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Optimal PID sliding surface for sliding mode control based on particle swarm optimization algorithm for an electro-hydraulic actuator system

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ABSTRACT – This paper presents the assessment on the sliding mode control (SMC) integrated with proportional-integral-derivative (PID) sliding surface which is optimized through particle swarm optimization (PSO) algorithm. The control scheme is established from the derived dynamic equation which stability is proven through Lyapunov theorem. In the evaluation of PID sliding surface, conventional Ziegler-Nichols (ZN) tuning method has been utilized to obtain the controller parameters and compared with the optimized controller parameters through PSO algorithm which is employed to the electro-hydraulic actuator (EHA) system to evaluate its positioning tracking performances. From the obtained simulation results, it can be concluded that the PSO tuning algorithm outperform the conventional ZN tuning method.

1. INTRODUCTION

In the past decades, electro-hydraulic actuator (EHA) system has been widely used especially in various heavy engineering works. The advanced design of EHA system with the versatile electronic and hydraulic components offers a massive enhancement in an application's performance. The integration of both electronic and hydraulic equipment that absorbed both advantages have been extensively used nowadays.

However, the dynamic features of the EHA system is known to be highly nonlinear in nature and the existing nonlinearities and uncertainties yield to the constraint in the control of EHA system. Such characteristics appeared in the system degrade its performance significantly. These disturbances simultaneously influence the position tracking accuracy and commonly affected by the occurrences of leakage and friction in the system.

Various control strategies have been reported and proposed in the literature to overcome the difficulties in the EHA control system. The raised numbers of works dealing with EHA system ranged from linear, nonlinear to intelligent control approaches have been proposed over the past decades. In the literature study of [1], sliding mode controller (SMC) nonlinear control strategy is found to be efficient and extensively applied to the nonlinear EHA system.

The SMC nonlinear control is verified to have a capability to maintain the control stability of various model classes that exposes to the disturbances and variations in the system parameters. In [2], the sliding surface has been improved by adding an integral action which is simultaneously enhanced the tracking performance of the SMC control on the electromechanical plant.

In this paper, the SMC control has been augmented with PID sliding surface for the purpose of enhancing the position tracking performance of the EHA system. The servo valve and hydraulic actuator integrating with the nonlinear dynamics model has been derived. Afterward, the SMC control scheme has been implemented in the system which stability of the control system is theoretically proven by Lyapunov theorem. Subsequently, the controller tracking performance has been compared to the optimized controller to demonstrate the significant improvement of the controller through the proposed technique.

2. MODELING EHA SYSTEM

The block diagram of the EHS system is described in Figure 1 below.

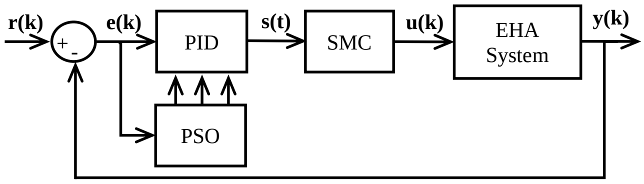

Figure 1 EHA system block diagram.

The dynamics of the servo valve are represented by a second order differential equation that related to an electric current drive from the torque of the motor as expressed in equation (1).

$$\frac{d^2 x_v}{dt^2} + 2\xi\omega_n \frac{dx_v}{dt} + \omega_n{}^2 = I\omega_n{}^2 \tag{1}$$

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

Through the overall dynamics equation of moving mass, damper, and spring, the total force produced from hydraulic actuator can be evinced in equation (2).

$$\begin{aligned} F_p &= A_p(P_1 - P_2) \\ &= M_p \frac{d^2 x_p}{dt^2} + B_s \frac{dx_p}{dt} + K_s x_p + F_f \end{aligned} \tag{2}$$

3. SLIDING MODE CONTROL DESIGN

The PID sliding surface for the SMC design implemented into third-order EHA system can be indicated by using the following equation where k_p, k_i, and k_d are referred to the PID parameters [3].

$$s(t) = k_p e(t) + k_i \int_0^t e(\tau)d\tau + k_d \dot{e}(t) \quad (3)$$

The general expression of SMC control structure consist of switching control and equivalent control as denotes in equation (4). Where the switching control, u_{sw} corresponding to the reaching phase when $s(t) \neq 0$. While the equivalent control u_{eq} corresponding to the sliding phase when $s(t) = 0$.

$$u_{smc}(t) = u_{eq}(t) + u_{sw}(t) \quad (4)$$

The tracking error will be confined in the sliding surface and converge to the equilibrium point where $s(t) = \dot{s}(t) = \ddot{s}(t) = 0$, where the second derivative of sliding surface is expressed as:

$$\ddot{s}(t) = k_p \ddot{e}(t) + k_i \dot{e}(t) + k_d \dddot{e}(t) \quad (5)$$

Assume that the lumped uncertainty is neglected (L=0), the equivalent control of the SMC control can be defined as:

$$u_{eq}(t) = (k_d C_n)^{-1}(k_p \ddot{e}(t) + k_i \dot{e}(t) + \cdots$$
$$\cdots + k_d(\dddot{x}_r + A_n \ddot{x}_p + B_n \dot{x}_p)) \quad (6)$$

By applying the sign function to the sliding surface, the switching control can be determined as:

$$u_{sw}(t) = k_s sign(s) \quad (7)$$

To ensure the stability of the switching control based on Lyapunov theorem, the chattering effect for the discontinuous function in (7) has been reduced by replace the function of hyperbolic tangent with the boundary layer of φ as proposed in [3].

$$u_{sw}(t) = k_s \tanh(\frac{s}{\varphi}) \quad (8)$$

4. RESULTS AND DISCUSSION

In order to evaluate the position tracking performance of the conventional tuning method and the optimization algorithm employed to the PID sliding surface, the step reference input signal has been fed into the plant and observe the controller tracking ability as shown in Figure 2. The PID controller parameters obtained through ZN conventional tuning method provide high overshoot and long settling time denoted in green dotted output signal. It can be clearly seen through Figure 2, the overshoot and settling time has been reduced when the SMC controller with PID sliding surface that utilized ZN parameter as its controller parameters denoted in the blue dotted output signal. By utilizing the PSO algorithm, an optimal PID parameters was obtained which applied to the PID sliding surface and produced the result as represented by the red dotted output signal. The value of k_s = 10 and φ = 15 has been applied in the switching control and the PID controller parameters obtained through two different tuning methods were tabulated in Table 1.

Table 1 Parameters value of the PID controller.

PID	Parameters Values	
	Ziegler-Nichols	**PSO Algorithm**
K_p	1020	1118.2151
K_i	0.0150	7.3249e-06
K_d	0.0038	4.0391

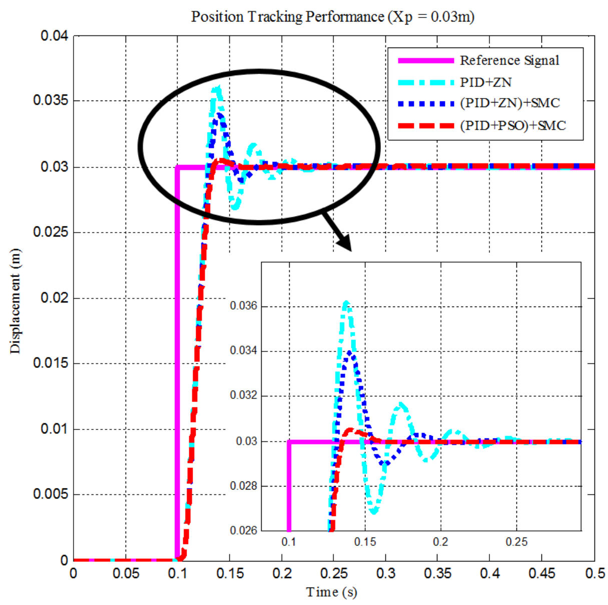

Figure 2 The output for step reference input signal.

5. CONCLUSION

In this paper, the performance of PID sliding surface for the SMC controller has been evaluated by considering the conventional ZN tuning technique and the PSO tuning algorithm that applied to the controller. The numerical simulation shows that the PSO optimization technique provides significant improvement to the controller and produced more precise position trajectory tracking.

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