International Journal of Advanced Computer Technology (IJACT)

ISSN:2319-7900

Speed Control of UGV using Electro Hydraulic Servo System and Fuzzy and PID controller

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Abstract

In this paper the electro-hydraulic servo system for speed controls of fixed displacement hydraulic motor using proportional valve and fuzzy and PID controller is simulated and a compression between the fuzzy and PID approach studied. While classical PID controllers are sensitive to variations in the system parameters, Fuzzy controllers do not need precise information about the system variables in order to be effective. However, PID controllers are better able to control and minimize the steady state error of the system. The results show fuzzy and PID control strategy which meets preferably the controlled demands, good real-time performance, fast response, small over shoot and output of the system also tracked the input given successfully. All the simulations and results have been performed in Matlab software.

Introduction

The University of Siegen in Germany working in the research and development of an autonomous unmanned ground vehicle (DORIS) project as in figure 1. As it is still a work-in-progress, a problem has been identified in the designing and implement a speed control system for DORIS_1 and DORIS_2 where a mechanical transmission and Hydrostatic transmission used. An electro hydraulic servo system developed for DORIS_3 [1].

Figure 1 DORIS_3

Electro-hydraulic actuator converts electrical signal to hydraulic power. It is used for delivering high actuation forces and high power. It is widely used since it has simple construction, low cost small size-to-power ratios and be able to apply very large torques and forces with fast response time. Since electro-hydraulic actuator can provide precise Movement, high power capability, fast response characteristics and good positioning capability, its applications are important in the field of robotics, suspension systems and industrial process [2].
The traditional control is adopting usually PID control, due to simple algorithms, good robustness, high reliability, which is widely applied to industrial processes of control. But accurate mathematical model for PID control is needed, it is difficult for PID control to meet the requirements of non linear and time variation, there is the great influence owing to the temperature, the PID controller introduced control strategy to improve the steady state , which is a simple effective way but most of the system used is based on the normal linear PID controller that has the advantages of simple structure and easy to implement, however, with the hydraulic characteristics of the complex cross-coupled electro-hydraulic servo systems, the conventional PID control is increasingly difficult to obtain satisfactory results, the greatest difficulty lies in the controller parameter tuning is difficult [3]. Fuzzy control have the advantages of experience knowledge, skill, direct inference, independent of accurate math model, simple structure , the conventional fuzzy controller of the two-dimensional is error and error variation regard as independent variable. Fuzzy logic theory poses a viable alternative for design of controllers for such systems. This is so because fuzzy logic based controllers or FLCs do not depend on the mathematical models of the system. On the other hand they rely more on the linguistic descriptions of the cause effect mapping of the plant. Consequently, any modeling uncertainties or nonlinearities become inconsequential. This strategy not only shields the controller Performance from any inexactness of the mathematical model of the system, but also bolsters it against any unanticipated change of the operating conditions. So the methodology of the FLC provides an algorithm which converts the linguistic control strategy based on expert knowledge into an automatic control strategy, and hence it appears particularly useful in cases where processes are too complex for analysis by con-

ventional control techniques, or where the available sources of information are inexact or Uncertain [4]. The structure of electro-hydraulic proportional valve system briefly discussed, transfer function is established and fuzzy and PID controller is designed and simulated by MATLAB/SIMULINK. Fig.2 show the structure of electro-hydraulic directional proportional valve system, which is composed of detecting element, control module, proportional reversing valve, Motors, Pumps and so on. The control variable, which is transported by sensor, is controlled by controlled unit of computer; the voltage signal of controlled unit is convened to digital proportion of electronics-hydraulics valve, which can control accurately Hydraulic Motor in both sides.

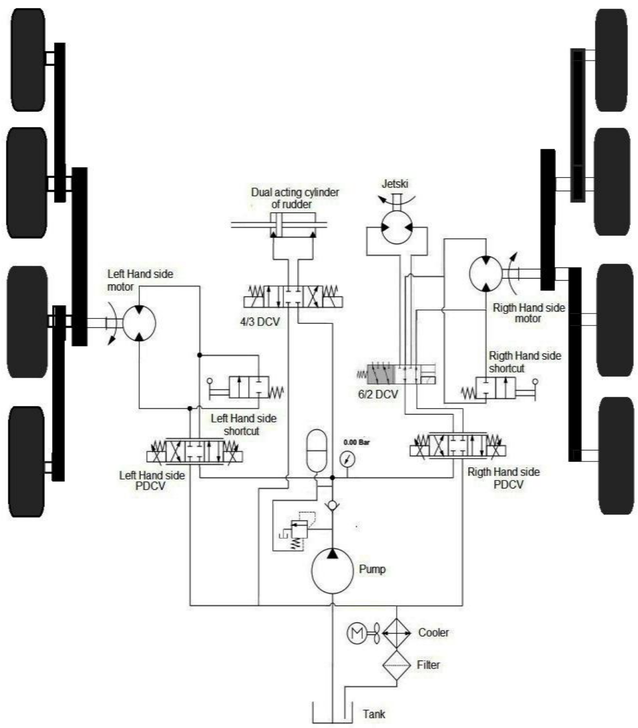

Figure 2 electro-hydraulic proportional valve system

Modeling of Elector-Hydraulic Actuator System

The nonlinear dynamic model of (EHSS) shown in Fig. 3, which consists of a hydraulic motor controlled with proportional valve, and by assuming that the pressure is constant and Fluid inertia is neglected the equations of flow through the PV are derived from the application of flow continuity through the orifices of proportional valve and defined by the following terms [5].

$$Q_1 = C_d\, A\sqrt{2/\rho(P_s - P_1)} \quad (1)$$

$$Q_1 = C_d\, A\sqrt{2/\rho(P_s - P_2)} \quad (2)$$

$$Q_1 = C_d\, A\sqrt{2/\rho(P_2 - P_0)} \quad (3)$$

$$Q_1 = C_d\, A\sqrt{2/\rho(P_1 - P_0)} \quad (4)$$

$$Q_L = C_d\,|A|\frac{x_v}{|x_v|}\sqrt{2/\rho(P_s - \frac{x_v}{|x_v|}P_L)} \quad (5)$$

Where QL is the load flow through the motor and PL is the loud pressure. Linearized flow equation, which describes dynamic behaviour of the proportional valve and around an operating point, is as follows:-

$$\Delta Q_L = K_q\,\Delta X_v - K_c\,\Delta P_L \quad (6)$$

$$\Delta Q_L = C_d\;\pi\, d\; spool\;\sqrt{2/\rho(P_s - P_L)} \quad (7)$$

$$K_c = \frac{C_d\;\pi\; d\; spool\;\; Xv}{\sqrt{2/\rho(P_s - P_L)}} \quad (8)$$

$$Q_L = \frac{Q_1 + Q_2}{2} \quad (9)$$

$$P_L = P_1 + P_2 \quad (10)$$

The continuity equation for each Motor is the same

$$Q_1 - C_{tm}(P_1 - P_2) - Q_{em}P_1 = D_m\;\omega_m + \frac{V_1}{\beta}\frac{dt_1}{d_t} \quad (11)$$

$$C_{tm}(P_1 - P_2) - Q_{em}P_1 - Q_{mo} = -D_m\;\omega_m + \frac{V_2}{\beta}\frac{dt_2}{d_t} \quad (12)$$

From equation 9,10,11,12

$$Q_L = D_m\;\omega_m + C_{tm}\,P_L + \frac{V_t}{2\beta}\,P_L\;s \quad (13)$$

Where

$$V_t = (V_1 + V_2)$$

The torque equation for motor is given by:-

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$$T_g = D_m(P_1 - P_2) =$$
$$J_m\ \omega_m\ s + B_m\ \omega_m\ + T_{fm}\ +\ T_m\ + T_s \quad (14)$$

From equation 6, 13, 14 over all TF of the system are given by:-

$$\omega_m = \frac{\frac{K_q}{D_m}X_v - \frac{TK_{ce}}{D_{m^2}}\left(1 + \frac{V_t}{2\beta K_{cB}}\right)}{\frac{J_m V_t}{2\beta D_{m^2}}s^2 + \left(\frac{J_m K_{ce}}{D_{m^2}} + \frac{B_m V_t}{2\beta D_{m^2}}\right)s + \frac{BK_{ce}}{D_{m^2}} + 1} \quad (15)$$

The transfer function for non load speed is given by:-

$$\frac{\omega_m}{X_v} = \frac{\frac{K_q}{D_m}}{\left(\frac{s^2}{\omega_h{}^2} + \frac{2\delta_h}{\omega_h}s + 1\right)} \quad (16)$$

Where ω_m is the Motor is angular speed and X_v is the proportional valve spool travelling distance and national frequency and damping ratio are given by:-

$$\omega_h = \sqrt{\frac{2\beta D_{m^2}}{J_m V_t}}$$

$$\frac{B_m}{2D_m}\sqrt{\frac{V_t}{\beta J_m}} + \delta_h = \frac{K_{ce}}{D_m}\sqrt{\frac{\beta J_m}{V_t}}$$

The directional proportional valve TF =

$$\frac{U(s)}{X_v(s)} = \frac{1}{\left(\frac{1}{\omega_v}s + 1\right)}$$

The valve –motor system TF =

$$\frac{\omega_m(s)}{U(s)} = \frac{1}{\left(\frac{1}{\omega_v}s + 1\right)}\ \frac{\frac{K_q}{D_m}}{\left(\frac{s^2}{\omega_h{}^2} + \frac{2\delta_h}{\omega_h}s + 1\right)}$$

Where U(s) the input voltage and $\omega_m(s)$ is the Motor angular speed in Laplace transformation.

Table 1 source of parameters of (EHSS) for velocity control

Sym	Description	Value	Unit	Source of Information
Kv	Proportional valve gain	$53 * 10^{-5}$	m/V	Manufacturer data
xv	Spool stroke	$4.5 * 10^{-3}$	m	Manufacturer data
Kq	Valve flow gain	1.7	m2/sec.	Calculated
Kce	Valve pressure gain	$0.6 * 10^{-9}$	m3/sec. Pa	Calculated
dspool	Spool diameter	$12 * 10^{-3}$	m	Manufacturer, data
ω_v	DPV angular speed	25	Rad/sec	Manufacturer, data
Tfm	Motor friction torque	2.92	N.m	Calculated experimentally
Jm	Inertia of motor and load	45	Kg.m2	Calculated
Vt	Total fluid volume in pipes	$76 * 10^{-4}$	m3	Calculated
Bm	Viscous damping coefficient of motor	0.0051	N.m.sec./rad	Calculated Experimentally [6]
Dm	motor displacement	$15.7 * 10^{-5}$	m3 /rad	Manufacturer, data
β	Effective bulk modulus	$108 * 10^{8}$	N/m2	Manufacturer, data
ρ	Density of the Hydraulic oil	857	Kg/m3	Manufacturer data
Cd	Discharge coefficient	0.65	---	Constant
Dp	Pump displacement	$56 * 10^{-6}$	m3/ rad	Manufacturer data
ω_m	Motor rotational speed	470	rpm	Manufacturer data

ISSN:2319-7900

System Description

As shown in the figure down the system consist of fixed displacement pump drives two fixed hydraulic motors through two directional proportional valves one for left side and one for right side .the directional proportional valve and the motors and pumps explained in [3] .Hydraulic motors connected to tachometers to measure the wheel speed according to the input speed from the input potentiometer which is connected to two Pedal one is Gas Pedal and one Brake Pedal .the signal from Tachometer and from the Pedals processes in the Microcontroller and voltage send to the Proportional Valve To correct the spool position.

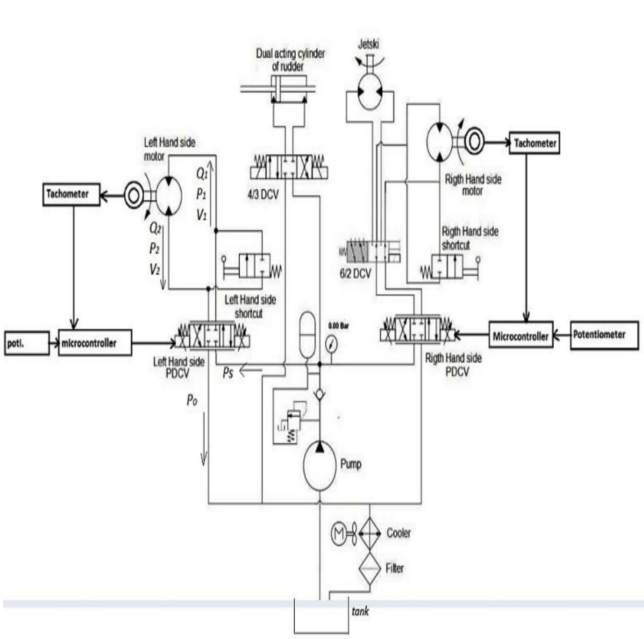

Figure3 electro-hydraulic proportional valve system

PID Controller

PID (proportional integral derivative) control is one of the earlier control strategies. Since it has simple control structure which was understood by plant operators and which they found relatively easy to tune, it still have wide range of applications in industrial control. By tuning the value of Kp, Ki and Kd of the PID controller, the performance of the system such as rise time, overshoot, settling time and steady state error can be improved. Though the output of the system with this controller will never reach zero steady state error, Kp or proportional controller is used to assure the output reach the reference input. Ki or integral controller is given to the system in order to obtain zero or very small steady state error. Derivative controller or Kd will improve the speed performance of the system. Sometimes derivative action may not be required since the proportional and integral action already produce good output response. The synthesis of PID can be described by

$$u(t) = K_p\, e(t) + K_i \int_0^t e(t)\, d(t) + K_D \frac{d_e(t)}{dt}$$

Where e (t) is the error, u (t) the controller output, and KP, KI, and KD are the proportional, Integral and derivative gains.

There is a wealth of literature on PID tuning for scalar systems. Good reviews of tuning PID methods are given. Among these methods are the well known Ziegler and Nichols and Cohen and Coon [7]. Many researchers have attempted to use advanced control techniques such as optimal control to restrict the structure of these con-trollers to PID type.

The tuning value of Kp, Ki and Kd are determined by using the self Tuning tool in Matlab /simulink.

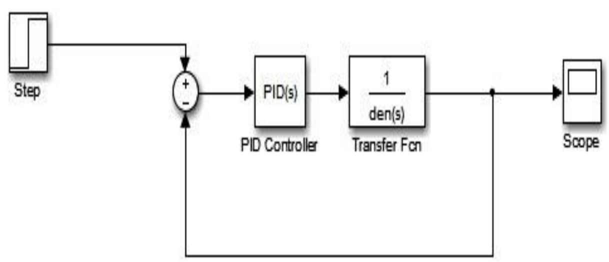

Figure4 PID controller in Matlab/Simulink

From equation 16 with the parameters from table 1 the transfer function for the system is given by:-

$$\frac{\omega_m(s)}{U(s)} = \frac{355}{\left(0.0015\, S^3 + 0.92\, S^2 + 124.37s + 1\right)}$$

Fuzzy Logic Controller Design

Fuzzy logic control is a control algorithm based on a linguistic control strategy, which is derived from expert knowledge into an automatic control strategy. Fuzzy logic control doesn't need any difficult mathematical calculation like the others control system. While the others control sys-

ISSN:2319-7900

tem use difficult mathematical calculation to provide a model of the controlled plant, it only uses simple mathematical calculation to simulate the expert knowledge. Although it doesn't need any difficult mathematical calculation, but it can give good performance in a control system . Thus, it can be one of the best available answers today for a broad class of challenging controls problems. A fuzzy logic control usually consists of the following as in figure 5 [8]:

1. Fuzzification: This process converts or transforms the measured inputs called crisp values, into the fuzzy linguistic values used by the fuzzy reasoning mechanism.
2. Knowledge Base: A collection of the expert control rules (knowledge) needed to achieve the control goal.
3. Fuzzy interface engine: This process will perform fuzzy logic operations and result the control action according to the fuzzy inputs.
4. Defuzzification unit: This process converts the result of fuzzy reasoning mechanism into the required crisp value

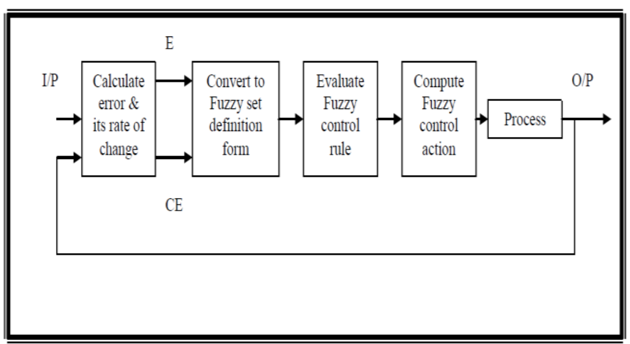

Figure 5 fuzzy logic controller

For a Fuzzy logic control design, the control parameters and set of terms that describe each linguistic variable must be determined when designing a FLC. Obviously, the position in the EHS is the parameter to be controlled in the system. A two-dimension structure will be used to product fast calculations. The two input linguistic variables are the error of the angular velocity "e" and the error change of the angular velocity "Δe" The output is the voltage signal to proportional valve. First, the two input variables must be defined in terms of linguistics. The error in angular velocity is expressed by a number in the interval from -6 to 6. There are five linguistic terms of the error in angular velocity: negative big (NB), negative (N), zero (Z), positive (P), and positive big (PB). Similarly, the fuzzy set of the error change of the angular velocity is presented as {NB, N, Z, P, PB} over the interval from -6 to 6. Finally, the fuzzy set of the output signal is presented as {NB, N, Z, P, PB} over the interval from -3 to 3. The knowledge base for a fuzzy controller consists of a rule base and membership functions. It is reasonable to present these linguistic terms by triangular-shape membership functions, as shown in figure 8. An expert's experience and knowledge method is used to build a rule base [9]. The rule base consists of a set of linguistic IF-THEN rules containing two antecedences and one consequence as expressed in the following form:-

Ri, j,k :IF e = Ai AND □e = Bj THEN u = Ck

Where $1 \le i \le 5$, $1 \le j \le 5$, and $1 \le k \le 5$. The total number of IF-THEN rules is 25 and is represented in matrix form, called a fuzzy rule matrix, as shown in table 2.
The decision-making output can be obtained using a maxim fuzzy inference where the crisp output is calculated by the center of gravity (COG) method. A set of fuzzy rules is shown in the table 2. The fuzzy rules in the center of the table are related to the steady state behaviour of the process. When both the angular velocity error (e) and the change of angular velocity error (Δe) are negative, the angular velocity is high the set point and is moving further away. In response the control action should be negative such that it will reduce the angular velocity error. While the "Δe" is positive and the "e" is negative, the piston is moving toward, and then the control action should be low enough to slow down the approach to the set point. The designed fuzzy set of the fuzzy controller accounts for this asymmetry as well [10],[11],[12]. With two inputs and one output the input-output mapping is a surface. Fig.9 is a mesh plot of a relationship between e and Δe on the input side, and controller output side. Fuzzy sets and fuzzy rules of a FLC in Fig. 6, 7, 8 and table II are developed by Matlab/simulink, as shown in Fig. 10.

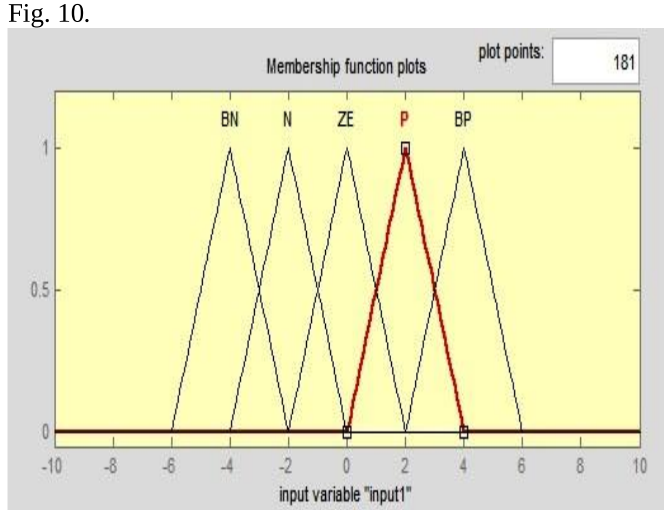

Figure 6 fuzzy member function of the error

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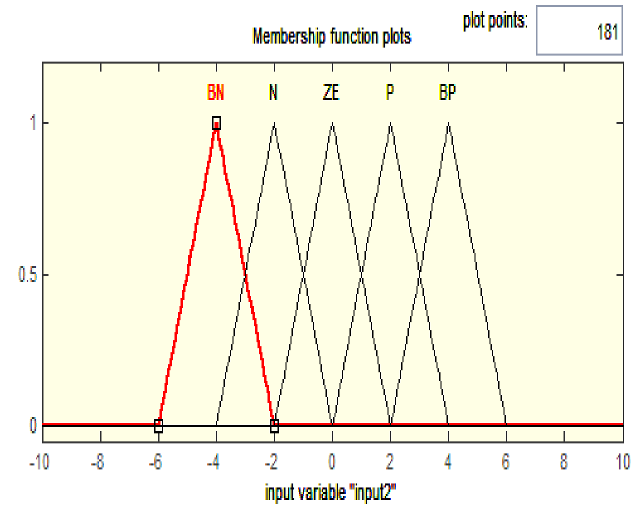

Figure 7 fuzzy member function of the changing error

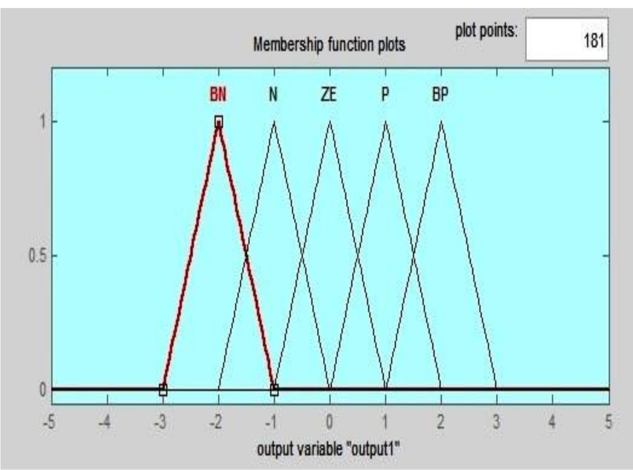

Figure 8 fuzzy member function of the fuzzy output

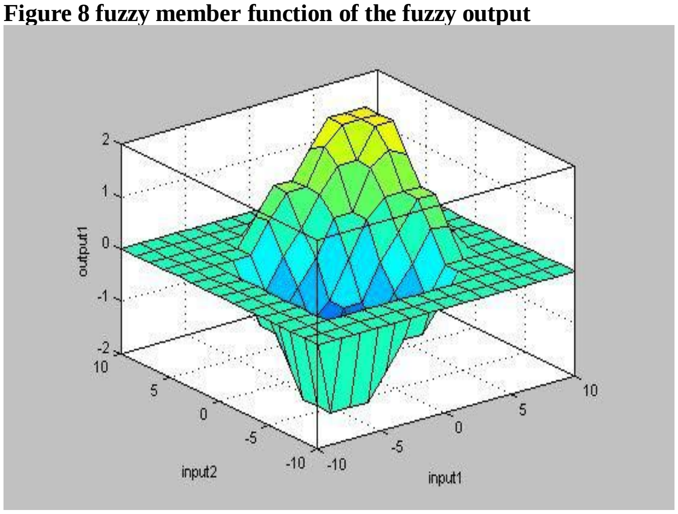

Figure 9 surface of the fuzzy member functions

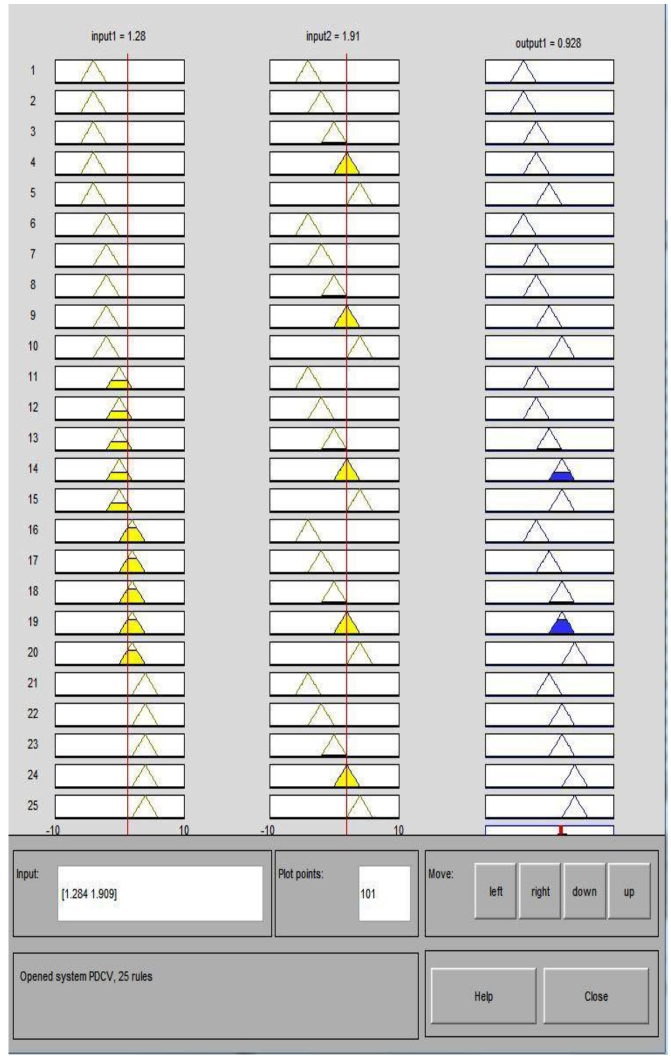

Figure 10 fuzzy member function of the fuzzy output

Table 2 fuzzy rule sets of (EHSS) for velocity control

e Δe	NB	N	Z	P	PB
NB	NB	NB	N	N	Z
N	NB	N	N	Z	P
Z	N	N	Z	P	P
P	N	Z	P	P	PB
PB	Z	P	P	PB	PB

Simulation results

The simulation block diagram of position closed loop step response of fuzzy control is showed in figure 10 for electro-hydraulic system.

ISSN:2319-7900

Precision, figure 12 and figure 14 are simulation results of curve tracking control of conventional PID and fuzzy with given the same amplitude, frequency is 50 Hz sine signal.
We can see that as a given frequency of sine signals for Fuzzy controller the steady state error is big and the control algorithm are slightly worse, but in comparison, PID control effectively reduces the time lag, response speed and accuracy are better than fuzzy control. The response to the step input shown in figure 11 and figure 13 .Figure 11 shows the best response to step input with kp=55.8 ,kd= 28.4 and ki =24.3 and figure 13 shows the response to step input for the fuzzy logic controller with more rising time with time delay .Figure 15 shows the compression between the Fuzzy and PID controller for our system.

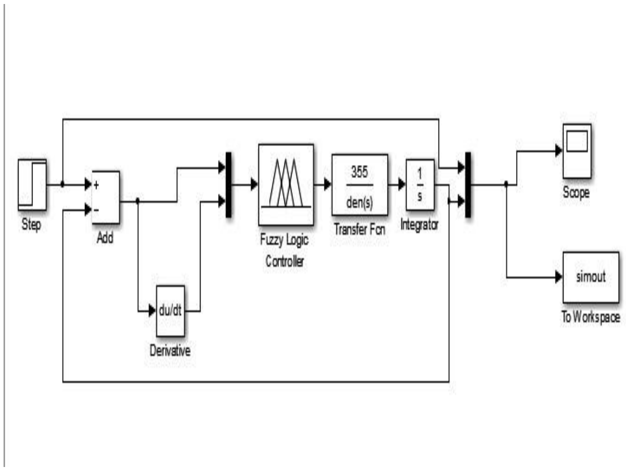

Figure 10 simulation block diagram of EHSS

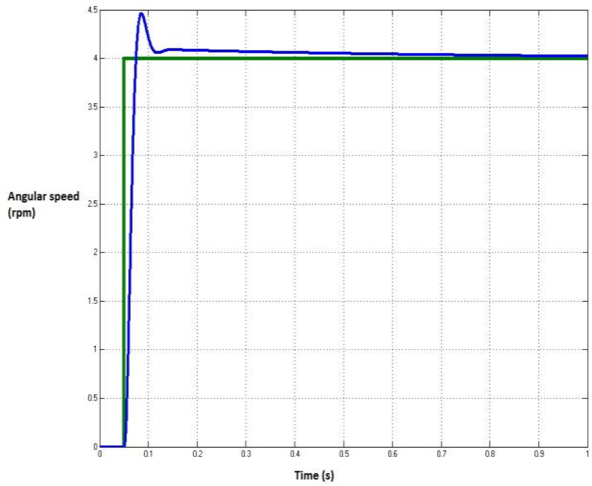

Figure 11 Response of PID controller with step input

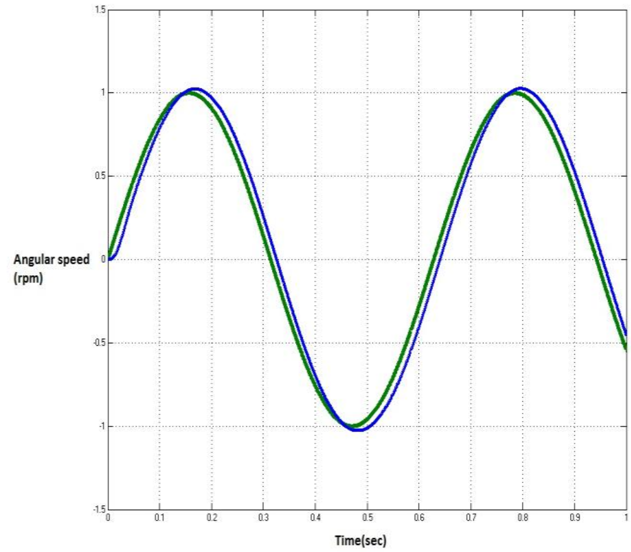

Figure 12 Response of PID controller with sine input

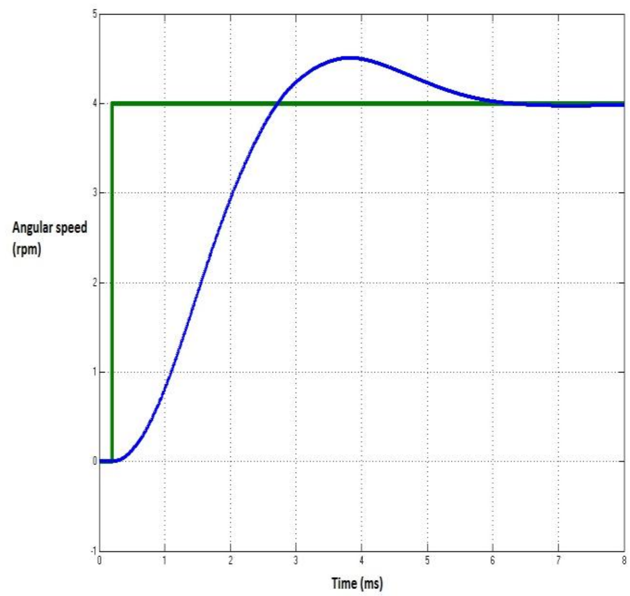

Figure 13 Response of Fuzzy controller with step input

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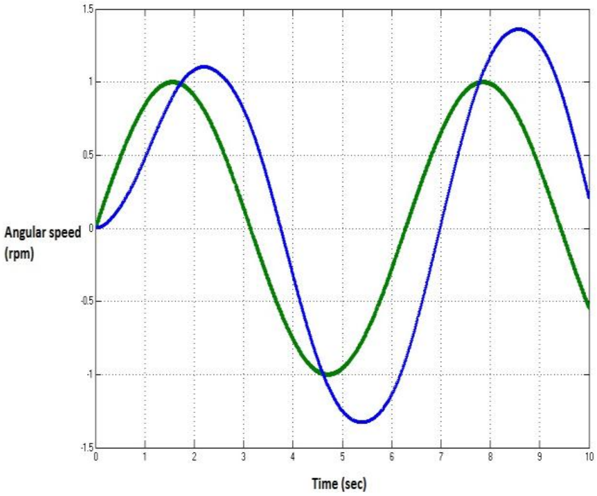

Figure 14 Response of PID controller with sine input

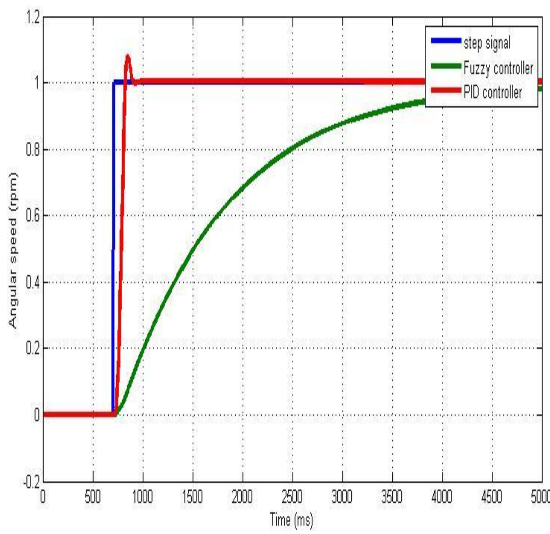

Figure 15 Response of PID and Fuzzy controller with step input

Conclusion

In this paper, the fuzzy and PID controller of electro hydraulic directional proportional valve system is Modeled and simulated , on the basis of that the dynamic open-loop simulation step is done by MA TLAB/SIMULINK. The result show that the system have the high response speed, the short transition time, obsolete overshoot, which can meet the requirement of real time control and have the strong robustness of variation of load.

Acknowledgments

The authors are thankful to IJACT Journal for the support to develop this document.

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