DOI: 10.54254/2753-8818/39/20240619

Research on DSP-based data model identification and triple-loop PID control of electro-hydraulic actuators

Bao Li[1,3,4], Jian Sun[1,2], Yang Li[1,2], Senyuan Li[1, 2]

[1]Lanzhou Wanli Aviation Electromechanical Co., Ltd, Lanzhou, Gansu, China
[2]Northwestern Polytechnical University, Xi'an, Shaanxi, China
[3]State Key Laboratory of Comprehensive Automation for Process Industries, Northeastern University, Shenyang, Liaoning, China

[4]libao0128@126.com

Abstract. This paper focuses on the electro-hydraulic actuator of a certain type of aircraft, detailing the DSP-based hardware structure and principles. The study utilizes data acquisition and data model identification to establish a second-order model for the electro-hydraulic actuator. Verification sets and mean squared error (MSE) calculations, with an MSE value of 0.0110, indicate a reasonable identification model. Subsequently, a controller design structure is proposed based on the identified model. Finally, simulations validate the identified model and the triple-loop PID control. Experimental results show that the system's sine response output amplification factor is 0.9242.

Keywords: DSP, Electro-hydraulic actuator, Model identification, Triple-loop control, PID

1. Introduction

In recent years, the application of electro-hydraulic actuators in UAVs, manned aircraft, missiles, and rockets has led to increased demands for reliability, sensitivity, and control accuracy [1]. Therefore, establishing an accurate mathematical model of the controlled object and designing superior control methods is crucial.

A mathematical model of the controlled object expresses the functional relationship between input quantities and corresponding output quantities under control. There are two main types of modeling: mechanism modeling and data modeling. Mechanism modeling derives mathematical models from physical principles using related equilibrium equations, while data modeling obtains mathematical models through mathematical operations on experimental input-output data, which is preferred for complex processes [2-4].

Additionally, as an essential component of flight control systems, precise control of electro-hydraulic actuators requires superior control methods [5]. With the rapid advancement of control technology, various control methods for electro-hydraulic actuators have emerged [6-9]. However, due to the simplicity and maturity of the PID control algorithm, it is widely used in control systems for electro-hydraulic actuators [10].

This study identifies the data model of an electro-hydraulic actuator of a certain aircraft type, establishes the actuator model, presents the control system structure, and conducts simulation and application of triple-loop PID control, analyzing and explaining the simulation results.

2. Structure and Principle of the Electro-Hydraulic Actuator System

The electro-hydraulic actuator, an indispensable part of servo systems, comprises a DSP-based control logic unit, drive logic unit, servo motor, reduction mechanism, and feedback position sensor, as shown in Figure 1.

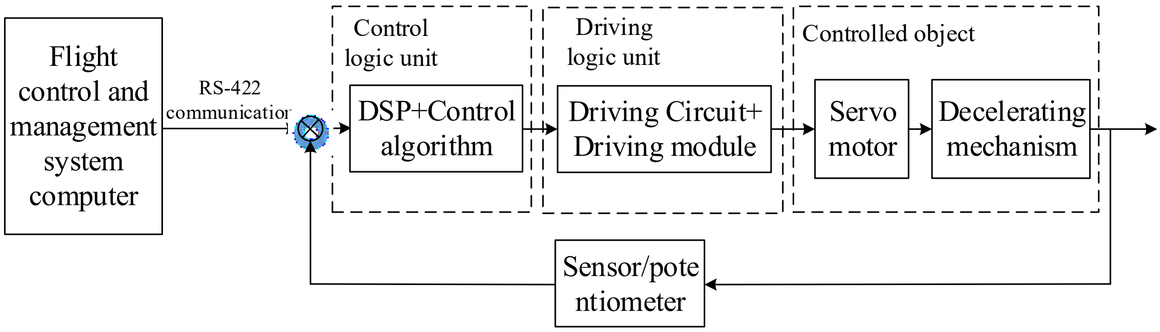

Figure 1. Hardware Structure and Principle Diagram of the Electro-Hydraulic Actuator System

The flight control and management system computer sends commands to the control logic unit via RS-422 communication. After data processing, the control logic unit drives the servo motor through the drive logic unit. The sensor/potentiometer collects real-time information about the actuator to achieve closed-loop control. The control logic unit consists of a DSP and corresponding control algorithms. This study uses the JDSPF28335 digital signal processor from China Electronics Technology Group Corporation No. 58 Research Institute, known for its high performance and low power consumption, which handles high-precision complex data, ensuring actuator control implementation.

3. Model Identification of the Electro-Hydraulic Actuator

Data modeling for the electro-hydraulic actuator involves system identification methods and classical identification methods. Classical methods do not account for random errors in experimental data, requiring only simple mathematical processing of a small amount of data to obtain non-parametric models. System identification methods, however, eliminate random errors from experimental data and do not require prior knowledge of the controlled object, dealing with large volumes of data.

This study employs the system identification method, using sine signals as excitation signals for model identification.

3.1. Data Acquisition

To improve modeling accuracy, extensive data collection is required with sampling times. This study uses a sine position command signal as shown in Figure 2 as the excitation input, and data is collected using the program in Figure 3, resulting in the position command output shown in Figure 4.

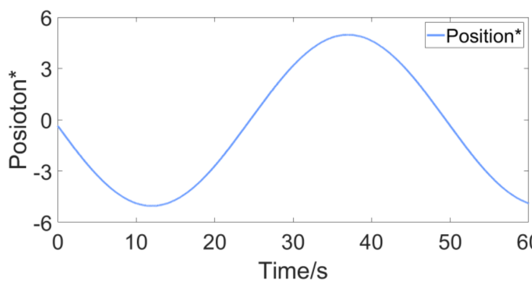

Figure 2. Excitation Input for Data Acquisition of the Electro-Hydraulic Actuator

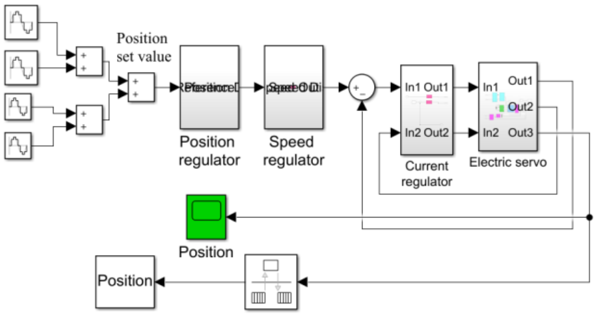

Figure 3. Data Acquisition Program for the Electro-Hydraulic Actuator

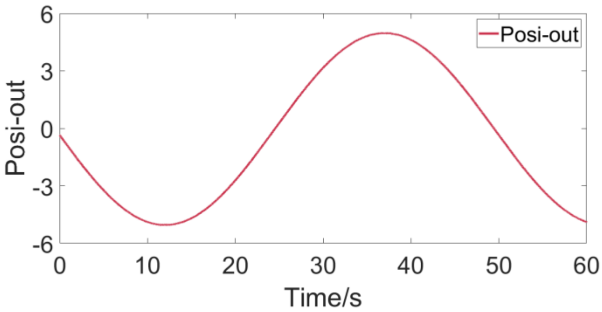

Figure 4. Output of Data Acquisition for the Electro-Hydraulic Actuator

3.2. Model Identification and Validation

Using the collected experimental data, the first 4000 sets are used as the training set, and the last 2000 sets as the validation set. The System Identification module is used for identification, as shown in Figure 5, with 2 poles and 0 zeros selected.

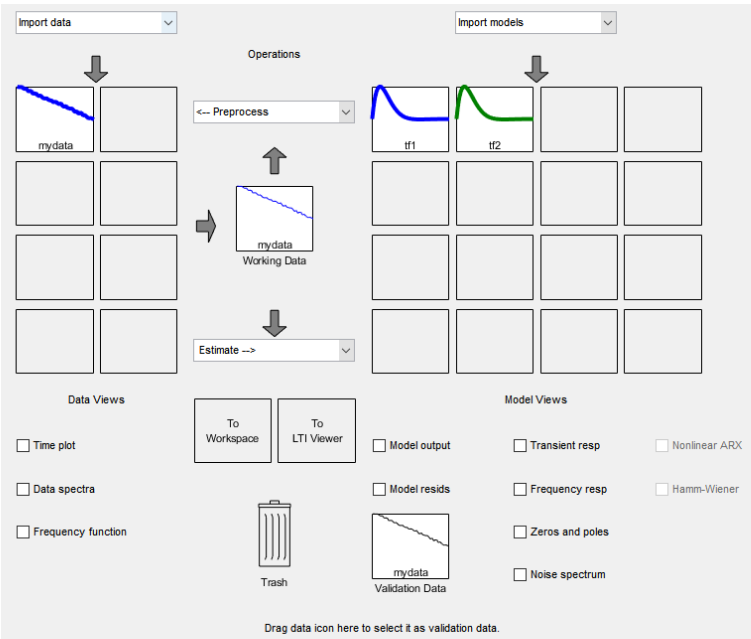

Figure 5. Model Identification of the Electro-Hydraulic Actuator

The system data model obtained is:

DOI: 10.54254/2753-8818/39/20240619

$$G(s)=\frac{\text{Posi-out}(s)}{\text{Postion*}(s)}=\frac{Y(s)}{U(s)} \\ =\frac{6.527\times10^{4}}{s^{2}+415.3s+6.526\times10^{4}} \tag{1}$$

Using the last 2000 sets of collected data for validation, the results are shown in Figure 6, with the error results in Figure 7.

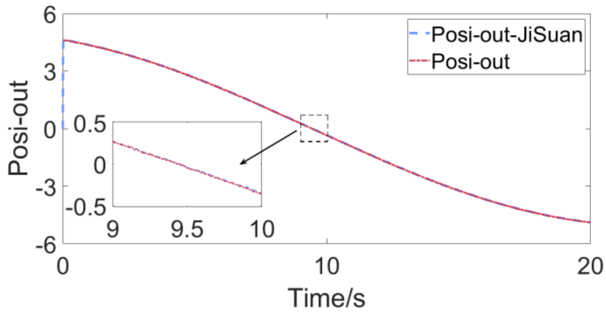

Figure 6. Model Identification Output Verification for the Electro-Hydraulic Actuator

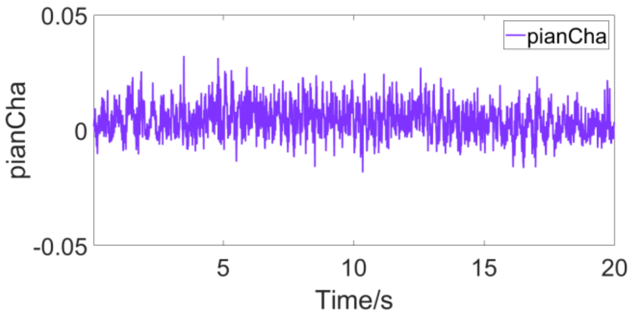

Figure 7. Output Error of the Electro-Hydraulic Actuator

The mean squared error (MSE) is calculated using Equation (2) [11]:

$$\text{MSE}=\frac{1}{L}\sum_{k=1}^{L}\left[\text{Posi-out-JiSuan}-\text{Posi-out}\right]^{2} \tag{2}$$

The result is a small MSE value, indicating a reasonable identification model.

4. Controller Design for the Electro-Hydraulic Actuator

The control structure of the electro-hydraulic actuator is shown in Figure 8. The identified model from Equation (1) serves as the system actuator model. The triple-loop control for position, speed, and current adopts the error PID control of Equation (3):

$$u(t)=K_P\left[e(t)+\frac{1}{T_I}\int_0^t e(t)dt+T_D\frac{de(t)}{dt}\right] \\ =K_Pe(t)+K_I\int_0^t e(t)dt+K_D\frac{de(t)}{dt} \tag{3}$$

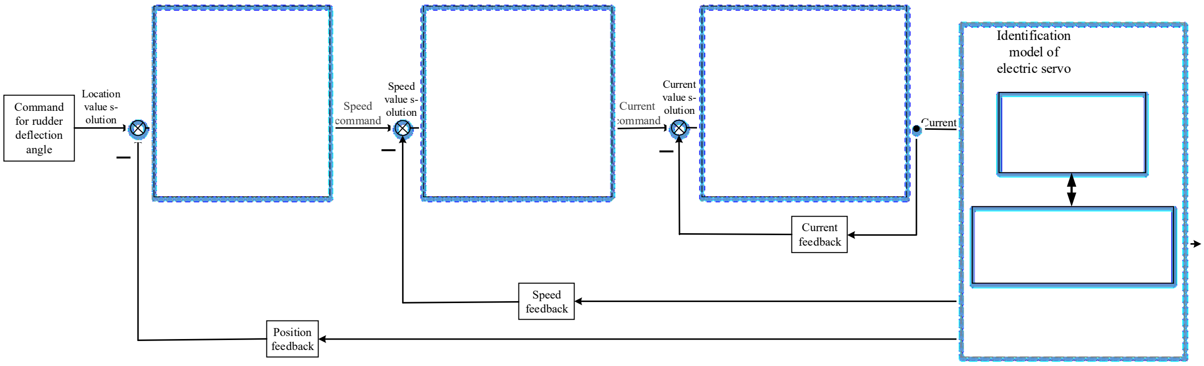

Figure 8. Triple-Loop PID Control Structure of the Electro-Hydraulic Actuator

Where $K_I = \frac{K_P}{T_I}$, $K_D = K_P T_D$, T_I is proportional term, T_D is differential time constant,and $r(t)$ is the specified input, $y(t)$ is the feedback value, $e(t)$ is the system deviation signal which is the controller input, $u(t)$ is the controller output.

5. Simulation and Application of Triple-Loop PID Control for the Electro-Hydraulic Actuator

To verify the control indicators of the identified model, a simulation model of the actuator system is built in Matlab/Simulink, as shown in Figure 9. For clarity, the position, speed, current loops, the actuator model, and feedback structure are encapsulated. The PID parameters for the position, speed, and current loops are tuned using the self-built Function module in Simulink.

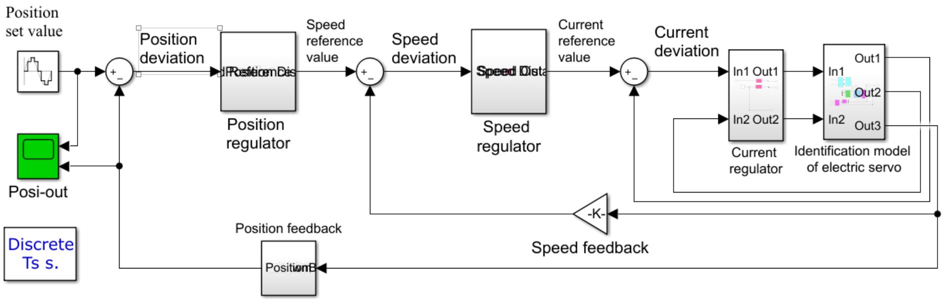

Figure 9. Simulation Program for Triple-Loop PID Control of the Electro-Hydraulic Actuator

Using a sine signal with an amplitude of 6 and frequency of 12 Hz as the input, the response curve is plotted as shown in Figure 10.

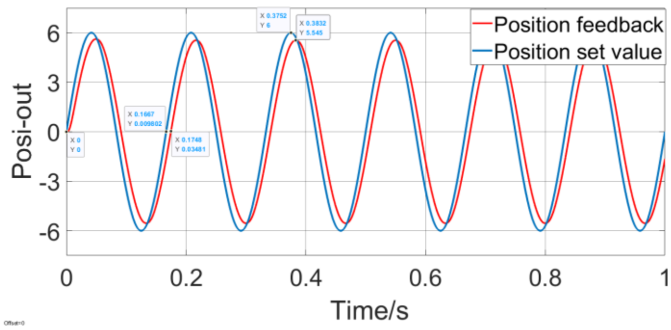

Figure 10. Response Curve for Triple-Loop PID Control of the Electro-Hydraulic Actuator

From Figure 10, the system's sine excitation response amplitude is 5.545, with a phase shift of 0.0081 s, resulting in an output amplification factor of 0.9242.

6. Conclusion

This study establishes a second-order data model for the electro-hydraulic actuator through data acquisition and model identification, validates the model using a validation set and MSE calculation. Based on the identified model, a triple-loop PID control structure is proposed. The Matlab/Simulink simulations validate the model and triple-loop PID control. The experimental results indicate the reasonableness of the identified model and designed controller.

This method is suitable for stable control systems, but achieving rapid tracking and control accuracy to meet practical control requirements remains challenging. Future research on electro-hydraulic actuators will consider integrating intelligent control methods.

References

[1] Guo, Y. G., Zhao, H. L., & Zhu, B. (2020). Design of high reliable steering gear controller based on DSP. Electric Drive, 50(7), 74-78.
[2] Chen, H. M., Zhuang, H. Y., Ma, S. H., & Shi, X. T. (2014). Model identification of electromechanical actuator based on tests. Aeronautical Computing Technique, 44(04), 6-9.
[3] Tian, Z., Li, Y. Y., Han, S., Bu, C. G., & Liu, T. (2016). Study of identification for nonlinear system of electronic actuator. Computer Measurement & Control, 24(05), 110-112+116.
[4] Jia, J. T., Cui, Y. L., & Feng, Z. L. (2019). Model identification for electromechanical actuator based on dSPACE. Automobile Applied Technology, (10), 97-99.
[5] Zhou, W., Yang, S. X., & Zhao, L. Y. (2017). Retuning the actuator proportional-integral-derivative controller of spinning missiles. Journal of Aerospace Engineering, 231(14), 2594-2602.
[6] Hu, Q., Zhang, J., Yu, D. M., & Cui, J. F. (2007). Velocity control for rope-less elevator using permanent magnet linear synchronous motor with adaptive fuzzy PID. In Automation and Logistics, 2007 IEEE International Conference on (pp. 2361-2366).
[7] Liu, Z. Y., & Song, X. E. (2019). Rolling controlled trajectory correction fuze electromechanical actuator system simulation. Ship Electronic Engineering, 39(3), 93-97.
[8] Espinosa, A. G., Ruiz, J. R. R., Cusido, J., et al. (2008). Sensorless control and fault diagnosis of electromechanical contactors. IEEE Transactions on Industrial Electronics, 55(10), 3742-3750.
[9] Peng, J. Z., & Rickey, D. (2011). Identification and adaptive neural network control of a DC motor system with dead-zone characteristics. ISA Transactions, 50(4), 588-598.
[10] Yang, Y., Wang, M. G., & Yan, J. (2010). A better non-linear PID controller of digital electromechanical actuator system. Journal of Northwestern Polytechnical University, 28(3), 323-326.
[11] Fu, Y., & Li, B. (2022). Saturation constraint one-step optimal control of electrode current for the fused magnesia smelting process. Acta Automatica Sinica, 48(1), 239-248.