Fuzzy Systems in Instrumentation: Fuzzy Control

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Abstract - **This paper presents a short overview of fuzzy control and discusses fuzzy partition in comparison with classical A/D and dither quantification. A fuzzy controller for docking a model truck and trailer is finally presented.**

I. INTRODUCTION

The basic idea of "fuzzy logic control" (FLC) was suggested by Zadeh in [1], [2] and [3]. The first implementation of a FLC was reported by Mamdani and Assilian, [4].

FLC provides a nonanalytic alternative to the classical analytic control theory. The following quotation may help to put FLC discussions in the right perspective:

"But what is striking is that its most important and visible application today is in a realm not anticipated when fuzzy logic was conceived, namely, the realm of fuzzy-logic-based process control," [L.A. Zadeh, "Fuzzy logic," *IEEE Computer Mag.,* pp. 83-93, Apr. 1988].

A development period of over 20 years has already generated an abundant literature on FLC including periodic review papers [5], [6], [7], and books [8], [9].

This paper presents a short overview of FLC and discusses the fuzzy partition in comparison with other domain partition techniques: the classical analog-to-digital and dither quantification. A fuzzy controller for docking a model truck and trailer is finally presented.

II. FUZZY CONTROL

Fig. 1 shows the general structure of a fuzzy logic control system. It consists of three major components: input interface, inference mechanism, and output interface.

Fuzzy Input Interface

The domain of each input- or output-variable is partitioned in a finite number of overlapping fuzzy sets. Each fuzzy set is characterized by a membership function which associates with each point in the domain a real number (membership value) between 0 and 1, [10].

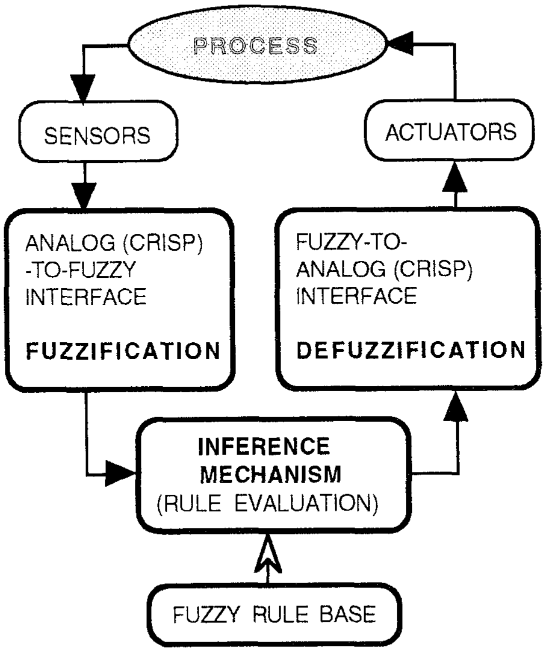

Fig. 1. Fuzzy control system.

As an example, Fig. 2 shows the membership functions which characterize the fuzzy partition for analog variable x defined in the domain $[-3\Delta, +3\Delta]$. The crisp value x^* belongs to fuzzy set P to degree $\mu P(x^*)$, fuzzy set Z to degree $\mu Z(x^*)$, and fuzzy set N to degree 0.

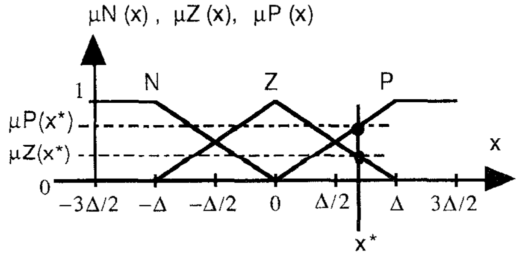

Fig. 2. Membership functions for a 3-set fuzzy partition.

Fig. 3 shows the quantization characteristics corresponding to this fuzzy partition but it does not provide any information regarding the degrees of membership.

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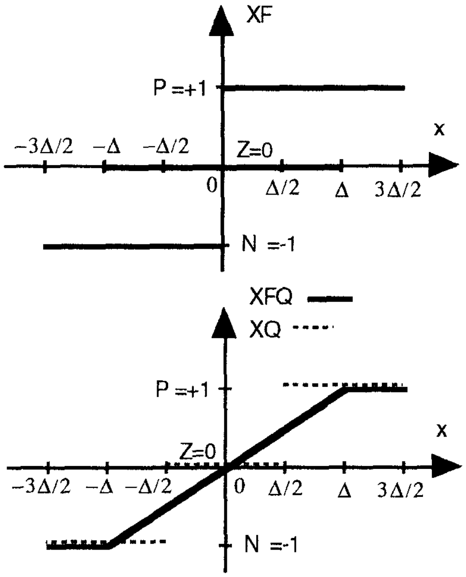


Fig. 3. Characteristics for the 3-set fuzzy partition

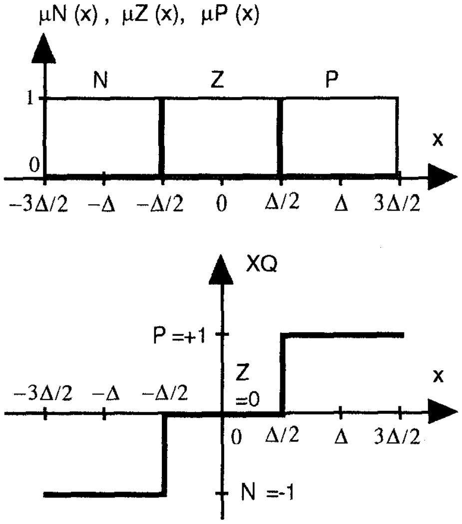


Fig. 4. Characteristics for a 3-level A/D converter.

Owing to the smooth linear transitions in the membership of overlapping fuzzy sets, the fuzzy partition doesn't introduce quantization noise. Fig. 3 shows the linear transfer function *XFQ* versus *x*, where *XFQ* are the crisp analog values recovered after a defuzzification of the fuzzy converted values *x*. It also shows the truncated information XQ recovered from an A/D converter having the Boolean partition and the quantization characteristics given in Fig. 4.

It is interesting to note that linear transfer characteristics associated with analog-to-fuzzy conversion are similar to those of dither A/D quantization shown in Fig. 5. However, dithering is a sequential process taking a longer time to recover the analog information from a sequence of quantized samples.

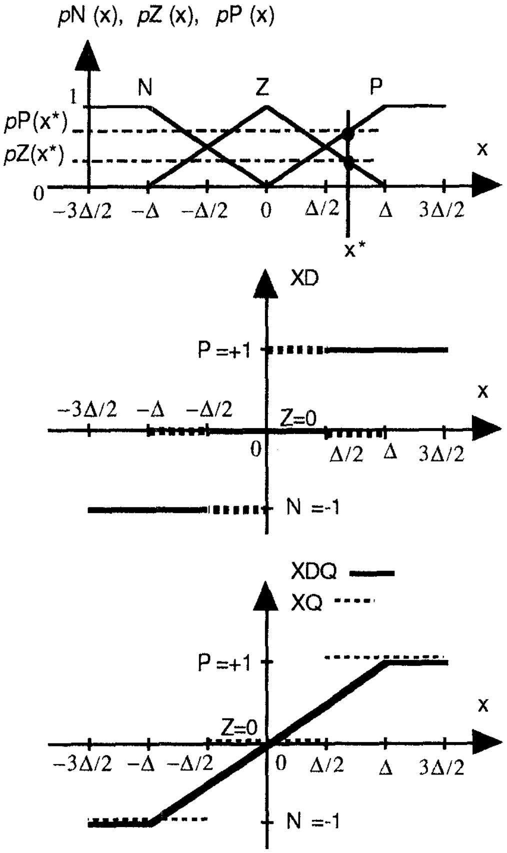


Fig. 5. Characteristics for a dither A/D converter.

Fuzzy Inference Mechanism

Assume a fuzzy controller with 2 inputs *x1* and *x2* and one output *y*. The rule base consists of a finite collection of rules with two antecedents and one consequent of the form:

Rule^i : if (x1 is $A1_j^i$) and. (x2 is $A2_k^i$) then (y is O_m^i)

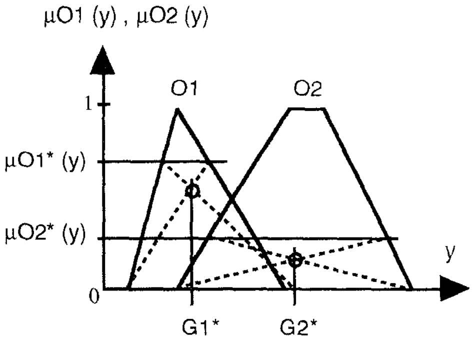
where:
$A1_j^i$ is a one of the fuzzy set of the fuzzy partition for *x1*
$A2_k^i$ is a one of the fuzzy set of the fuzzy partition for *x2*
O_m^i is a one of the fuzzy set of the fuzzy partition for *y*

For a given pair of crisp input values *x1** and *x2** the antecedents are the degrees of membership obtained during the fuzzification: $\mu A1_j^i(x1^*)$ and $\mu A2_k^i(x2^*)$. The strength of the **Rule**^{i} is: $\mu O_m^i(y)=\mathbf{min}\,[\mu A1_j^i(x1^*), \mu A2_k^i(x2^*)]$.

If more than one activated rule, for instance **Rule**^{p} and **Rule**^{q}, specify the same output action, (y is O_m), then the strongest rule will prevail: $\mu O_m(y)=\mathbf{max}\,\{\mathbf{min}[\mu A1_j^p(x1^*), \mu A2_k^p(x2^*)], \mathbf{min}[\mu A1_j^q(x1^*), \mu A2_k^q(x2^*)]\}$.

Defuzzification

Defuzzification combines the strengths of all rules activated by a given set of crisp input values and delivers a crisp analog values to the controlled process.



$$y^* = [\mu O1^*(y) \cdot G1^* + \mu O1^*(y) \cdot G1^*] \,/\, [\mu O1^*(y) + \mu O1^*(y)]$$

Fig. 6. "Center of gravity" defuzzification method.

There are several defuzzification procedures [9]. The "center of gravity" (COG) method illustrated in Fig. 6 avoids the defuzzification ambiguities which may arise when an output degree of membership can come from more than one crisp output value.

III. FUZZY CONTROLLER FOR DOCKING A TRUCK AND TRAILER MODEL

The analysis of backing a truck and trailer to a loading dock, [11], [12], can be simplified by using polar frames attached to the dock, trailer and truck, as shown in Fig. 7, [13]. The docking can be stated as follows: "Given any initial values of three state variables reduce their values to zero so that $\alpha = \beta = d = 0$." We can essentially ignore d and assume that it will eventually go to zero.

The developed FLC uses two input fuzzy variables: $AB=\alpha-\beta$ and $GAMMA=\gamma$ and two output variables: $STEER=\theta$ and *DIRN* defined in Fig. 8.

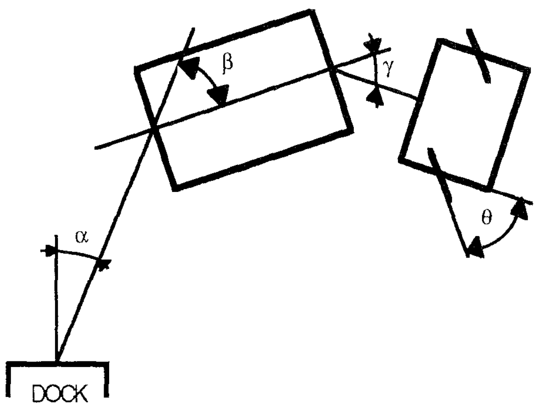


Fig. 7. Problem analysis for truck and trailer docking.

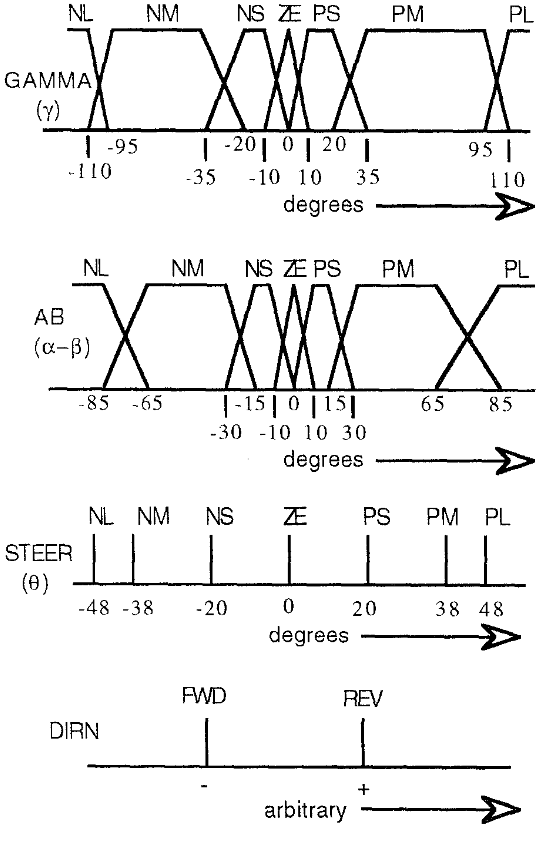


Fig. 8. Fuzzy membership functions.

Fig. 9 shows the fuzzy rule base organized as a matrix containing the 49 rules for steering and direction control.

A model truck with onboard sensors for α, β, γ, and d has been implemented as a testbed for the FLC. All control functions are implemented on an MC68HC11E9 8-bit microcontroller. Any rule requires less than 4 bytes of memory. A COG defuzzification takes less than 50μs.

Fine tuning of the membership functions has resulted, as shown in Fig. 10, in a linearization of the I/O fuzzy control characteristic around its central (docking station) region.

AB (α−β)

STEER/DIRN
rule base

GAMMA (γ)

	NL	NM	NS	ZE	PS	PM	PL
NL	LH/F	LH/F	LH/F	LM/F	LS/F	RS/F	RM/F
NM	LH/F	LH	LH	LM	ZE	RM	RH/F
NS	LH/F	LH	LM/R	LS/R	RS/R	RM	RH/F
ZE	LH/F	LH	LS/R	ZE/R	RS/R	RH	RH/F
PS	LH/F	LM	LS/R	RS/R	RM/R	RH	RH/F
PM	LH/F	LM	ZE	RM	RH	RH	RH/F
PL	LM/F	LS/F	RS/F	RM/F	RH/F	RH/F	RH/F

Fig. 9. Fuzzy rule base for docking the truck and trailer.

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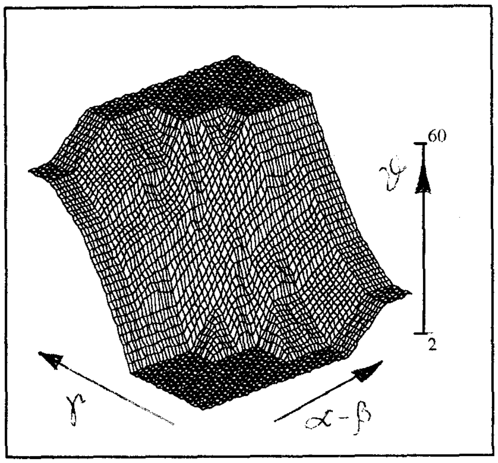

Fig. 10. I/O characteristics of the FLC

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