Performance Analysis of Position Tracking Control with PID Controller using an Improved Optimization Technique

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***Abstract*— An Electro-Hydraulic Actuator (EHA) system is usually utilized in production industry such as automotive industry which requires precision, high force and long operating hours. When dealing with the production of engineering parts that require precision, high force and long operating hours, a controller is usually required. It is observed from the literature, an appropriate tuning technique is essential in order to obtain optimal controller's performance. Therefore, a computational tuning technique, namely Priority-based Fitness Particle Swarm Optimization (PFPSO) is proposed to obtain the parameters of the Proportional-Integral-Derivative (PID) controller in this paper. The performance of the EHA system will be evaluated and compared based on the priority characters of the PFPSO tuning technique, which included settling time and overshoot percentage that affect the output results of the EHA system. As a result, it is observed that the priority based on settling time produced a better result, which enhances the steady-state performance of the EHA system that fulfills the requirement of the precision control.**[1]

***Index Terms*—Electro-hydraulic actuator system; particle swarm optimization; priority-based fitness; position tracking control**

I. INTRODUCTION

The dynamics of an actuator are usually generated through a different type of energy sources, including hydraulic, pneumatic and electric. As compared to the pneumatic and electrical actuators, a hydraulic actuator is widely used in industries due to its capability in generating large torque, high power and accurate positioning with fast motion [1]. The hydraulic actuator is an actuator system that utilizes pressurized hydraulic fluid, which is functioning as a drive or transmission system in generating a dynamic [2].

However, the nonlinear electro-hydraulic system is suffering from nonlinearities and time-varying characteristics such as high speed, outburst starting and stopping dynamic that produced by the flow and the pressure in the hydraulic system. The nonlinear properties causing a backlash in the control valve, actuator friction, distinction in fluid volume that make the system models and controller designs more complex [3].

The nonlinear properties that are produced through pressure and flow rate of the hydraulic system required a suitable controller to achieve better performances. In the previous works, there are many types of control techniques have been reported, which can be utilized to control the tracking capability of a nonlinear electro-hydraulic actuator system. Each of the control techniques required a proper tuning technique and some of the advanced tuning techniques have been reported recently such as Particle Swarm Optimization (PSO) [4-7], Genetic Algorithm (GA) [8-10], and Differential Evolution (DE) [11,12].

Instead of using a conventional PSO tuning technique, a different tuning method has been implemented in the gantry crane system which is the PSO based on the priority-based fitness schemes as proposed in [13]. The priority-based fitness Particle Swarm Optimization (PFPSO) has been utilized to obtain the parameters of the Proportional-Integral-Derivative (PID) that used to control the trolley position and the Proportional-Derivative (PD) that control the oscillation of the payload. The accuracy and the robustness toward the disturbance for the trolley's position and the payload's oscillation have been significantly improved.

In this paper, the effect of the PFPSO algorithm applied to the EHA system will be analysed. Rather than searching for the entire particles fitness, the algorithm will be executed by exploring the fitness based on the priorities, including the settling time and the overshoot of the EHA system. The priority that generates better steady-state performance will be referred since the accuracy is considered as the highest priority in the performance evaluation of the EHA system.

Manuscript received January 5, 2018; revised February 17, 2019.

doi: 10.18178/ijmerr.8.3.401-405

The paper will continue by following sections: section II will describe the model of the system. The simulation studies will be explained in section III. Section IV will present the results and discussion. Finally, conclusions are drawn in section V.

II. System Modelling

The pipeline will act as a medium of oil transmission between hydraulic cylinder and the servo valve in an EHA system as shown in Fig. 1. The oil flow regulated from the cylinder chamber to the hydraulic cylinder will produce the cylinder actuator displacement. The damper and spring that are attached to the mass will generate the counter force against the cylinder actuator [14].

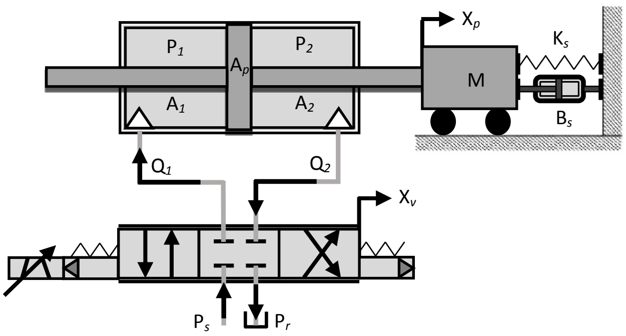

Figure 1. The EHA system schematic diagram.

The mechanical motion of the spool valve will be produced by electric current that supplied by the coil connected to the servo valve. The servo spool valve will be drive to the desired position by the torque motor that received the power source. The voltage of the motor is given as in (1), [15].

$$V = \frac{dI}{dt}L_c + R_c I \tag{1}$$

where L_c and R_c are the inductance and resistance in the coil respectively.

The dynamics equation of the servo valve is represented by an equation that related from the motor to electric current drive as expressed in (2).

$$\frac{d^2x_v}{dt^2} + 2\xi\omega_n\frac{dx_v}{dt} + \omega_n{}^2 = I\omega_n{}^2 \tag{2}$$

where ω is the natural frequency of servo valve, while ξ is the damping ratio.

The spool valve is unexposed from dead-zone problems and flow leakages for each port in servo valve mechanical design. The flow rate, Q for the chamber which controlled by servo valve can be modelled from the orifice equations relates the pressure difference P_v and spool valve displacement x_v. The orifice ideal equation is written in (3).

$$Q = Kx_v\sqrt{\Delta P_v} \tag{3}$$

The equation of flow rate can be calculated using (4) and (5) by neglecting the servo valve internal leakages for each chamber.

$$Q_1 = \begin{cases} K_1x_v\sqrt{P_s - P_1} & ; x_v \geq 0, \\ K_1x_v\sqrt{P_1 - P_r} & ; x_v < 0, \end{cases} \tag{4}$$

$$Q_2 = \begin{cases} -K_2x_v\sqrt{P_2 - P_r} & ; x_v \geq 0, \\ -K_2x_v\sqrt{P_s - P_2} & ; x_v < 0, \end{cases} \tag{5}$$

The volume of hydraulic actuator for chambers 1 and 2 are modelled in (6) and (7).

$$V_1 = V_{line} + A_p(x_s + x_p) \tag{6}$$

$$V_2 = V_{line} + A_p(x_s - x_p) \tag{7}$$

where V_{line} is the volume of pipeline and hydraulic cylinder.

Pressure for both chambers 1 and 2 can be obtained by relate the flow rate, volume and bulk modulus as expressed in (8) and (9).

$$P_1 = \frac{\beta}{V_{line} + A_p(x_s + x_p)}\int(Q_1 - q_{12} - q_1 - \frac{dV_1}{dt})dt \tag{8}$$

$$P_2 = \frac{\beta}{V_{line} + A_p(x_s - x_p)}\int(\frac{dV_2}{dt} - Q_2 - q_{21} - q_2)dt \tag{9}$$

The total force which produced by hydraulic actuator after considering all the dynamics equation can be obtained in (10).

$$F_p = A_p(P_1 - P_2) = M_p\frac{d^2x_p}{dt^2} + B_s\frac{dx_p}{dt} + K_sx_p + F_f \tag{10}$$

The EHA system parameters used in simulation study have been tabulated in Table I.

TABLE I. EHA System Parameters

Symbol	Value	Description
I_{sat}	0.02 A	Torque motor saturation current
L_c	0.59 H	Servo-valve coil inductance
R_c	100 Ω	Servo-valve coil resistance
ξ	0.48	Servo-valve damping ratio
K_s	10 Nm	Spring stiffness
X_s	0.1 m	Total actuator displacement
A_p	$645\text{x}10^{-6}$ m^2	Piston area
M_p	9 kg	Total mass
B_s	2000 Ns/m	Damping coefficient
ω_n	543 rad/s	Servo-valve natural frequency
K	$2.38\text{x}10^{-5}$ $m^{5/2}/kg^{1/2}$	Servo-valve gain
β	$1.4\text{x}10^9$ N/m^2	Hydraulic fluid bulk modulus
P_s	$2.1\text{x}10^7$ Pa	Pump pressure
P_r	0 Pa	Return pressure

III. Methodology

A. Electro-hydraulic Actuator (EHA) System

Fig. 2 demonstrates the established EHA system model which is adopted from the work done in [15].

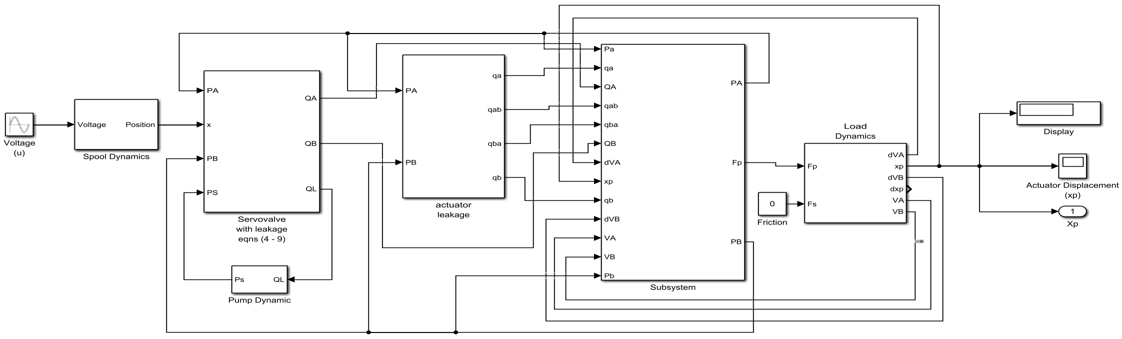

Figure 2. The Structure of EHA system.

Fig. 3 illustrates the block diagram of EHA system with PID controller optimize by using PFPSO technique with different priorities as discussed earlier.

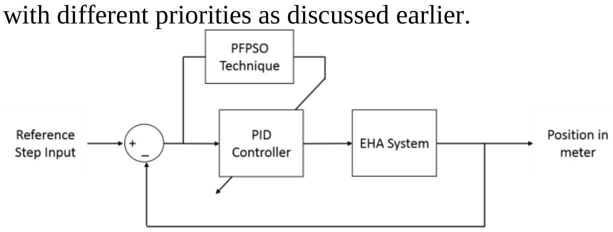

Figure 3. The block diagram of EHA system with PID controller.

B. *Particle Swarm Optimization (PSO) Technique*

Particle Swarm Optimization (PSO) is introduced by James Kennedy and Russell Eberhart in 1995. It was developed from the swarm intelligence and based on fish and bird flock movement behavior to find the food [16].

A number of particles that are moving around the searching space is used on the basic principle of the PSO algorithm to look for the best solution. Each particle will keep track of its coordinate in the fitness equation that has achieved by that particular particle. This value is known as personal best, P_{BEST}. Another value called global best, G_{BEST} is tracked by the PSO. Each particle can be shown by its current position and velocity as shown in (11) and (12).

$$x^{i+1} = x^i + v^{i+1} \tag{11}$$

$$v^{i+1} = \omega v^i + c_1 r_1 (P_{BEST} - x^i) + c_2 r_2 (G_{BEST} - x^i) \tag{12}$$

where:

x^{i+1} = position of particle at iteration k
v^{i+1} = velocity of particle at iteration k
ω = inertia weight factor
r_1, r_2 = random numbers between 0 and 1
c_1, c_2 = acceleration coefficients

C. *Priority-based Fitness in PSO (PFPSO) Technique*

As discussed earlier in section I, Priority-based Fitness Particle Swarm Optimization (PFPSO) is introduced by Jaafar in 2012 [17] The P_{BEST} and G_{BEST} values are updated according to the priority: settling time (T_s) and overshoot percentage (OS%). The Fig. 4 shows the flowchart of Priority-based Fitness Particle Swarm Optimization (PFPSO) technique in optimizing the PID parameters in EHA system.

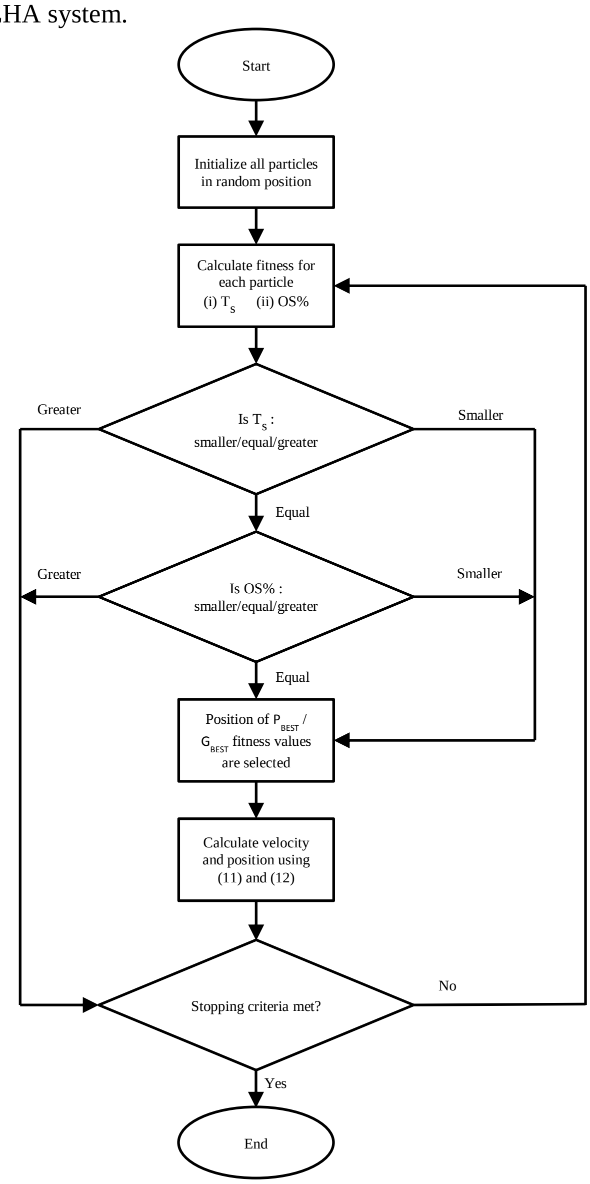

Figure 4. The flowchart of PFPSO technique in optimizing PID parameters.

The main study in this paper is the optimization technique to find out the parameters of the PID controller. As discussed earlier, the particle swarm optimization (PSO) technique with two different priorities which are settling time and overshoot percentage will be chosen to optimize the PID parameters. This technique is called as Priority-based Fitness Particle Swarm Optimization (PFPSO) technique.

First, the settling time will be chosen as the priority followed by overshoot percentage in optimization process and get the PID controller parameters as shown in Fig. 4. The step input is then fitted into the system and the performance of the controller to the EHA system is recorded. The same procedure is done by exchanging the settling time and overshoot percentage as the priority in the optimization process.

The PID parameters and performance of the EHA system in terms of steady-state error is recorded. All the results are tabulated in tables and discuss in the next section.

IV. Result And Discussion

Table II shows the PID parameters after optimization using the PFPSO technique with different priorities.

TABLE II. PID Parameters after Optimization with Different Priorities

Priorities / PID Parameters	Settling Time (T_s)	Overshoot Percentage (OS%)
Proportional (P)	317.3733	203.0915
Integral (I)	0.0215	0.0107
Derivatives (D)	0.0796	0.0294

Using the value of PID parameters in Table II, the simulation is executed and the output performance of the EHA system with different priorities is shown in Fig. 5.

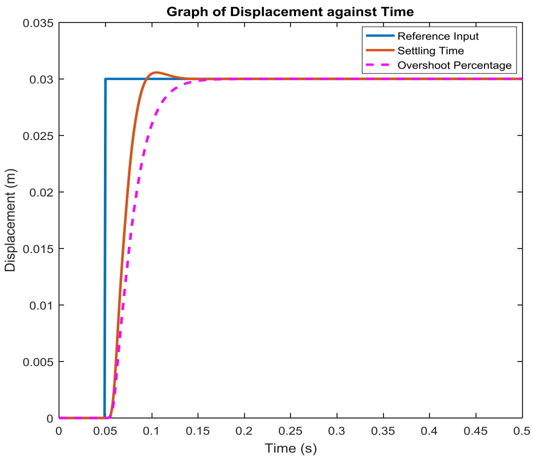

Figure 5. Graph of EHA Displacement against Time with different priorities PID parameters.

The performance analysis is done on both simulation based on the overshoot percentage (OS%), settling time (T_s), and the steady-state error (e_{ss}) of the EHA system. All the results are recorded as in Table III.

TABLE III. Performance Analysis of EHA System for Different Priorities

Simulation / EHA Performance	1st Priority: Settling Time 2nd Priority: Overshoot Percentage	1st Priority: Overshoot Percentage 2nd Priority: Settling Time
Settling Time (s)	0.0150 s	0.0190 s
Overshoot Percentage (%)	1.8964 %	1.5989×10^{-4} %
Steady-state Error (e_{ss})	1.3673×10^{-4} m	1.5989×10^{-4} m

From the result in Table III, for the first simulation that settling time is chosen as the priority in PSO optimization, the settling time is less than the second simulation which overshoot percentage is the priority of the PSO optimization. As for the second simulation, the overshoot percentage is obviously much less than that in the first simulation.

As for the steady-state error, the first simulation that takes settling time as priority has the less steady-state error which has a value of 1.3673×10^{-4} m as compared with the second simulation that takes overshoot percentage as the priority which has a value of 1.5989×10^{-4} m. The simulation that generates better steady-state performance will be referred since the accuracy is considered as highest priority in the performance evaluation of the EHA system.

V. Conclusion

A PID controller is designed in this simulation works to improve the positioning performance of the Electro-Hydraulic Actuator (EHA) system. An existing PSO optimization technique with different priorities is studied and applied in optimizing the PID parameters. From the simulation results, the first simulation which has the settling time as the highest priority had given a satisfactory output performance than the second simulation based on their steady-state error. It is recommended for the future works that the robustness of the proposed controller in this paper will be tested according to the changes in the system's parameters.

Acknowledgement

The support of Universiti Teknikal Malaysia Melaka (UTeM), Centre for Robotics and Industrial Automation (CeRIA), Universiti Teknologi Malaysia (UTM), and Ministry of Education (MOE) are greatly acknowledged. The research was funded by Fundamental Research Grant Scheme (FRGS) Grant No. (FRGS/1/2017/TK04/FKE-CeRIA/F00333) and Short-Term Grant No. (PJP/2017/FKE/HI11/S01534).

References

[1] C. C. Soon, R. Ghazali, H. I. Jaafar, S. Y. S. Hussien, Y. M. Sam, and M. F. Rahmat, "The effects of parameter variation in open-loop and closed-loop control scheme for an electro-hydraulic actuator system," *Int. J. Control Autom.*, vol. 9, no. 11, pp. 283–294, 2016.

[2] R. Ghazali, C. C. Soon, H. I. Jaafar, Y. M. Sam, and M. F. Rahmat, "System identification of electro-hydraulic actuator system with pressure and load effects," in *Proc. IEEE International Conference on Control System, Computing and*

Engineering, pp. 256–260, 2014.
[3] C. C. Soon, R. Ghazali, H. I. Jaafar, and S. Y. S. Hussien, "PID controller tuning optimization using gradient descent technique for an electro-hydraulic servo system," *J. Teknol. Sci. Eng.*, vol. 77, no. 21, pp. 33–39, 2015.
[4] J. Yao, G. Jiang, S. Gao, H. Yan, and D. Di, "Particle swarm optimization-based neural network control for an electro-hydraulic servo system," *J. Vib. Control*, vol. 20, no. 9, pp. 1369–1377, 2014.
[5] C. C. Soon, R. Ghazali, H. I. Jaafar, and S. Y. S. Hussien, "Sliding mode controller design with optimized pid sliding surface using particle swarm algorithm," in *Procedia Comput. Sci.*, vol. 105, no. Iris 2016, pp. 235–239, 2017.
[6] J. Yao *et al.*, "Acceleration harmonic estimation for a hydraulic shaking table by using particle swarm optimization," *Trans. Inst. Meas. Control*, vol. 39, no. 5, pp. 738–747, 2017.
[7] S. M. Rozali *et al.*, "Robust control design of nonlinear system via Backstepping-PSO with sliding mode techniques," in *Proc. Asian Simulation Conference*, pp. 27–37, 2017.
[8] Z. Chen, X. Yuan, B. Ji, P. Wang, and H. Tian, "Design of a fractional order PID controller for hydraulic turbine regulating system using chaotic non-dominated sorting genetic algorithm II," *Energy Convers. Manag.*, vol. 84, no. August 2014, pp. 390–404, 2014.
[9] A. Montazeri, C. West, S. D. Monk, and C. J. Taylor, "Dynamic modelling and parameter estimation of a hydraulic robot manipulator using a multi-objective genetic algorithm," *Int. J. Control*, vol. 7179, pp. 1–23, 2016.
[10] T. Samakwong and W. Assawinchaichote, "PID controller design for electro-hydraulic servo valve system with genetic algorithm," *Procedia Comput. Sci.*, vol. 86, no. March, pp. 91–94, 2016.
[11] M. Dangor, O. a. Dahunsi, J. O. Pedro, and M. M. Ali, "Evolutionary algorithm-based PID controller tuning for nonlinear quarter-car electrohydraulic vehicle suspensions," *Nonlinear Dyn.*, vol. 78, no. 4, pp. 2795–2810, 2014.
[12] Y. C. Hung, F. J. Lin, J. C. Hwang, J. K. Chang, and K. C. Ruan, "Wavelet fuzzy neural network with asymmetric membership function controller for electric power steering system via improved differential evolution," *IEEE Trans. Power Electron.*, vol. 30, no. 4, pp. 2350–2362, 2015.
[13] S. Y. S. Hussien, R. Ghazali, H. I. Jaafar, and C. C. Soon, "Robustness analysis for PID controller optimized using PFPSO for underactuated gantry crane system," in *Proc. 5th IEEE Int. Conf. Control Syst. Comput. Eng. ICCSCE 2015*, no. November, pp. 520–525, 2016.
[14] R. Ghazali, Y. M. Sam, M. F. Rahmat, Zulfatman, and A. W. I. M. Hashim, "Simulation and experimental studies on perfect tracking optimal control of an electrohydraulic actuator system," *J. Control Sci. Eng.*, vol. 2012, 2012.
[15] M. Kalyoncu and M. Haydim, "Mathematical modelling and fuzzy logic based position control of an electrohydraulic servosystem with internal leakage," *Mechatronics*, vol. 19, no. 6, pp. 847–858, 2009.
[16] J. Kennedy and R. Eberhart, "Particle swarm optimization," *Neural Networks, 1995. Proceedings., IEEE Int. Conf.*, vol. 4, pp. 1942–1948, 1995.
[17] H. I. Jaafar and Z. Mohamed, "PSO-tuned PID controller for a nonlinear double-pendulum crane system," in *Proc. IEEE International Conference on Control System, Computing and Engineering (ICCSCE)*, vol. 752, pp. 515–519, 2012.

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