模糊控制器之分解式設計

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摘　要

在本文中，將以分解式之方式來簡化模糊控制器的設計。　經由分解式之設計方式，多輸入-單輸出 (MISO) 之模糊控制器可被分解成數個單輸入-單輸出 (SISO) 之模糊控制器。　而此多輸入-單輸出之模糊控制器的輸出等於數個單輸入-單輸出 (SISO) 之模糊控制器輸出的乘積。　如此一來，將可簡化多輸入-單輸出之模糊控制器的設計。　本文亦包含模擬之範例來說明此設計方式之效能。

關鍵詞：分解式之方式、模糊控制。

A Decomposition-based Design Approach of Fuzzy Controllers

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abstract

In this paper, a decomposition-based approach is proposed to simplify the design of the fuzzy controllers. Usually, the antecedents of the fuzzy rules in the fuzzy rule base of the multi-input single-output (**MISO**) fuzzy controller are constructed to include all the combinations of conditions of input variables. Assume that the triangular type membership functions and the centroid defuzzification method are adopted in the fuzzy controller. Furthermore, the algebra product is selected to be the fuzzy **and** operator. Then a simple crisp output with the denominator equal to one is obtained for the **MISO** fuzzy controller. By the proper design, the input variables in the crisp output of the **MISO** fuzzy controller can be separated from each other so that the crisp output is represented as the multiplication of terms. Each term involves only one single input variable. Thus, the **MISO** fuzzy controller can be decomposed into several **SISO** fuzzy sub-controllers and the output of the **MISO** fuzzy controller is the product of the outputs of the **SISO** sub-controllers. That is, with this decomposition-based approach, the design of a **MISO** fuzzy controller can be simplified into the design of **SISO** fuzzy controllers. This approach is adopted to design the **PD**-like fuzzy controller in this paper. And simulations are also carried out to show the effectiveness of the **PD**-like fuzzy controllers designed with the proposed approach.

Key Words: Decomposition-based Approach, Fuzzy Control.

1. Introduction

It is known that fuzzy logic techniques [2,12] provide a method for representing and implementing the expert's experience and knowledge [6]. And the linguistic information from experts is usually described by the fuzzy if-then rules with linguistic predicates [4,5,7,9]. Based on the expert's knowledge, the fuzzy controller with the fuzzy if-then rules have been developed to control the complex systems with unknown dynamics [1,8,11]. However, it is difficult to design and realize the fuzzy controllers with a large number of input variables. One approach to reduce the number of input variables and simplify the design of the multi-input fuzzy controllers is to generate new input variables by linearly combining the original input variables [1,10]. Nevertheless, the number of the design parameters is decreased by the input variable combination approach, and the system requirements may not be satisfied. In this case, a new simplification approach called decomposition-based approach is proposed in this paper to alleviate the difficulty of the performance degration for the implementation of the fuzzy controllers. Usually, the antecedents of the fuzzy rules in the fuzzy rule base of the multi-input single-output (**MISO**) fuzzy controller are constructed to include all the combinations of conditions of input variables. Assume that the triangular type membership functions and the centroid defuzzification method are adopted in the fuzzy controller. Furthermore, the algebra product is selected to be the fuzzy **and** operator. Then a simple crisp output with the denominator equal to one is obtained for the **MISO** fuzzy controller [3]. By the proper design, the input variables in the crisp output of the **MISO** fuzzy controller can be separated from each other so that the crisp output is represented as the multiplication of terms. Each term involves only one single input variable. Thus, the **MISO** fuzzy controller can be decomposed into several **SISO** fuzzy sub-controllers and the output of the **MISO** fuzzy controller is the product of the outputs of the **SISO** sub-controllers. That is, with this decomposition-based approach, the design of a **MISO** fuzzy controller can be simplified into the design of **SISO** fuzzy sub-controllers. And the **SISO** fuzzy sub-controllers are constructed according to the reasonable information directly acquired from the experienced operators. Moreover, if the transformed (input coordinates rotated) **MISO** fuzzy controllers can be decomposed into **SISO** fuzzy sub-controllers with respect to the new input variables, and the output of the transformed **MISO** fuzzy controller is equal to the multiplication of the outputs of the **SISO** fuzzy sub-controllers, then the transformed **MISO** fuzzy controllers are shown to be improved with the decomposition-based approach. Since the multi-input multi-output (**MIMO**) fuzzy controller can always be separated into several **MISO** fuzzy controllers [5], the decomposition-based design approach proposed here can be further applied to the design of **MIMO** fuzzy controllers. The decomposition-based designs of the **PD**-like fuzzy controller and the transformed **PD**-like fuzzy controller are included in this paper.
And simulations are also carried out to show the effectiveness of **PD**-like fuzzy controllers designed with the proposed approach.
The remainder of this paper is organized as follows. The construction of the **MISO** fuzzy

controller is presented in Section 2. The decomposition procedure is described in Section 3. Section 4 provides the proposed decomposition design for the **PD**-like fuzzy controller based on the linguistic information for each **SISO** fuzzy sub-controller. The decomposition design for the transformed **PD**-like fuzzy controller is studied in Section 5. Simulations are included in Section 6. Finally, Section 7 provides a conclusion.

2. Construction of a MISO Fuzzy Controller

In this section, the construction of a **MISO** fuzzy controller is presented. Let the input variables of the fuzzy controller be $x_j,\ j=1,2,....,m$, and the output variable be y .Also, we assume that the universe of the input variable x_j is partitioned into fuzzy sets $A_1^{\,j}$, $A_2^{\,j}$,..., $A_{kj}^{\,j}$, and the universe of the output variable y is partitioned into fuzzy sets B_1, B_2,..., B_s. Moreover, for each combination of conditions of input variables

x_1 is $C_1^{\,i}$, x_2 is $C_2^{\,i}$,..., and x_m is $C_m^{\,i}$,

it is assumed that there is a fuzzy rule in the fuzzy rule base of the **MISO** fuzzy controller with the form:

Ri: If x_1 is $C_1^{\,i}$, x_2 is $C_2^{\,i}$,..., and x_m is $C_m^{\,i}$, then y is D^i

where $C_j^{\,i} \in \{A_1^{\,j}, A_2^{\,j},..., A_{kj}^{\,j}\}$, for $1 \leqq j \leqq m$; and $D^i \in \{B_1, B_2,..., B_s\}$. That is, the fuzzy rule base of the **MISO** fuzzy controller consists of

$$n = \prod_{j=1}^{m} k_j$$

fuzzy if-then rules. For the following discussion in this paper, the notations A(·),B(·),...$, are used to represent the membership functions of fuzzy sets A,B,..., respectively. With the algebraic product as the fuzzy **and** operator, triangular type membership functions (see Figure 2), and the centroid defuzzification method, the crisp output of the **MISO** fuzzy controller is

$$y = \frac{\sum_{i=1}^{n} p_i \prod_{j=1}^{m} C_j^i(x_j)}{\sum_{i=1}^{n} \prod_{j=1}^{m} C_j^i(x_j)} \qquad (1)$$

where p_i is the value such that $D^i(p_i)$ has the maximum value one. Note that the denominator of Eq. 1 is equal to one and the output of the **MISO** fuzzy controller can be simply calculated as

$$y = \sum_{i=1}^{n} p_i \prod_{j=1}^{m} C_j^i(x_j) \tag{2}$$

3. Decomposition Procedure for the **MISO** Fuzzy Controller

Based on the **MISO** fuzzy controller constructed in the Section 2, the decomposition procedure for the **MISO** fuzzy controller is provided in this section. To simplify the explanation of the decomposition procedure, the number of the input variables of the **MISO** fuzzy controller is assumed to be two (m=2) without loss of generality. And the crisp output y derived from Eq. 2 is

$$y = \sum_{i=1}^{k_1 k_2} p_i \prod_{j=1}^{2} C_j^i(x_j)$$

Let the crisp output y be expressed explicitly in terms of the fuzzy sets A_1^j, A_2^j,..., A_{kj}^j, for $1 \leqq j \leqq 2$. Then we will have

$$\begin{aligned} y = {} & p_1 A_1^1(x_1)A_1^2(x_2) + p_2 A_1^1(x_1)A_2^2(x_2) + \cdots + p_{k_2} A_1^1(x_1)A_{k_2}^2(x_2) + \cdots \\ & + p_{((k_1-1)k_2+1)} A_{k_1}^1(x_1)A_1^2(x_2) + p_{((k_1-1)k_2+2)} A_{k_1}^1(x_1)A_2^2(x_2) + \cdots + p_{k_1k_2} A_{k_1}^1(x_1)A_{k_2}^2(x_2) \end{aligned} \tag{3}$$

Furthermore, assume that we can find the variables q_i and r_j which satisfy the following conditions

$$p_{((i-1)k_2+j)} = q_i r_j \quad ; \forall\ i \in \{1,2,...,k_1\}, \quad j \in \{1,2,...,k_2\} \tag{4}$$

When $p_{((i-1)k_2+j)}$ in the Eq. 3 is substituted with $q_i r_j$, the output y of the **MISO** fuzzy controller becomes

$$\begin{aligned} y &= q_1 r_1 A_1^1(x_1)A_1^2(x_2) + q_1 r_2 A_1^1(x_1)A_2^2(x_2) + \cdots + q_1 r_{k_2} A_1^1(x_1)A_{k_2}^2(x_2) + \cdots \\ &\quad + q_{k_1} r_1 A_{k_1}^1(x_1)A_1^2(x_2) + q_{k_2} r_1 A_{k_1}^1(x_1)A_2^2(x_2) + \cdots + q_{k_1} r_{k_2} A_{k_1}^1(x_1)A_{k_2}^2(x_2) \\ &= \sum_{i=1}^{k_1} q_i A_i^{\,1}(x_1) \sum_{j=1}^{k_2} r_j A_j^{\,2}(x_2) \end{aligned} \tag{5}$$

From Eq. 5, it can be seen that the input variables in the calculation formula for the crisp output y of the **MISO** fuzzy controller can be separated from each other and the crisp output y can be represented as the product of terms. Each term includes only one single input variable.

In the **SISO** fuzzy controller with the input variable x_1, the universe of x_1 is partition into fuzzy sets A_1^1, A_2^1,...., $A_{k_1}^1$. If q_i is the value such that

$O_i(q_i)=1; \forall\ i \in \{1,2,...,k_1\}$,

and O_i is one of the output fuzzy sets of the **SISO** fuzzy controller, then the crisp output of the **SISO** fuzzy controller is equal to

$$y_1 = \sum_{i=1}^{k_1} q_i A_i^1(x_1)$$

Likewise, the value

$$y_2 = \sum_{j=1}^{k_2} r_j A_j^2(x_2)$$

can also be considered as the output of a **SISO** fuzzy controller. Thus, the **MISO** fuzzy controller can be decomposed into several **SISO** fuzzy sub-controllers and the output of the **MISO** fuzzy controller is the product of the outputs of the **SISO** sub-controllers. That is, with this decomposition approach, the design of a **MISO** fuzzy controller is simplified to be the design of **SISO** fuzzy sub-controllers. Since the multi-input multi-output (**MIMO**) fuzzy controller can always be separated into several **MISO** fuzzy controllers [5], the decomposition design approach proposed here can also be applied to the design of **MIMO** fuzzy controllers. In the next section, the **PD**-like fuzzy controller is designed with its output being calculated as the product of the outputs of two **SISO** fuzzy sub-controllers with the input variable e and $\dot{e}$ respectively.

4. Decomposition-based Design of a **PD**-like Fuzzy Controller

In this section, the design of a **PD**-like fuzzy controller will be used to illustrate the proposed decomposition approach. The decomposed **PD**-like fuzzy controller consists of a fuzzy-P sub-controller and a fuzzy-*D* sub-controller with e and $\dot{e}$ as input respectively. The fuzzy sub-controllers are constructed based on the common knowledge. And the output of the decomposition-based **PD**-like fuzzy controller (**DPDFC**) is designed as the product of the outputs of the fuzzy-*P* and fuzzy-*D* sub-controllers. Let the input variable e be defined as

$$e=d-y_o,$$

where d is the desired output and y_o is the output of the fuzzy control system with the fuzzy controller **DPDFC** (see Figure 1).

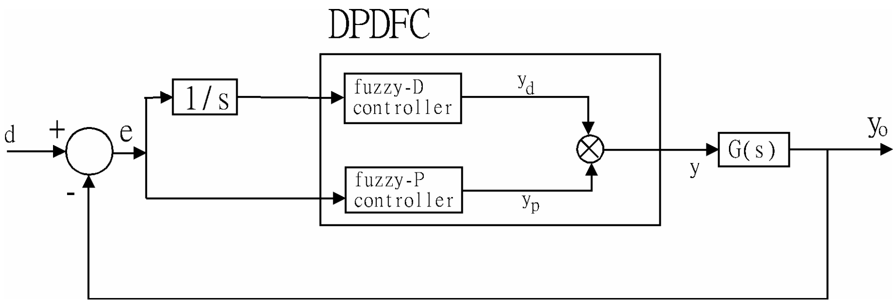

Figure 1. Block Diagram of the Fuzzy Control System with **DPDFC**.

The universes of the input variables e and $\dot{e}$ are both partitioned into fuzzy sets Negative big (nb), Negative small (ns), Zero (ze), Positive small (ps), and Positive big (pb) with membership functions shown in Figure 2. Then, the fuzzy-*P* and fuzzy-*D* controllers are constructed based on the expert's experiences with only the input variable e and $\dot{e}$ respectively. The **PD**-like fuzzy controller is assumed to have the general fuzzy control rules as shown in Figure 3(a). From the rule table in Figure 3(a), it is easy to find the characteristic that the fuzzy set ze of the output variable is assigned to the cells on the diagonal line. And the output fuzzy sets with positive (negative) sign appear above (below) the diagonal cells. If the diagonal line happened to be a vertical line, then the rule table in Figure 3(b) can be reduced to be a rule table in Figure 3(c). (The reason to discuss this situation will be explained in Section 5.) In this case, the **PD**-like fuzzy controller is equivalent to a fuzzy-*P* controller. Likewise, if the diagonal line is assumed to be a horizontal line, then the **PD**-like fuzzy controller is equivalent to a fuzzy-*D* controller with the rule table as in Figure 3(d). Let the zero output and the positive/negative sign of the output of **DPDFC** be determined by the output of the fuzzy-*P* controller. The rule table for the fuzzy-*D* controller is modified as the Table 1. According to Figure 3(c), the output variable y_p of the fuzzy-*P* controller is partitioned into fuzzy sets Negative big (nb), Negative small (ns), Zero (ze), Positive small (ps), and Positive big (pb) with membership functions presented in Figure 4(a). Also, from Table 1, the output variable y_d is partitioned into fuzzy sets Positive small (ps) and Positive medium (pm), and Positive big (pb) (c.f. Figure 4(b)).

To obtain the outputs y_p and y_d, the triangular type membership functions and centroid defuzzification method are adopted. And the outputs y_p and y_d are calculated as

$$y_p = \sum_{i=1}^{5} q_i A_i^1(e) \quad \text{and} \quad y_d = \sum_{j=1}^{5} r_j A_j^2(\dot{e}) \tag{6}$$

where q_i and r_j are the values at which the membership functions of the output fuzzy sets have the maximum values. The A_i^1 and A_j^2 represent the input fuzzy sets.

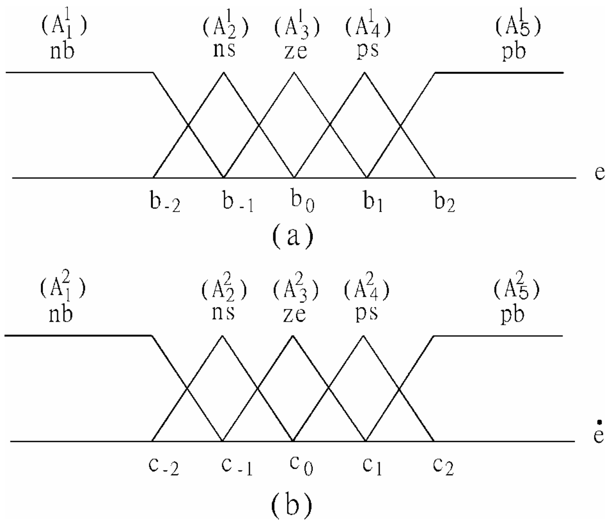

Figure 2. Membership functions for input fuzzy sets and A_{α}^{β}'s are adopted to represent corresponding fuzzy sets in the calculation formula.

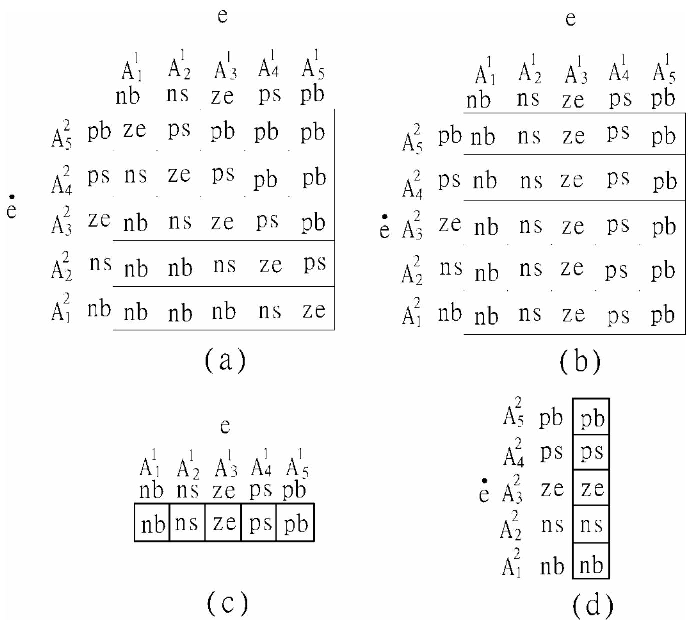

Figure 3. (a) Two-dimensional rule table. (b) Two-dimensional rule table with the ze output fuzzy set on a vertical line. (c) Reduced rule table of (b). (d) Rule table of a fuzzy-*D* controller.

$\dot{e}$				
nb	ns	ze	ps	pb
pb	pm	ps	pm	pb

Table 1. The fuzzy rules of the fuzzy-*D* controller.

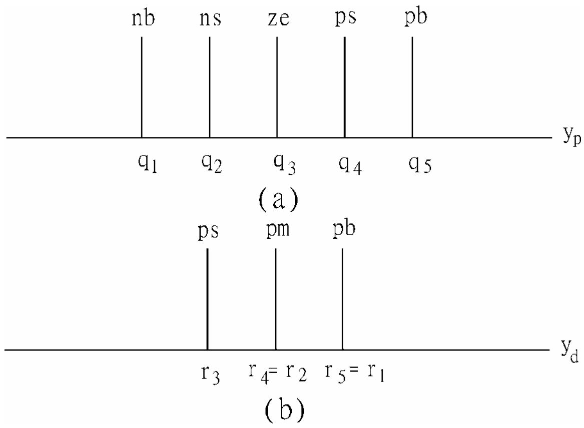

Figure 4. Simplified membership functions for output fuzzy sets.

Therefore, the output y of the decomposition-based **PD**-like fuzzy controller (**DPDFC**) can be obtained as

$$y = y_p * y_d = \sum_{i=1}^{5} q_i A_i^1(e) \sum_{j=1}^{5} r_j A_j^2(\dot{e}) . \tag{7}$$

If Eq. 7 is expanded for the crisp output y, then y can be considered as the output of a **PD**-like fuzzy controller with two dimensional rule table specified in Figure 5(a) in which $P_{ij}(q_i r_j)=1$. That is, we have completed the design of the decomposition-based **PD**-like fuzzy controller with two **SISO** fuzzy controllers (fuzzy-*P* and fuzzy-*D*). Since the r_j, j=1,2,...,5, are all positive, the positive/negative sign of the fuzzy sets of the output y can be seen as in Figure 5(b). The simulations in Section 6 are carried out to show the effectiveness of the decomposition-based design approach.

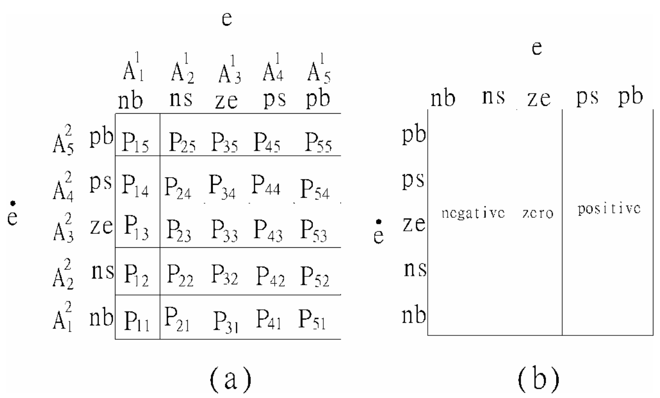

Figure 5. (a)Two dimensional rule table for the **PD**-like fuzzy controlle (b)The positive/negative sign of the output *y*.

5. Decomposition of A Transformed **PD**-like Fuzzy Controller

As mentioned in Section 4, the general fuzzy control rules are presented in the Figure 3(a). And the important feature of the table in Figure 3(a) is that the fuzzy set ze of the output variable is assigned the diagonal cells. And the output fuzzy sets with positive (negative) sign appear above (below) the diagonal cells. Thus, if the coordinates (e, $\dot{e}$) is transformed (rotated) with

$$\begin{aligned} x_1 &= e\ \cos(\theta) + \dot{e}\ \sin(\theta) \\ x_2 &= -e\ \sin(\theta) + \dot{e}\ \cos(\theta) \end{aligned} \tag{8}$$

to the coordinates (x_1,x_2) as shown in Figure 7(a), then the **PD**-like fuzzy controller can be transformed with respect to the new input variables x_1 and x_2. With the universes of the new input variables, x_1, x_2, being partitioned into fuzzy sets Negative big (nb), Negative small (ns), Zero (ze), Positive small (ps), and Positive big (pb), the control rule table for the transformed **PD**-like fuzzy controller is designed in the Figure 7(b). With the centroid defuzzification method, the output of the transformed **PD**-like fuzzy controller is

$$\begin{aligned} y_t &= \sum_{i=1}^{5} q_i F_i^1(x_1) = \sum_{i=1}^{5} q_i F_i^1(x_1) * 1 \\ &= \sum_{i=1}^{5} q_i F_i^1(x_1) \sum_{j=1}^{5} F_j^2(x_2) \end{aligned} \tag{9}$$

where q_i and r_j are the values at which the membership functions of the output fuzzy sets have the maximum values. The F_i^1 and F_j^2 represent the input fuzzy sets with the triangular type membership function in Figure 6. Let the fuzzy-x_1 and fuzzy-x_2 controllers are two **SISO** fuzzy controllers with input variables x_1 and x_2, respectively. Then the outputs of the fuzzy-x_1 and fuzzy-x_2 controllers, y_{x_1} and y_{x_2} are

$$y_{x_1} = \sum_{i=1}^{5} q_i F_i^1(x_1) \quad \text{and} \quad y_{x_2} = \sum_{j=1}^{5} r_j F_j^2(x_2)$$

If

$$r_j = 1,\ \forall\ j, \tag{10}$$

the transformed **PD**-like fuzzy controller can be decomposed into two **SISO** fuzzy controllers (fuzzy-x_1 and fuzzy-x_2 controllers) with

$$y_t = y_{x_1} * y_{x_2}.$$

Since the special condition in the Eq. 10 is adopted in the structure of the transformed **PD**-like fuzzy controller, the performances of the fuzzy control system with the transformed **PD**-like fuzzy controller may not satisfy the system requirements. In the following, it is shown that the transformed **PD**-like fuzzy controller can be improved to have better performances with the decomposition-based design approach. From the same discussion in the section 4, the rule table in Figure 7(b) can be reduced to a rule table in Figure 7(c). Then the transformed **PD**-like fuzzy controller is equivalent to a fuzzy-x_1 controller. The same approach can be applied to obtain the fuzzy-x_2 with the rotation angle θ in the Eq. 8 replaced by δ (c.f. Figure 7(d)). And the rule table for the fuzzy-x_2 controller is presented in the Figure 7(e). Thus, the decomposition-based design of the transformed **PD**-like fuzzy controller is to generate the output y_t of the transformed **PD**-like fuzzy controller by multiplying together the outputs of the fuzzy-x_1 and fuzzy-x_2 controllers. That is,

$$y_t = y_{x_1} * y_{x_2} = \sum_{i=1}^{5} q_i F_i^1(x_1) \sum_{j=1}^{5} r_j F_j^2(x_2). \tag{11}$$

where q_i and r_j are the values at which the membership functions of the output fuzzy sets have the maximum values. With the comparison of Eq. 11 and Eq. 9, it can be seen that the condition in the Eq. 10 needs not be satisfied in the Eq. 11. And the transformed **PD**-like fuzzy controller can be improved to have better or at least equivalent (r_j=1, $\forall$ j) performances with the decomposition-based design approach.

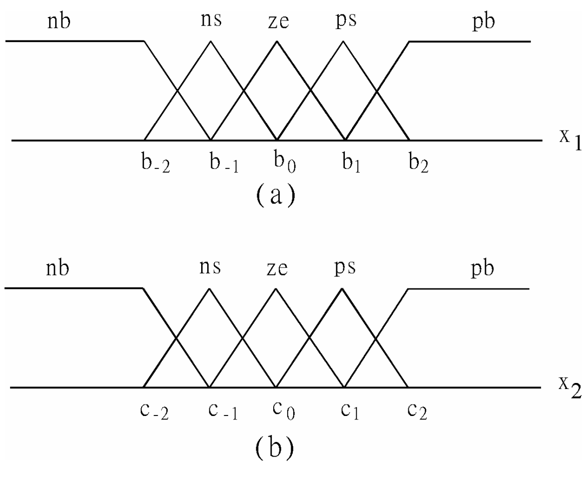

Figure 6. Input membership functions.

6. Simulation results

For simulations, the linear, nonlinear, and delayed discrete systems with difference equations

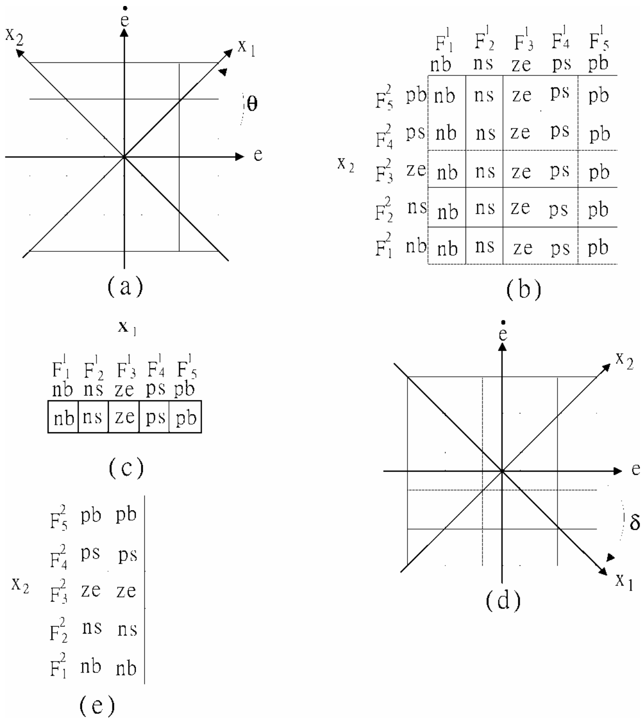

Figure 7. (a) (e, $\dot{e}$) coordinates rotated to (x_1,x_2) coordinates. (b)Two-dimensional rule table of the transformed **PD**-like fuzzy controller. (c) Reduced rule table of (b). (d) Coordinates rotation with angle δ (e) Rule table of a fuzzy-x_2 controller.

$$y(k)=y(k\text{-}1)+.1u(k), \quad (12)$$

$$y(k)=.6y(k\text{-}1)+.4[y(k\text{-}1)]^{\wedge}3+.1u(k), \quad (13)$$

and

$$y(k)=y(k\text{-}1)+.1u(k\text{-}2) \quad (14)$$

are used as the plant models where y is the output of the model and u is the output of the fuzzy controller. To show the effectiveness of the decomposition-based design approach proposed here, the performances of the three systems with the **DPDFC** are compared with those of the same systems utilizing the **MISO PD**-like fuzzy controller with rule table in Figure 3. Since the number of design parameters of the fuzzy controller **DPDFC** is larger than that of the **MISO PD**-like fuzzy controller, the systems with proper designed **DPDFC** can be expected to perform better than the systems with the **MISO PD**-like fuzzy controller in the following three subsections.

6.1. Fuzzy Controller for The Linear Plant

The performances of the fuzzy control system with the linear plant in Eq. 12 are required to satisfy

- $|u| \leq 10$.

- no overshoot and zero steady state error.
- time index $k \leq 5$ when the output y of the fuzzy control system gets to 90 percent of the reference input. That is, the rise time is less than 5.

With the fuzzy sub-controllers fuzzy-*P* and fuzzy-*D* constructed, the decomposed **PD**-like fuzzy controller generates the output by multiplying the outputs of the fuzzy-*P* and fuzzy-*D* sub-controllers. The input membership functions of fuzzy-*P* controller is as in Figure 2(a) with

$[b_{-2}\quad b_{-1}\quad b_0\quad b_1\quad b_2]=[-2/3\quad 1/3\quad 0\quad 1/3\quad 2/3]$.

And the input membership functions of fuzzy-D controller in Figure 2(b) has

$[c_{-2}\quad c_{-1}\quad c_0\quad c_1\quad c_2]=[-2000/3\quad -1000/3\quad 0\quad 1000/3\quad 2000/3]$.

The output membership functions of the fuzzy-*P* and fuzzy-*D* subcontrollers contain the pick values as

[-10 -7 0 7 10] and [7/12 7/16 7/16 7/16 7/12],

respectively. Figure 8 indicates that the fuzzy controller **DPDFC** can be fairly designed to produce better performances than the **MISO PD**-like fuzzy controller.

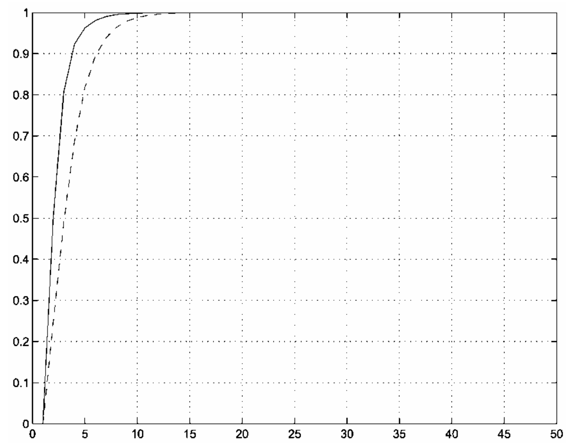

Figure 8. Performances of fuzzy controller **DPDFC** (solid line) and **MISO PD** controller (dashed line) for linear plant.

6.2 Fuzzy Controller for The Nonlinear Plant

The desired design requirements for the fuzzy control system with the nonlinear plant in Eq. 13 are assumed to be

- $|u| \leq 10$.
- no overshoot.
- the rise time is less than 5.
- steady state error is zero.

As in Figure 9, both performances of the nonlinear systems with **DPDFC** and **MISO PD**-like fuzzy controllers satisfy the performance requirements. However, the performance of the system with **DPDFC** is more preferable in the sense of short settle time.

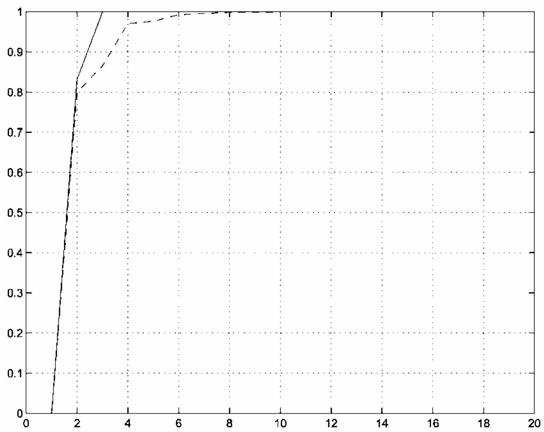

Figure 9. Performances of fuzzy controller **DPDFC** (solid line) and **MISO PD** controller (dashed line) for nonlinear plant.

6.3 Fuzzy Controller for The Delayed Plant

Assume that the design requirements for the fuzzy control system with the delayed plant in Eq. 14 are

- $|u| \leq 5$.
- no overshoot.
- the rise time is less than 10.
- steady state error is zero.

The simulation results in Figure 10 show that the required rise time performance is not satisfied when the **MISO PD**-like fuzzy controller is adopted. Moreover, the performance in the transient period is improved by the **DPDFC** fuzzy controller.

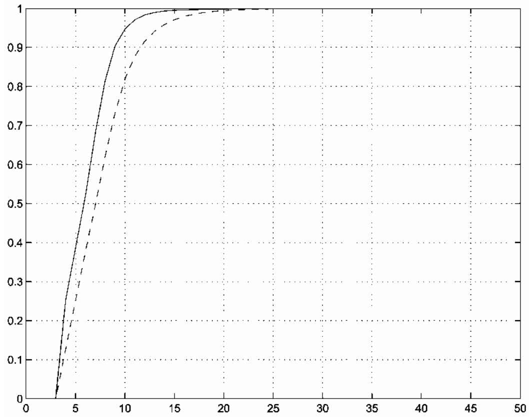

Figure 10. Performances of fuzzy controller **DPDFC** (solid line) and **MISO PD** controller (dashed line) for delayed plant.

7. Conclusion

A decomposition-based design approach is proposed to simplify the design of the fuzzy controllers in this paper. With the algebraic product as the fuzzy **and**' operator, triangular type membership functions, and the centroid defuzzification method, the simple crisp output with the denominator being equivalent to one can be obtained for the **MISO** fuzzy controller. By the proper design, the **MISO** fuzzy controller can be decomposed into several **SISO** fuzzy sub-controllers and the output of the **MISO** fuzzy controller is the product of the outputs of the **SISO** sub-controllers. That is, with this decomposition approach, the design of a **MISO** fuzzy controller can be simplified into the design of **SISO** fuzzy controllers. The decomposition-based design approach can also be applied to decompose the transformed **MISO** fuzzy controller into the product of several **SISO** sub-controllers. The decomposition-based design of the **PD**-like fuzzy controller is included in this paper. And the simulations indicate the effectiveness of the decomposed **PD**-like fuzzy controllers.

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