



SYSTEM IDENTIFICATION AND CONTROL OF A HYDRAULIC ACTUATOR

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ABSTRACT

This paper basically is the modeling and control of an electro-hydraulic actuator which is an important system. It is applied in systems like ships, airplanes, manufacturing systems, process systems, robots, flight and sailing simulators and others. The system was modeled using ARX modeling technique using the system identification toolbox in MATLAB. A fuzzy logic controller was then developed for the electro-hydraulic actuator using Simulink/MATLAB. The Sugeno type fuzzy logic was used and a conventional Proportional Integral Derivative (PID) controller was also developed for comparison. The fuzzy controller outperformed the PID controller, it yields zero steady state error, 2.8% overshoot and settling time of 0.36 seconds. The system response was better with the PID controller which has a 0.0021 or 0.21% steady state error, 4.8% overshoot and settling time of 0.32 seconds. The response parameters of the system without controller are 0.0010 or 0.1% steady state error, an undershoot of 1.4% and 0.54 seconds settling time. Therefore, the controller had improved the system in speed of operation as well as accuracy.

Keywords: electro-hydraulic actuator, sugeno type fuzzy logic, PID controller, controller.

INTRODUCTION

Hydraulic actuators are devices that are used to generate forces with the help of fluids for driving loads. Electro-hydraulic actuators produce actuating signals that are function or dependent on the amount applied of electrical signals which are usually voltages (Poley, 2005), (Alleyne and Liu, 2000). The importance of these systems needs not to be over emphasized. They have so many applications that touch human lives in different ways that include: in aircrafts and flight simulators, ships, manufacturing devices and systems, industrial processes, in laboratory test equipment, they are also used in milling machines; for paper production, steel and aluminum industries, used in robots and moulding equipments (Poley, 2005), (Alleyne and Liu, 2000), (Sen and Mukhopadhyay, 2014). Motors can perform some or all the mentioned functions, but electro-hydraulic actuators are better alternatives when applications require higher bandwidths (beyond 20Hz), power (above 15kW) and very high precisions. Others include generation of huge forces with high speed of operation, also poses higher gains and resonating frequencies, better performance, cooling system and dynamics characteristics decoupling (Poley, 2005), (Alleyne and Liu, 2000), (Sen and Mukhopadhyay, 2014), (Habibi and Goldenberg, 1999).

System identification or modeling deals with the techniques for producing an acceptable mathematical model of a system for the purpose of analysis. The models produced are utilized for important applications which comprise of prediction, control, interpretation, design of systems to mention a few. System identification or modeling is important in many fields; some of which include electrical, mechanical, civil, aeronautical, naval, aerospace and chemical engineering as well physics and so

on (Forssell and Lindskog, 1997), (Adnan, 2012), (Hassan, 2014). Precision requirement in the modeling varies and is a function or dependent on the area of application. There are different tools/approaches used for system identification which include mathematical (differential equations, algebra and matrices), statistical (probability and estimation theories) and artificial intelligent (neural networks and ANFIS) (Forssell and Lindskog, 1997), (Adnan, 2012), (Hassan, 2014), (Goodwin and Payne, 1997). Figure-1 is a simple illustration of how system identification is done. The plant and its estimate are excited with the same input u and their outputs y_p and y_m are compared and the difference is the error e . A modeling or system identification technique is then employed to reduce the by adjusting the parameters in the developed plant model until it was able to mimic the original plant to some extent (Forssell and Lindskog, 1997), (Adnan, 2012), (Hassan, 2014), (Goodwin and Payne, 1997).

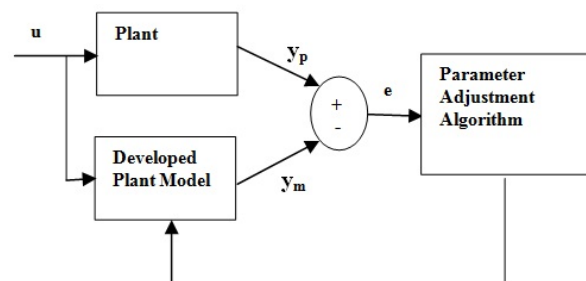


Figure-1. Plant model development illustration.

Controllers are usually subsystems or components added to existing system usually called plant,



in order to improve its dynamics such as operational speed, stability, disturbance rejection and many more (Mandal, 2006). Figure-2 is a block diagram which portrays the basic closed loop control system. It becomes an open loop system if the feedback path is not present.

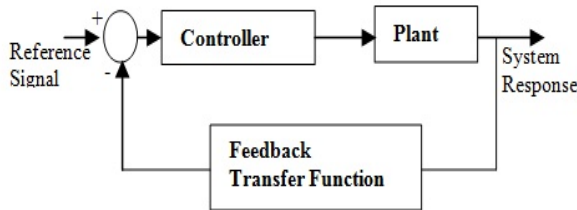


Figure-2. Control scheme development illustration.

In that regards Poley (Poley, 2005) in his work developed a digital controller for an electro-hydraulic using the digital signal processor (DSP) C2000 series which was new at that time and has a distinguishing feature that it has assisted structures for programming. Hence, the advantage of using digital systems was harnessed with relative ease, and it entailed improved performance and flexibility. In another contribution in control of the electro-hydraulic systems Bonchis (Bonchis, 2001) proposed a position controller using variable structure algorithm for such systems with the aim of eradicating errors caused by frictional disturbances which are nonlinear in nature. In the research the load on the system and the disturbances were regarded as external perturbations, and results showed that the control scheme was effective. Zhong and He in 2008 (Zhong and He, 2008) proposed solution to arrest the time varying disturbances and nonlinearities associated with the electro-hydraulic systems by utilizing a combination of fuzzy logic and neural networks techniques. They also employed a method known as the hierarchical fuzzy error with the aim of improving the weight and convergence rate of the neuro-fuzzy system. Results showed that the developed system was able to improve on accuracy and robustness of the system (Zhong and He, 2008). In the work of Troung and Ahn (Troung and Ahn, 2009) a sandwich of grey predictor and fuzzy logic was utilized to improve on the overshoot and settling time response of a hydraulic actuator system. The proposed method also showed ability to reduce disturbances both internal and external. In another development by Guan and Pan (Guan and Pan, 2008) an adaptive sliding mode control scheme was developed for the electro-hydraulic systems to curb the effects of both linear and nonlinear unknown parameter variations in such systems. Results show that the proposed method was effective with good system stability.

In this work the ARX modeling technique was harnessed for identification of an electro-hydraulic system. After which a control system was designed for the system using the Sugeno type fuzzy logic. The Sugeno type was explored due to its numerous and desirable advantages for control applications and also it is newer and not yet used for many control systems as compared to the Mamdani

counterpart. Improvement of the actuator system dynamics is of paramount importance due to its sensitive applications. In this research using the basic Sugeno type fuzzy logic is just like the beginning. Therefore more robust and organized form the controller would be investigated further.

THE HYDRAULIC ACTUATOR MODEL

The electro-hydraulic actuator data recordings at 45ms sampling time for the inputs and outputs sets were used to obtain the system model. The readings are 1000 in number and the input/output parameters are voltage (v) and distance (cm). The device was a standard industrial bidirectional cylinder type actuator with piston diameter of 25mm, piston rod diameter of 16mm, stroke of 400mm and piston area ratio of 1.6:1. It is an inductive type built-in position transducer with an electronically controlled valve for the pressurized fluid flow. The valve is a proportional and directional type with input voltage of $\pm 10V$ dc and current of 4-20mA, and also had 2300psi pressure regulation capability (Adnan, 2012), (Hassan, 2014). The ARX modeling technique was used to obtain the transfer function as given by equation (1).

$$\frac{0.2169 z^2}{z^3 - 0.9914 z^2 - 0.1820 z + 0.1720} \quad (1)$$

THE CONTROLLER

A proportional integral (PI) controller was developed for the electro-hydraulic actuator system using the Sugeno type fuzzy logic. Another was developed using the conventional PID technique for comparison purpose. The MATLAB/SIMULINK platform was used for the simulations. The two inputs which are the error (E) and the integral of the error (iE) signals and for both inputs three trapezoidal membership functions were used. The membership functions are given names as: negative (N), zero (Ze) and positive (P) and are defined as shown in equations (2) – (9). The controller single output was the control signal (CI) and was made of five linear membership functions named: negative large (NI), negative small (Ns), zero (Ze), positive small (Ps) and positive large (PI). The definitions of the membership functions for output are given by equations (10) – (15).

$$E = \{N, Ze, P\} \quad (2)$$

$$N = \{(e(a_n, b_n, c_n, d_n), \mu_N(e)) | e \in E\} \quad (3)$$

$$Ze = \{(e(a_{ze}, b_{ze}, c_{ze}, d_{ze}), \mu_{Ze}(e)) | e \in E\} \quad (4)$$

$$P = \{(e(a_p, b_p, c_p, d_p), \mu_P(e)) | e \in E\} \quad (5)$$

$$iE = \{N, Ze, P\} \quad (6)$$

$$N = \{(ie(a_n, b_n, c_n, d_n), \mu_N(ie)) | ie \in iE\} \quad (7)$$



$$Ze = \{(ie(a_{ze}, b_{ze}, c_{ze}, d_{ze}), \mu_{Ze}(ie)) | ie \in iE\} \quad (8)$$

$$P = \{(ie(a_p, b_p, c_p, d_p), \mu_P(ie)) | ie \in iE\} \quad (9)$$

$$Cl = \{Nl, Ns, Ze, Ps, Pl\} \quad (10)$$

$$Nl = \{(cl(a_{nl}, b_{nl}, c_{nl}), \mu_{Nl}(cl)) | cl \in Cl\} \quad (11)$$

$$Ns = \{(cl(a_{ns}, b_{ns}, c_{ns}), \mu_{Ns}(cl)) | cl \in Cl\} \quad (12)$$

$$Ze = \{(cl(a_{ze}, b_{ze}, c_{ze}), \mu_{Ze}(cl)) | cl \in Cl\} \quad (13)$$

$$Ps = \{(cl(a_{ps}, b_{ps}, c_{ps}), \mu_{Ps}(cl)) | cl \in Cl\} \quad (14)$$

$$Pl = \{(cl(a_{pl}, b_{pl}, c_{pl}), \mu_{Pl}(cl)) | cl \in Cl\} \quad (15)$$

Since the Sugeno type fuzzy logic was used the output of the controller is given in the form as shown in equation (16), where a_{xx} , b_{xx} and c_{xx} are constants and the output is not completely linear as portrayed by the equation (Mandal, 2006).

$$f(E, iE) = a_{xx} + b_{xx}E + c_{xx}iE \quad (16)$$

RESULTS AND DISCUSSION

Table-1 shows the various fittings of the different ARX models obtained using the system identification toolbox in MATLAB. Sixty percent of the data was used as working data and the remaining forty percent for validation. The accuracy shows the percentage fit of each of the models. Therefore the best was chosen such that it has high percentage fit with appropriate order such that difficulties will not be encountered during the controller design. Therefore, the ARX model 311 was chosen which has three poles one zero and one delay. It is also stable and has 96.21% fit. The transfer function was as shown by equation (1).

Figures-3, 4 and 5 are the unit step responses of the system without controller, with PID controller and with fuzzy controller respectively. Figure-6 was the combine responses of the system. It can be deduced from the responses that the system with the fuzzy controller produces the best response with zero steady state error, 2.8% overshoot and settling time of 0.36 seconds. The system response was better with the PID controller which has a 0.0021 or 0.21% steady state error, 4.8% overshoot and settling time of 0.32 seconds. The response parameters of the system without controller comprise of 0.0010 or 0.1% steady state error, an undershoot of 1.4% and 0.54 seconds settling time. Table-2 shows the summary of the results discussed.

Table-1. The ARX modeling results.

Model	Accuracy (%)
ARX 243	97.00
ARX 433	96.96
ARX 463	96.77
ARX 321	96.21
ARX 331	95.97
ARX 233	96.75
ARX 411	96.33
ARX 311	96.21

Table-2. Results of the control schemes.

Parameter Scheme	Overshoot (%)	Settling Time (s)	Steady State Error
Fuzzy	2.8	0.36	0.000
PID	4.8	0.32	0.0021
No Controller	1.4 (Undershoot)	0.54	0.0010

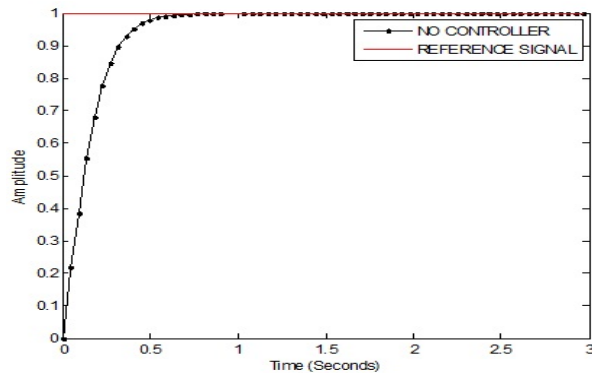


Figure-3. Unit step response of the system without controller.

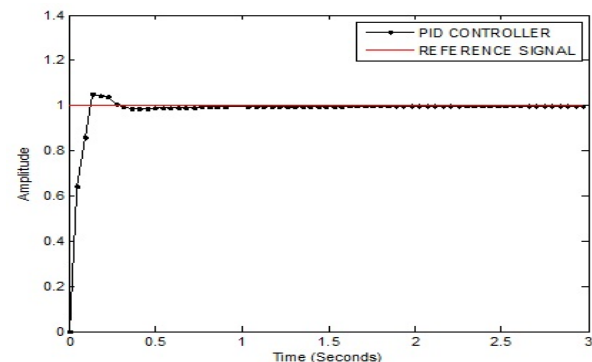


Figure-4. Unit step response of the system with PID controller.

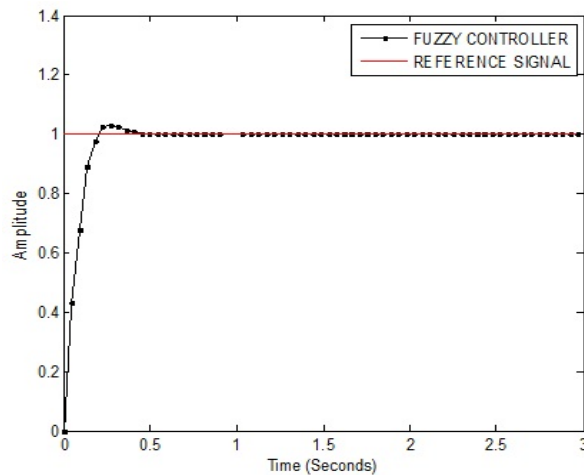


Figure-5. Unit step response of the system with fuzzy controller.

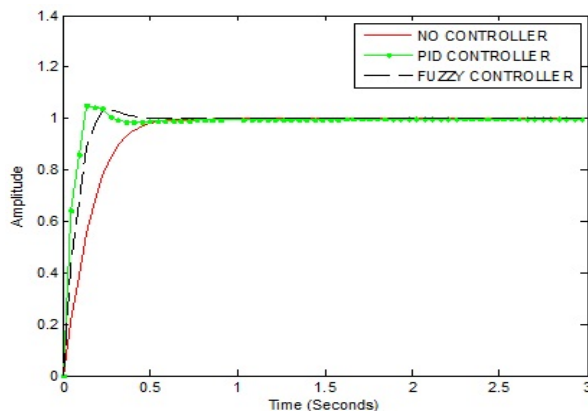


Figure-6. A combination of the unit step responses of the system.

CONCLUSIONS

In this work, effort was made to model and control an electro-hydraulic actuator system which has applications in systems like ships, airplanes, manufacturing systems, process systems, robots, flight and sailing simulators and so on. The hydraulic actuator system was modeled using ARX modeling technique using system identification toolbox in MATLAB, and a fuzzy controller was developed using Simulink also in MATLAB software. The Sugeno type fuzzy logic was used and a conventional Proportional Integral Derivative (PID) controller in order to compare the results. The fuzzy controller showed better performance than the PID controller. It made the system steady state error zero, with a 2.8% overshoot and settling of 0.36 seconds. The system response was better with the conventional PID controller with a 0.0021 or 0.21% steady state error, 4.8% overshoot and settling time of 0.32 seconds, while without controller the system had 0.0010 or 0.1% steady state error, an undershoot of 1.4% and 0.54 seconds settling time. Therefore, the controller had improved the system in

terms of speed of operation as well as accuracy, and the controller is in its simplest configuration. Therefore, there is the tendency of having better results using other variants of the Sugeno type fuzzy logic for controlling such systems.

REFERENCES

- [1] Adnan R. 2012. ARX modeling and controller design. Workshop on System Identifications for Sensing and Process (SYSID 2012).
- [2] Alleyne A. and Liu R. 2000. A simplified approach to force control for electro-hydraulic systems. *Control Engineering Practice*, Vol. 8, pp.1347-1356.
- [3] Bonchis A. Corke P. I. Rye D. C. and Ha Q. P. 2001. Variable structure methods in hydraulic servo systems control. *Automatica*, Vol. 37, pp.589-595.
- [4] Forssell U. and Lindskog P. 1997. Combining semi-physical and neural network modeling: an example of its usefulness. 11th IFAC Symposium on System Identification (SYSID'97), Fukuoka, Japan.
- [5] Goodwin G. C. and Payne R. L. 1997. *Dynamic System Identification: Experiment Design and Data Analysis*. New York: USA: Academic Press.
- [6] Guan C. and Pan S. 2008. Adaptive sliding mode control of the electro-hydraulic system with unknown nonlinear parameters. *Control Engineering Practice*, Vol. 16, pp.1275--1284.
- [7] Habibi S. and Goldenberg A. 1999. Design of a new high performance electrohydraulic actuator, IEEE/ASME International Conference on Advanced Intelligent Mechatronics Proceedings, pp.227--232.
- [8] Hassan M. K. 2014. *EEE4404 Intelligent Control Lecture Notes*. Serdang, Malaysia: University Putra Malaysia.
- [9] Mandal A. K. 2006. *Introduction to Control Engineering: Modeling, Analysis and Design*. New Delhi, India: New Age International (P) Ltd., Publishers.
- [10] Poley R. 2005. *DSP control of electro-hydraulic servo actuators*. Texas Instruments Application Report, pp.1-26.
- [11] Sen S. and Mukhopadhyay S. 2014. *Hydraulic Actuation Systems*. Industrial Automation and Control (Web Course), Indian Institute of Technology Kharagpur, Kharagpur 721302, West Bengal, India. http://nptel.iitk.ac.in/courses/Elec_Engg/IIT%20Khar



agpur/Industrial%20Automation%20and%20Control.
htm retrieved 12/02/2014.

- [12] Truong D. Q. and Ahn K. K. 2009. Force control for hydraulic load simulator using self-tuning grey predictor fuzzy PID. *Mechatronics*, 19, pp.233-246.
- [13] Zhong W. and He X. 2008. Fuzzy neural network control of electro-hydraulic position servo system [J]. *Electric Machines and Control*, Vol. 4, p.024.