Modeling and Simulation on Fuzzy-PID Position Controller of Electro Hydraulic Servo System

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Abstract: ***Conventional (classical) PID controller has been difficulty to compensate uncertainties, internal and external disturbances and highly nonlinearity in the control of EHS (electro hydraulic servo) position control system. In this paper a fuzzy-PID controller is proposed due superior to the conventional ones, particularly for higher-order, time-delayed, and nonlinear systems and for those systems that have only vague mathematical models which the conventional PID controllers are difficult to handle. The fuzzy-PID controller design methods are conceptually easy to understand, flexible and based on natural languagehas advantages and it can be used to directly replace the conventional ones in applications. A simulation model of position servo system is constructed in MATLAB/Simulink based on asymmetrical hydraulic cylinder. By comparing the conventional PID and fuzzy-PID controller, the simulation result shows that fuzz-PID control system has better static and dynamic performance.***

Keywords: servo position control system, electro hydraulic, Fuzzy-PID, MATLAB/Simulink

1. Introduction

Electro-hydraulic position servo system (EHPSS) is one of the most basic and commonly used hydraulic servo system, such as the location of the machine table, plate thickness of strip rolling, strip running deviation control, the steering gear control of aircraft and ships, radar and gun control system as well as the vibration test rig and so on. In other physical quantity control system, such as speed control and force control system, is also very small position control loop as a link in the large loop [2].In order to satisfactorily control such plants, it is necessary to have position servo controller for fast control actions and which enables fast and accurate control under two factors which are internal parameter variations and external disturbances. These inconveniences may lead to degradation of control performance in force, pressure or position of the system. Position performance of EHPSS can be assured when its robustness and accuracy are guaranteed. The robustness and accuracy can be ensured when nonlinear behaviors, uncertainties and disturbances in the EH system are compensated.

However, few studies have given attention to PID controllers. While PID controllers are appropriate too many control problems in many main industrial applications.

In the study by AymanA.Aly (2011) PID controller is designed and attached to electrohydraulic servo actuator system to control its angular position. The PID parameters are optimized by the Genetic Algorithm (GA). The controller is verified on the state space model of servo valve attached to a rotary actuator by SIMULINK program. The appropriate specifications of the GA for the rotary position control of an actuator system are presented. It is found that the optimal values of the feedback gains can be obtained within 10 generations, which corresponds to about 200 experiments.

Dasgupta et al, 2011 cited in AL-Assady, (2013) introduced modeling and simulation study dealt with comprehensive model of closed-loop servo valve controlled hydro motor drive system has been made using (Bond graph simulation technique). The dynamic performance of the complete system has been studied with respect to the variation of the parameters of the PI controller that drives the servo valve; they have also studied the effects of the variation of torque motor parameters on the servo valve performance using MATLAB Simulink environment.

While PID controllers are appropriate to many control problems and often perform adequately without tuning, can also perform unsatisfactorily and do not generate optimal control mechanism and do not perform well when applied to electro-hydraulic position servo system because of nonlinear character and asymmetrical cylinder.

Therefore, Fuzzy-PID controller is proposed. Fuzzy-PID controllers are slightly more complicated than the conventional ones, in the sense that they have variable control gains in their linear structures. These variable gains are nonlinear functions of the errors and changing rates of the error signals. The main contribution of these variable gains in improving the control performance is that they are self-tuned gains and can adapt to the rapid changes of the errors and the (changing) rates of the error signals caused by the time-delayed effects, nonlinearities and uncertainties of the underlying system (plant, process). This paper describes the mathematical and simulation model for the valve controlled electro hydraulic servo position system by setting Fuzzy-PID parameters.

2. Methodology

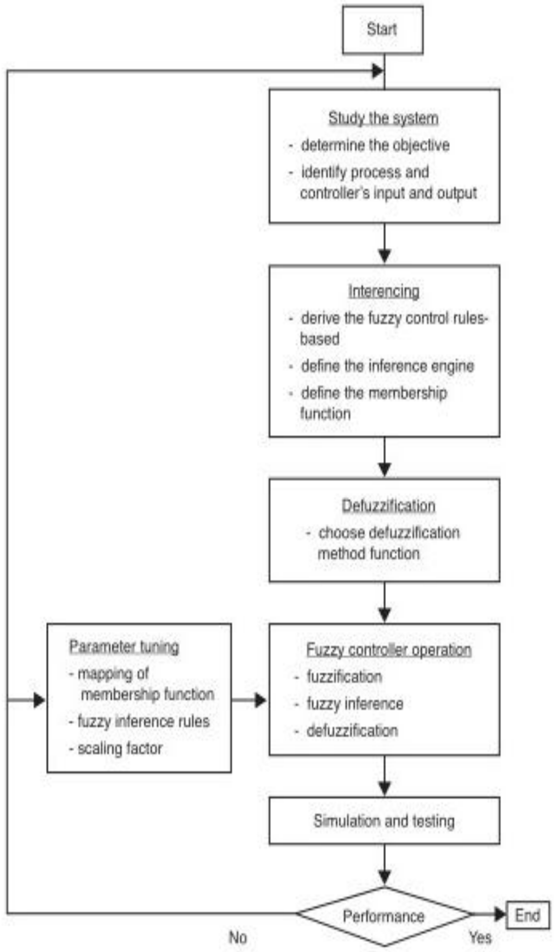


Figure 1: Fuzzy Logic Control design methodology

3. Position Servo

A schematic diagram of a complete position servo is shown in figure 2. The actuator or load position is measured by a position device (transducer), which gives an electric signal (u_f) in voltage as an output. The servo amplifier compares the command signal (u_c) in voltage with the feedback signal (u_f). Then, the resulting error signals are gained with the factor Ksa. The output current signal (i) from the amplifier will control the servo valve [1]

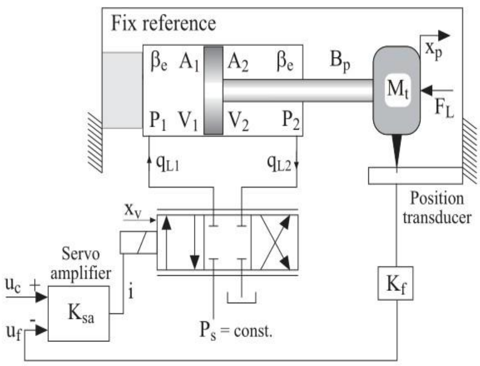


Figure 2: Position servo valve

Position transducer control ensures perfect steady state precision and dynamic tracking performance and makes the system run steadily and efficiently. The position control block is a main part in the design of hydraulic servo control system and it should have the desired response of stability and zero-overshoot. Therefore, a fuzzy-PID controller is introduced in position control loop.

4. Design of the Control System

The first step in the design strategy is to install and tune a PID controller. Second to replace the summation in PID control by a linear fuzzy controller acting like summation. The last step in the design procedure is to transfer the PID gains to the linear fuzzy controller.

4.1 PID- Proportional, Integral and Derivative

The PID controller is tuned to perform in any particular application by adjusting the gain constants for proportional, integral, and derivative. The tuning adjustments are made to PID (K_P, K_I and K_D), and the system is operated again until the desired system response is achieved

$$u(k)=k_p e(k)+k_i T\sum_{j=0}^{k} e(j)+k_d \frac{e(k)-e(k-1)}{T}$$

Where T is sampling time, $e(k)$ is error at time k .

The term $e(k)$ is

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

Where $y_d(k)$ is the desired value.

The range of e and *ce* are defined as [-10 10]. The fuzzy set of e and *ce* are all defined as $\{N,O,P\}$, which represents Negative, Zero, and Positive.

K_P - contributes to stability and medium rate responsiveness.

K_I - tracking and disturbance rejection, slow rate responsiveness may cause oscillation.

K_D- in minimizing sensitive to noise and for fast rate responsiveness.

4.2 Design of fuzzy logic controller for Servo System

Fuzzy control involves fuzzification, a fuzzy rule base generalized from experts' experience, fuzzy inference and defuzzification. The membership functions of these inputs and output fuzzy sets are given in table 1. The linguistic variable levels are assigned as negative (N), zero (Z) and positive (P). Similarly, the fuzzy set of the change error of (*ce*) is presented as {N, Z, and P}. These levels are chosen from the characteristics and specification of the EHSPS. The ranges of these inputs are from [-10 10].

Table 1: Fuzzy control rules of tuning

CE / E	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

4.3 Membership function of fuzzy-PID

The membership function is the tool that lets you display and edits all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system. The membership function editor shares some features with the fuzzy logic designer, as shown in the figure 3. Here membership functions are (Negative, Zero and Positive)

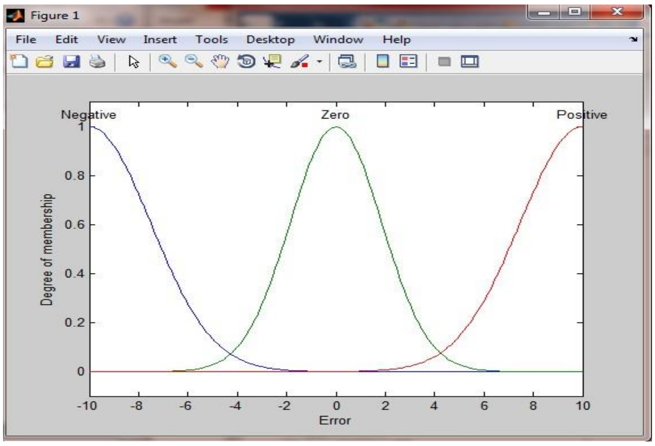


Figure 3: The Membership Function Editor

4.4 Control rule of fuzzy-PID

To edit the list of rules that defines the behavior of the system. Based on the descriptions of the input and output variables defined with the fuzzy logic designer, the rule editor allows to construct the rule statements automatically, from thegraphical user interface (GUI). Constructing rules using the graphical rule editor interface is fairly self-evident. Totally nine rules are set out from three membership functions of error, change error and FPID. Figure 4 shows two inputs and one output forms nine fuzzy rules.

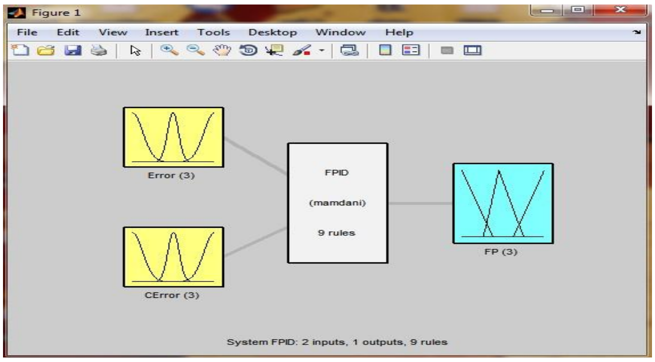


Figure 4: Fuzzy logic designer

a=readfis('FPID')
name: 'FPID'
type: 'mamdani'
and Method: 'min'
or Method: 'max'
defuzz Method: 'centroid'
impMethod: 'min'
aggMethod: 'max'
input: [1x2 struct]
output: [1x1 struct]
rule: [1x9 struct]
>>showrule(a)
ans =
1. If (E is N) and (CE is N) then (FPID is N) (1)
2. If (E is N) and (CE is Z) then (FPID is N) (1)
3. If (E is N) and (CE is P) then (FPID is Z) (1)
4. If (E is Z) and (CE is N) then (FPID is N) (1)
5. If (E is Z) and (CE is Z) then (FPID is Z) (1)
6. If (E is Z) and (CE is P) then (FPID is P) (1)
7. If (E is P) and (CE is N) then (FPID is Z) (1)
8. If (E is P) and (CE is Z) then (FPID is P) (1)
9. If (E is P) and (CE is P) then (FPID is P) (1)

5. Surface Viewer

To show the view of output depends on the two inputs (Error and Change Error) in the form of plot(figure 5).These graphical user interfaces are dynamically connected, if you make the change to the fuzzy inference system using one of them, then you see on any of the other open GUIs. For example, if the names of the membership functions in the membership function editor changed, in the rules shown in the rule editor the changes are reflected (appeared).

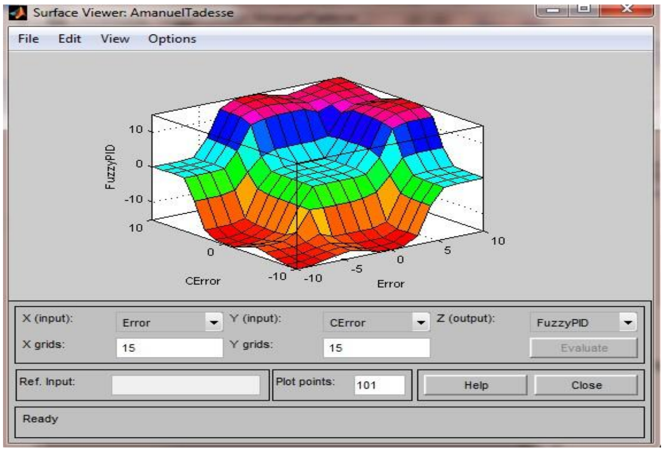


Figure 5: Surface viewer based on Error and CError

6. Computer Simulation Results

According to the controllers proposed above, the system was respectively modeled by MATLAB/Simulink model. The parameters used for simulation are given in table 2.

Table 2: Specification of hydraulic cylinder and servo valve

Sym	Description		unit
Xp	Total stroke of the piston	1.25	m
Ap	Active area of piston annulus	$10*10^{-4}$	m^2
Qr	Rated flow of valve	$5.230*10^{-4}$	m^2/sec
p	Supply pres from hydraulic pump	$10*10^6$	Pa
Vmax	Maximum velocity	0.523	m/s
F	maximum thrust	$25.8*10^3$	N
ρ	Density of oil	780	Kg/m
C_d	Discharge coefficient	0.65	No

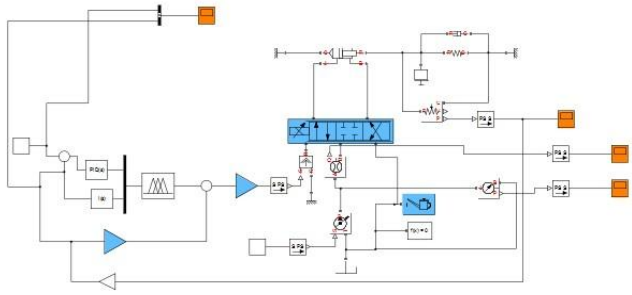
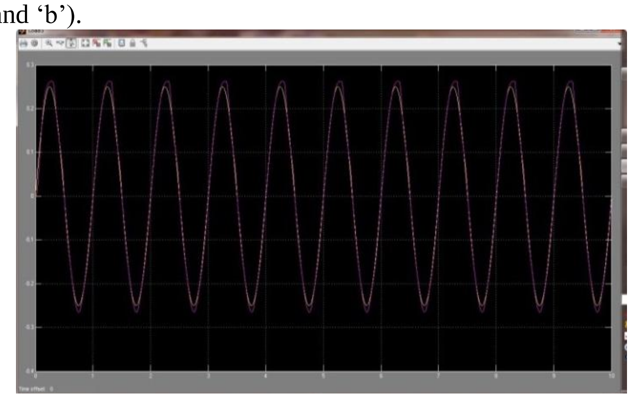


Figure 6: New proposed Fuzzy-PID controller for asymmetric cylinder of EHSPS

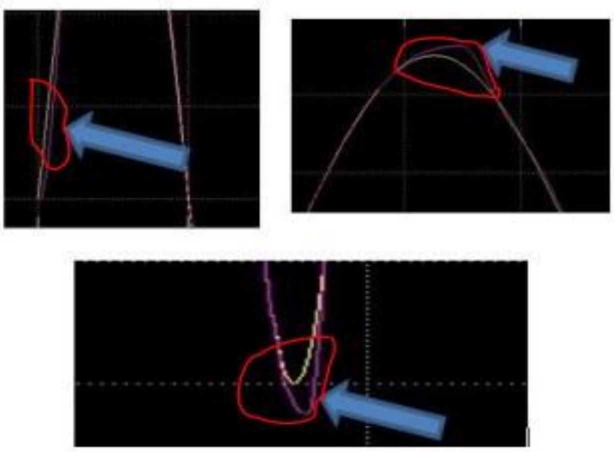
Computer simulations were executed (implemented) for the servo system to verify the availability of the proposed controller in practical implementation. The sampling frequency was selected to be 1Hz. With the same input of step signals, the outputs of systems with different controllers were plotted for comparison. The simulation results are shown in figure 7 and 8.

6.1 Response to command signal

The response of the command to output signal by classical PID controller for frequency 1Hz can be seen in figure 7('a' and 'b').



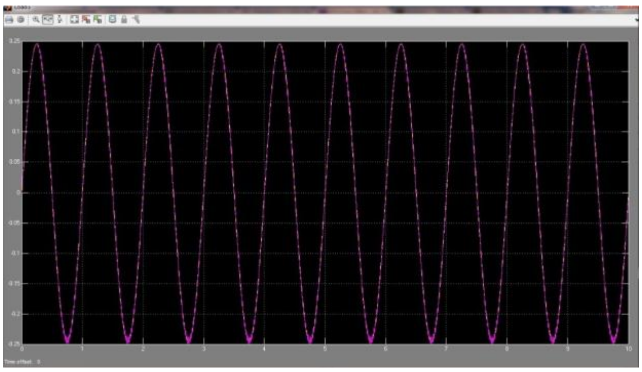
(a)



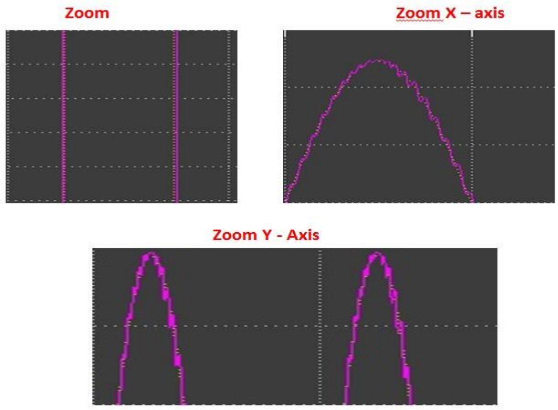
(b)

Figure 7: Input and output signal for PID control

And the figure shows phase lag difference between command and output signal has deviation (as indicated by the arrows) from normal in the PID controller. But in fuzzy PID controller the phase lag between command (input) and output signal is zero as show in figure 8 ('a' and 'b').



(a)

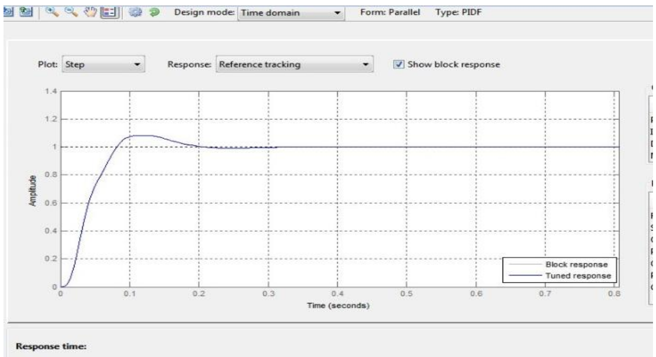


(b)

Figure 8: Input and output signal for Fuzzy-PID control

6.2 Response to performance indicators for classic PID controller

Fig. 9 ('a' and 'b') shows that performance parameters for classical PID controller. Even though the closed-loop system is stable, the rise time, setting time, peak and overshoot percent are higher (and perform very less) than Fuzzy- PID controller.



(a)

Controller parameters

	Tuned	Block
P	60.6918	60.6918
I	873.2891	873.2891
D	0.60506	0.60506
N	2834.6627	2834.6627

Performance and robustness

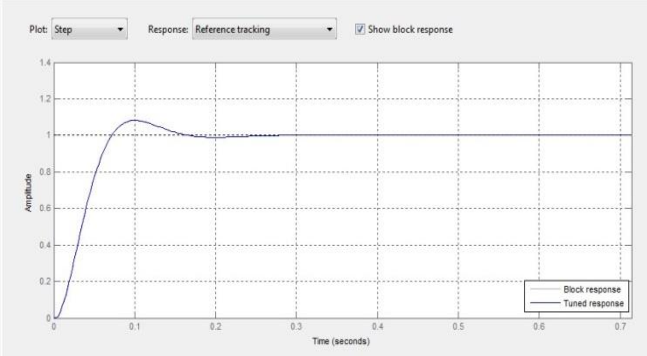
	Tuned	Block
Rise time	0.0531 seconds	0.0531 seconds
Settling time	0.181 seconds	0.181 seconds
Overshoot	8.24 %	8.24 %
Peak	1.08	1.08
Gain margin	13.2 dB @ 120 rad/s	13.2 dB @ 120 rad/s
Phase margin	60 deg @ 24.8 rad/s	60 deg @ 24.8 rad/s
Closed-loop stability	Stable	Stable

(b)

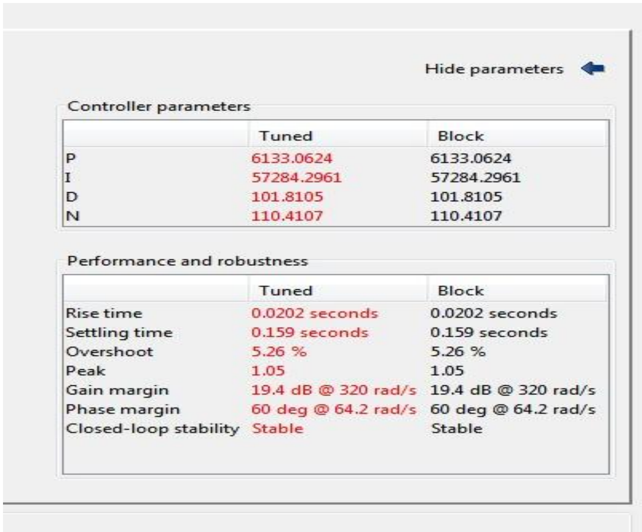
Figure 9: Conventional PID controller with Performance parameters

The response of the performance and robustness indicators after the system compensated by a Fuzzy- PID controller can be seen in figure 10 ('a' and 'b'). It shows that the rise and setting time, overshoot percentage and peak time very small.

In addition steady-state errors are very less compared to classical PID controller.



(a)



(b)

Figure 10: Fuzzy- PID controller with Performance parameters

Table 3 shows summary of performance parameters for Fuzzy-PID and classical PID controller. In PID controller the rise time, setting time, peak and overshoot percent are higher and perform very less than Fuzzy-PID controller. Additionally, comparing Fuzzy-PID control mechanism to PID family has better for electro hydraulic servo control system in itsperformance robustness

Table 3: Performance parameters of Fuzzy-PID and PID

Performance parameters						
Controllers	Rise time	Settingtime	Over shoot (%)	Peak	Gain margin (rad/s)	Phase margin (rad/s)
FPID	0.02	0.16	5.26	1.05	19.4dB@ 320	60^0@64
PID	0.05	0.18	8.24	1.08	13.2dB@ 120	60^0@24.8

7. Conclusion

Based on the selected model for position control of asymmetric double acting cylinder, the simulation in MATLAB/Simulink is done and the data is analyzed for the classical or conventional PID controller, the rise time 0.05s, setting time 0.16s, overshoot of the system is 8.24% and peak time 1.08s and for the Fuzzy-PID controller, the rise time 0.02s, setting time 0.16s, overshoot time less than 5.26% and peak time 1.05s. So the performance of Fuzzy-PID controller is better than conventional PID system

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