sugeno Fuzzy Models

- These models are characterized by fuzzy rules, where each premise represents a fuzzy subspace and the consequences are linear relation of input-output

Example

$$\textit{If}\ \text{x is } A_1 \text{ Then } y = Cx + D$$

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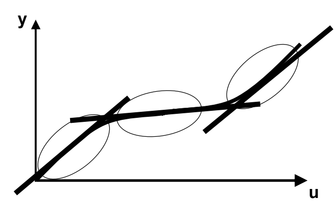
Takagi & Sugeno Fuzzy Models

- Linear models for the consequences



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Takagi & Sugeno Fuzzy Models

- In general,

$$R_i : \text{If } X1 \text{ is } Al_i \text{ and} \ldots \text{and } Xk \text{ is } Ak_i$$
$$\text{Then } Y_i = p_0^i + p_1^i\, X1 + \ldots + p_k^i\, Xk$$

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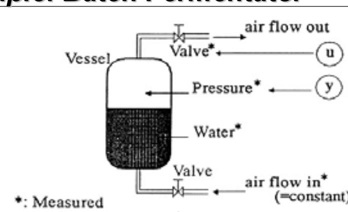
Example: Batch Fermentator



1	If pressure y(k) is *Low* and valve u(k) is *Open* then $y(k+1) = 0.67y(k) + 0.0007u(k) + 0.35$
2	If y(k) is *Medium* and u(k) is *Half Closed* then $y(k+1) = 0.80y(k) + 0.0028u(k) + 0.07$
3	If y(k) is *High* and u(k) is *Closed* then $y(k+1) = 0.90y(k) + 0.0071u(k) - 0.39$

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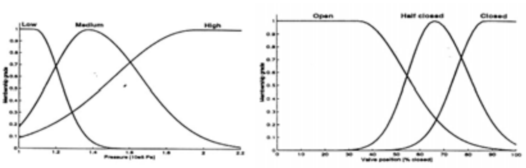
Example: Batch Fermentator

- Membership functions



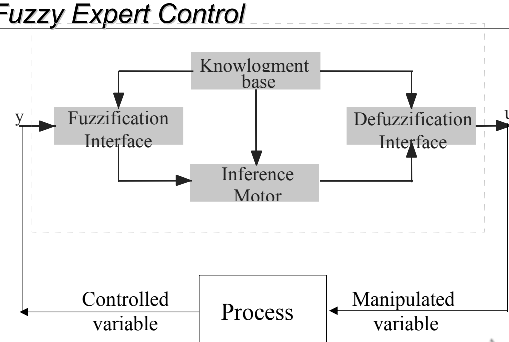
Control Strategies Based on Fuzzy Models

- Fuzzy expert control
- PID fuzzy control

Fuzzy Expert Control

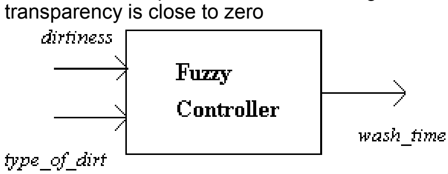
- These controllers are based on heuristic rules where the input and output linguistic variables are represented by fuzzy sets
- Example:
  - If temperature is high then fun velocity is fast

Fuzzy Expert Control



Fuzzy Expert Control

- Example: Washing machine
  - The dirtiness is determined by the transparency of the water.
  - Type of dirt is given from the saturation time. Saturation is the point at which the change in water transparency is close to zero



Fuzzy Expert Control

- Example: Washing machine

Rules

if dirtness_of_clothes is Large and type_of_dirt is Greasy then wash_time is VeryLong;

if dirtness_of_clothes is Large and type_of_dirt is Medium then wash_time is Long;

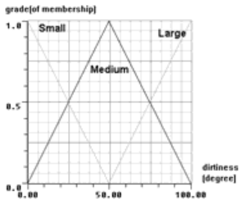
if dirtness_of_clothes is Medium and type_of_dirt is Medium then wash_time is Medium;

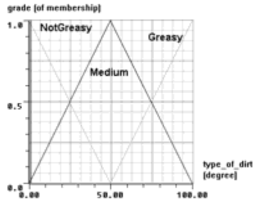
if dirtness_of_clothes is Large and type_of_dirt is NotGreasy then wash_time is Medium;

Fuzzy Expert Control

→ Example: Washing machine

Input membership functions

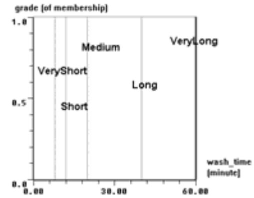




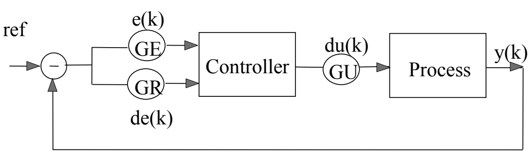
Fuzzy Expert Control

→ Example: Washing machine

Output membership functions



Fuzzy PID Control



$e(k) = r - y(k)$

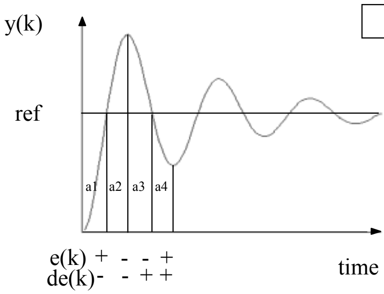
$de(k) = e(k) - e(k-1)$

Fuzzy PID Control

→ Characteristics:

- Two or seven fuzzy sets for the input variables
- Two or seven fuzzy sets for the output variables
- Triangular membership functions
- Fuzzyfication with continuous universes
- Inference based on fuzzy implicance
- Desfuzzyfication by the maximum mean method

Fuzzy PID Control



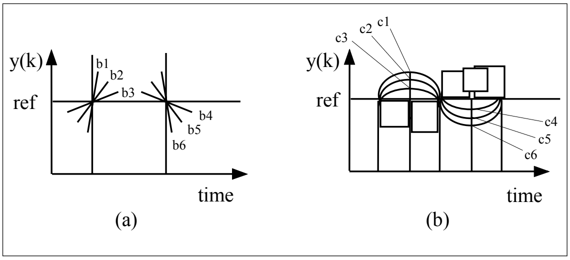
Fuzzy PID Control

	e(k)	de(k)
a1	>0	<0
a2	<0	<0
a3	<0	>0
a4	>0	>0

	e(k)	de(k)
b1	=0	<<<0
b2	=0	<<0
b3	=0	<0
b4	=0	>0
b5	=0	>>0
b6	=0	>>>0

	de(k)	e(k)
c1	=0	<<<0
c2	=0	<<0
c3	=0	<0
c4	=0	>0
c5	=0	>>0
c6	=0	>>>0

Fuzzy PID Control



Fuzzy PID Control

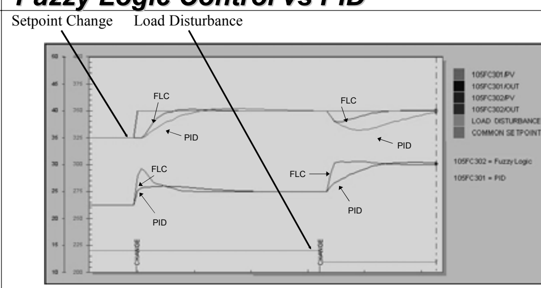
		de(k)						
		NB	NM	NS	ZE	PS	PM	PB
	NB	a2	a2	a2	c1	a3	a3	a3
	NM	a2	a2	a2	c2	a3	a3	a3
	NS	a2	a2	a2	c3	a3	a3	a3
e(k)	ZE	b1	b2	b3	ZE	b4	b5	b6
	PS	a1	a1	a1	c4	a4	a4	a4
	PM	a1	a1	a1	c5	a4	a4	a4
	PB	a1	a1	a1	c6	a4	a4	a4

Fuzzy PID Control

		de(k)						
		NB	NM	NS	ZE	PS	PM	PB
	NB	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NB	NM	NM	NS	ZE	PS
	NS	NB	NM	NS	NS	ZE	PS	PM
e(k)	ZE	NM	NM	NS	ZE	PS	PM	PM
	PS	NM	NS	ZE	PS	PS	PM	PB
	PM	NS	ZE	PS	PM	PM	PB	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

– *"If the error is Negative Small and the incremental error is Positive Medium then the increment control variable is Positive Small"*

Fuzzy Logic Control vs PID



Notice at both SP change and at load disturbance the FLC output change is more dramatic than PID. Resulting in faster return to SP. Also notice as PV approaches SP, the FLC exhibits less overshoot.

DeltaV Tune - Fuzzy Logic Commissioning