Design and Simulation of a PID Controller Based on Fuzzy Control

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Abstract—According to the fuzzy control theory, the paper describes the principle and feature of the fuzzy control by fuzzy control having strong robustness in allusion to the control system which has the characteristics of pure hysteresis and unprecise parameter time-variance and model. On this basis, it conducts the design and algorithm of the fuzzy controller. And it emulates the related project content by the use of Simulink software package of MATLAB in order to test and verify the availability of the project. Besides, in this paper, in order to deal with the delay lag link, deviation and deviation change rate are taken as inputs, a fuzzy inference method is utilized to optimize the traditional PID control, and the controller is designed and simulated with MATLAB. Good control performance can be acquired from the simulation result, the fuzzy PID controller improves the dynamic and static performance of the system. Combining the fuzzy control and PID control together can get their good qualities, which also has good practical significance and research value.

Keywords- Fuzzy control; PID control; Simulation modeling; Delay lag link; Fuzzy PID Controller

I. INTRODUCTION

As a kind of intelligent control method, fuzzy control is used to solve complex nonlinear system and some other system which is difficult to establish mathematical model, in addition, it is always applied to control problem of multiple input multiple output system which is unable to determine internal disturbance. Zadeh fuzzy set theory is the basis of fuzzy control[1], besides, the multivalue factors of fuzzy logic and artificial intelligence (the simplified reasoning principles) are applied in fuzzy control to simulate human thinking and reaction [2].

II. DESIGN OF FUZZY PID CONTROLLER

A. Structure of Fuzzy PID Controller

A serious of languages which come from expert's knowledge are used to describe and characterize the fuzzy system, and the control rules are determined by the practical experience and knowledge of the operators or experts. Meanwhile these rules could be adjusted in the process of actual operation constantly. The form of fuzzy control rules of fuzzy control system is shown as follow:

$$\text{If } E= A_i, \text{ and } EC= B_j, \text{ then } U= C_{ij}. \qquad (1)$$

In (1), i=1, 2, 3, ⋯⋯, m-1, m and j=1, 2, ⋯⋯, n-1, n. E represents the deviation variables and A_i is the language variables of the deviation variables; EC represents the deviation change rate and B_j is the language variables of deviation change rate variables; U represents the output control variables and C_{ij} is the language variables of output control variables refer to A_i and B_j. Finally we can get the controlled variables by the center of gravity method which is used with Max-Min Algorithm to defuzzy output U solution in order to produce accurate physical quantities.
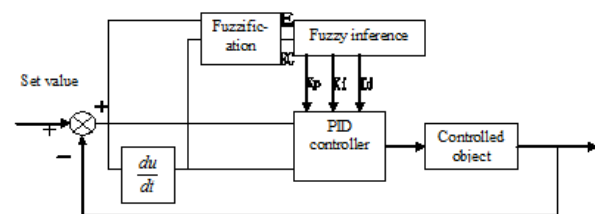

Figure 1. Fuzzy PID controller structure chart.

B. Rules of Fuzzy PID Controller

The design of the control rules is the key of the design of fuzzy controller, and it always include three parts: choose the words which are set of input/output variables, define the fuzzy subsets of the fuzzy variables and establish the control rules of fuzzy controller [3]. The core of the fuzzy controller is fuzzy inference which is based on fuzzy language rules, and the basis of fuzzy logic reasoning is fuzzy knowledge base. If the fuzzy control method could be combined with the traditional PID control method, it would make the both sides play better, and it could access a wider practicability. The structure chart of fuzzy PID controller is shown in Figure 1.

As for the concrete practice, according to the language variable deviation E and deviation change rate EC, and the application of the fuzzy set theory combined with the experience of PID parameters adjustment, a set of fuzzy control rules under different conditions of K_p, K_i, K_d is summarized. The {NB, NM, NS, ZE, PS, PM, PB} represent {negative big, negative middle, negative small, zero, positive small, positive middle, positive big} as shown in Table1, 2, and 3.

TABLE I. FUZZY CONTROL RULES FOR K_p

Kp EC \ E	NB	NM	NS	ZE	PS	PM	PB
PB	ZE	NS	NS	NM	NM	NB	NB
PM	ZE	ZE	NS	NM	NM	NM	NB
PS	PS	PS	ZE	NS	NS	NM	NM
ZE	PM	PS	PS	ZE	NS	NM	NM
NS	PM	PM	PM	PS	ZE	PS	NM
NM	PB	PB	PM	PM	PS	ZE	ZE
NB	PB	PB	PM	PM	PS	PS	ZE

TABLE II. FUZZY CONTROL RULES FOR K_i

Ki EC \ E	NB	NM	NS	ZE	PS	PM	PB
PB	ZE	ZE	PS	PM	PB	PB	PB
PM	ZE	ZE	PS	PM	PM	PB	PB
PS	NS	NS	ZE	PS	PS	PM	PM
ZE	NM	NS	NS	ZE	PS	PS	PM
NS	NM	NM	NS	NS	ZE	PS	PS
NM	NB	NB	NM	NM	NS	ZE	ZE
NB	NB	NB	NB	NM	NM	ZE	ZE

TABLE III. FUZZY CONTROL RULES FOR K_d

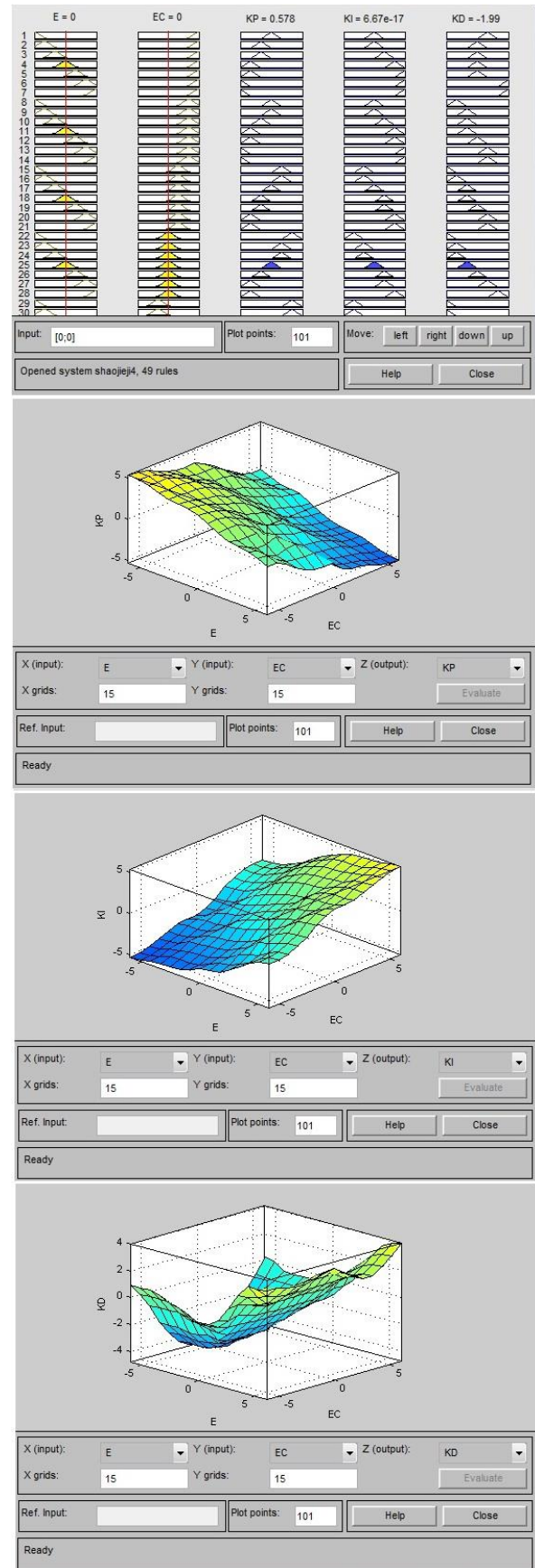| Kd EC \ E	NB	NM	NS	ZE	PS	PM	PB
PB	PS	ZE	ZE	ZE	ZE	PB	PB
PM	NM	NS	NS	NS	ZE	PS	PS
PS	NB	NM	NS	NS	ZE	PS	PS
ZE	NB	NM	NM	NS	ZE	PS	PM
NS	NB	NB	NM	NS	ZE	PS	PM
NM	NS	NS	NS	NS	ZE	ZE	PM
NB	PS	PS	ZE	ZE	ZE	PB	PB

Figure 2. Rules and output surfaces

By combining the above 3 tables together, 49 fuzzy control rules can be acquired. FIS (Fuzzy inference system) file comes from the rules in MATLAB. Open the surface view windows, rules and output surfaces for K_p, K_i, K_d in universe are shown in Figure 2. Besides, all rules can be checked and changed by rule editor, as shown in Figure 3.
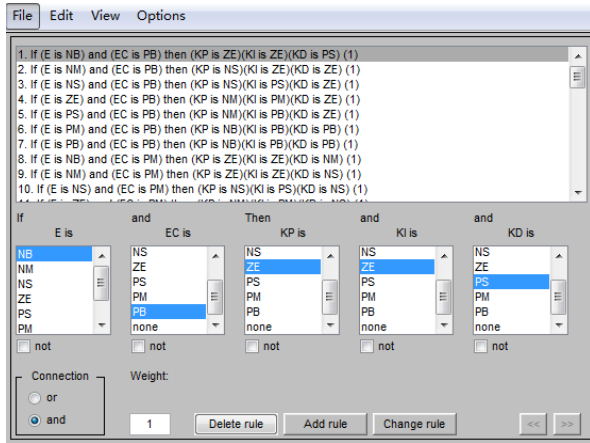

Figure 3.   Rule editor

III.   MODELING AND SIMULATION OF FUZZY PID CONTROLLER

A.   *The simulation chart of system structure*

The object simulation mathematical model of this paper is shown as follow (pure hysteresis and delay lag link transfer function):

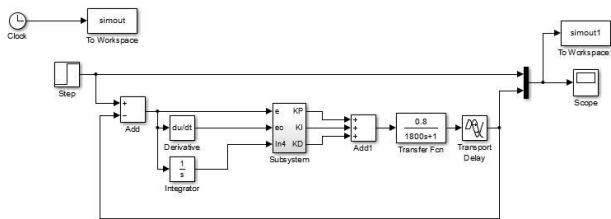$$G(s) = \frac{0.8}{1800s + 1} \quad (2)$$

Figure 4.   Simulation block diagram of fuzzy PID control system

The simulation time T is 3000 seconds, and the system of the fuzzy PID controller has two inputs and three outputs (Shown in Figure4).The subsystem is shown in Figure 5. The inputs are system deviation E and system deviation change rate EC (Gaussian membership function),

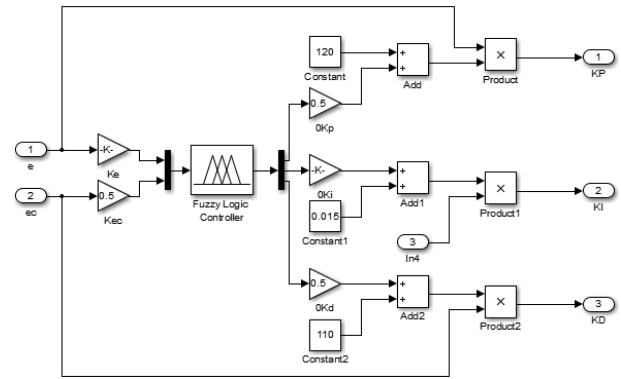and the outputs are K_p, K_i, K_d (Triangle membership function), shown in Figure 6.
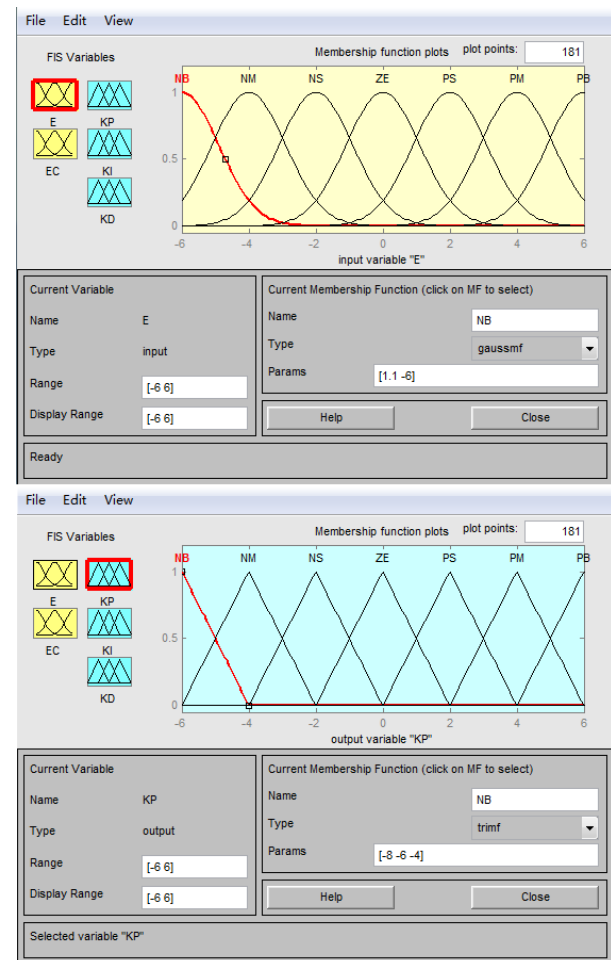

Figure 5.   Subsystem of the fuzzy PID control

Figure 6.   Membership function editor

B. Experiment result

Figure 7 is the fuzzy PID control chart, and the results show that as for the large delay lag link, the fuzzy PID control has quicker response speed, small overshoot, and its control effect is good.
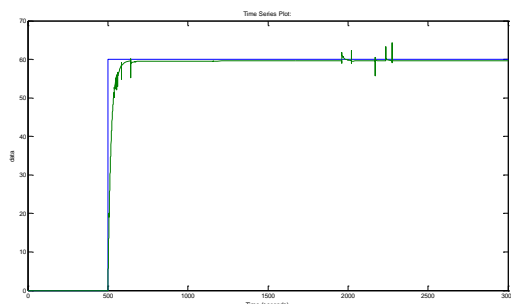

Figure 7.   Fuzzy PID control output graph

IV. CONCLUSIONS

In this paper, the design method of fuzzy controller and the realization of the fuzzy control method are analyzed based on the basic theoretical knowledge of fuzzy control, and the determination of membership function , fuzzy control rules , fuzzy PID controller design are introduced. Finally, a better experiment result has been acquired by checking the design of fuzzy controller with MATLAB simulation.

Fuzzy PID algorithm is used in this paper to control the object with pure time delay and time variation in the simulation, this algorithm realizes short response time, small overshoot, high control accuracy, and strong robustness. However, small glitch is still exist in the result, in order to get more accurate result, more date and parameter of the object or rule should be adjusted and redesigned.

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