OPTIMIZED ROBUST CONTROLLER FOR MULTI-TRAJECTORY ACTUATOR TRACKING

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ABSTRACT

Precision control is essential in most engineering applications, which affecting the outcome of the product. In order to achieve precise motion during the positioning tracking, controller playing vital roles that lead to a better outcome. In this paper, three different control strategies are proposed. The widely-known Proportional-Integral-Derivative (PID) is first designed. Then, the improved PID controller, which is so called Fractional Order (FO-PID) is designed. Followed by the designs of the robust Sliding Mode Control (SMC). The main objective of this paper is to evaluated and compared the performance of these controllers, implemented for positioning or trajectory tracking. The results show that SMC capable to generate most precise trajectory tracking compared with others.

Keywords: mutli-trajectory positioning tracking control, electro-hydraulic actuator , robust control; sliding mode control.

1. INTRODUCTION

Controller is noted to be crucial in dealing with an Electro-Hydraulic Actuator (EHA) system that is inherently nonlinear with various uncertainties in real-time [1]. Apart from reduces the energy usage, precise motion can be achieved through an appropriate control system. Precise motion is one of the most important factors in producing perfect product in real-world. The common product that involving EHA system, which required high force and precision is the fabrication of the vehicle body parts. Imprecise motion can cause unfit and damage, which simultaneously lead to a financial loss in a particular company.

Owing to the fact of the EHA system is commonly known to be confronting with the nonlinear and uncertain characteristics, the mathematical representation can hardly imitate the physical system of the EHA in the real-world [2]. Ordinarily, the resources of the nonlinearities including the compressibility of the oil due to the working temperature, the internal and external friction of the cylinder, the fluid flow characteristic in valve and cylinder [3]. While the general uncertainties can be divided into two main types, including parametric uncertainties and uncertain nonlinearities [4]. For that reason, control system is emerged to compensate these matters and concurrently challenging to be designed due to these existing issues.

Over years, the industry preferred control approach, which is the widely-known Proportional-Integral-Derivative (PID) controller has been usually performed in the EHA system [5-6]. By virtue of practical and user-friendly advantages, this controller has also become a subject of interest that extensively explored by researchers and academia. One of the common methods that often seen in the literature is the modification in terms of the controller's structure. For example, the fractional order control and the gain scheduling control that have been generally integrated to the PID controller [7-8]. These methods are proved to have more efficient performance compared with the traditional PID controller.

However, when it is come to the robustness performance, the notable Sliding Mode Control (SMC) approach is seemed to have more remarkable achievement implemented in various applications [9-10]. Despite that, SMC is recognized to has no appropriate method in obtaining its parameter and try and error method frequently utilized [11-13]. Hence, computational tuning methods such as Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA), and Genetic Algorithm (GA) have been gradually noticed in the control field due to their prominent performance in searching for the controller's optimal parameter [14-16].

In the literature, it is observed EHA system is generally applied to dealing with positioning control applications. The common applications including vehicle [17], robotic [18], construction machineries [19], and aerodynamic [20] required precise positioning control from the actuator. Thus, this paper aims to compare the positioning or trajectory tracking capabilities of the proposed controllers implemented in the EHA system.

This paper is organized as, modelling and control methods are briefly discussed in Section 2. The performance of each controller is presented in Section 3. Lastly, the summary of the outcome is drawn in Section 4.

2. MODELLING AND METHODS

Two types of transmission systems in hydraulic apparatus, which are pump operated and valve operated transmission system are generally used in the industry fields. However, this study will only cover the valve operated transmission system, since it is found to be performed efficiently nowadays [21]. This study is conducted based on the structure as illustrated in Figure-1. Commonly, the EHA system consists of actuator and sensing, valve or control, and power units.

The spool in the servo-valve is driven by the motor. The torque of the motor is generated from the voltage, V_v that drive the current, I_v flow to the coil that connected to the servo-valve as expressed in (1).

ARPN Journal of Engineering and Applied Sciences

$$V_v = \frac{dI_v}{dt} L_c + R_c I_v \qquad (1)$$

where the coil consists of inductance and resistance as denoted in L_c and R_c respectively.

The electrical current, which produces torque to the motor will generate the dynamic motion in the servo-valve that represented in a second order form of differential equation as indicated in (2).

$$\frac{d^2 x_v}{dt^2} + 2\xi_v \omega_v \frac{dx_v}{dt} + \omega_v^2 x_v = I_v \omega_v^2 \qquad (2)$$

The flow rate, Q controlled by the spool-valve in the chamber is generated through the orifice equation, which consists of different pressure, P_v, the position of the spool valve, x_v, and the gain of the servo-valve, K_v as written in (3).

$$Q = K_v x_v \sqrt{\Delta P_v} \qquad (3)$$

By neglecting the effect of internal leakage occur in the servo-valve, the fluid flow characteristic in each chamber represented in (4) and (5) [22].

$$Q_1 = \begin{cases} K_{v1} x_v \sqrt{P_s - P_1} & ; x_v \geq 0, \\ K_{v1} x_v \sqrt{P_1 - P_r} & ; x_v < 0, \end{cases} \qquad (4)$$

$$Q_2 = \begin{cases} -K_{v2} x_v \sqrt{P_2 - P_r} & ; x_v \geq 0, \\ -K_{v2} x_v \sqrt{P_s - P_2} & ; x_v < 0, \end{cases} \qquad (5)$$

where the servo-valve gain coefficient is assumed for a symmetrical valve as, $K_v = K_{v1} = K_{v2}$.

The pressure, P_s supplied from the pump will drive to the servo-valve. In the evolution of the EHA system, it is commonly equipped along with pressure regulator nowadays, which can adjust the maximum operating pressure supported by particular applications. The pressure generated form the dynamics between the pump and the servo-valve can be expressed as:

$$P_s = \frac{\beta_e}{V_t} (Q_{pump} - Q_L) dt \qquad (6)$$

Where β_e is the bulk modulus of the fluid, V_t is the piping volume, which is connected between the pump and the servo-valve, Q_{pump} is the constant flow rate from the pump volume, Q_L is the flow rate from the servo-valve volume.

After the modelling of the EHA system, controller is designed to overcome the issue existed in the EHA system. The controller that have been designed including PID, FOPID, and SMC controllers.Followed by the positioning or the trajectory tracking of each controller implemented in the EHA system which is the main objective of this study.

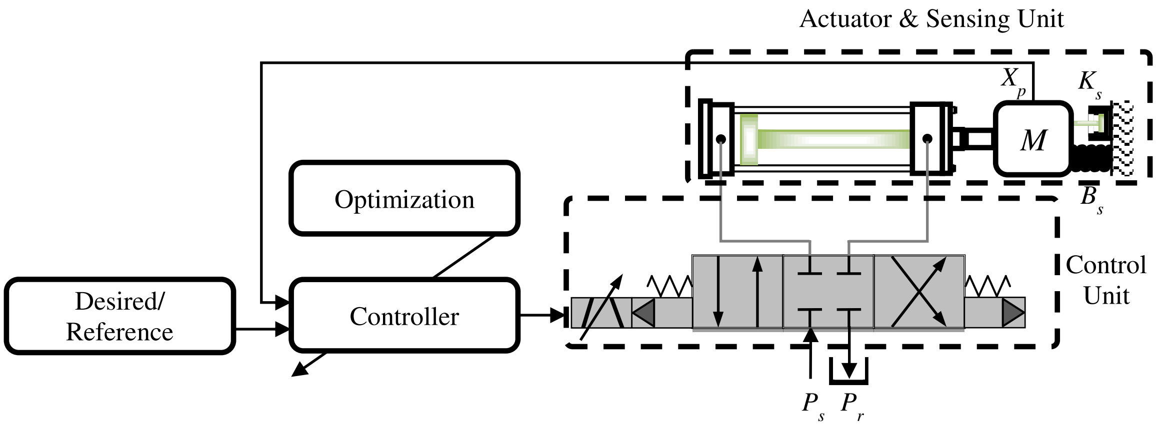

Figure-1. Block diagram of the EHA system.

The discussions of the PID, the FOPID, and also the SMC controller have been carried out in the past study in [23], which is the study mainly focus on the robustness performance achieved by these controllers.

3. RESULTS AND DISCUSSIONS

To examine the performance of the proposed controller, two main trajectories namely multi-step and multi-sine references or desired responses are designed. Due to the characteristics in the multi-step and the multi-sine references responses specifically diverse duration and velocity, these references responses are suitable to be used in the positioning tracking inspections. The simulation works are performed using MATLAB/Simulink 2018 software.

Figure-2 depicts the output of the multi-step with error. In accordance to the error signal at 9 seconds for the designed PID, FO-PID, and SMC controllers, the rise time of the PID and the FO-PID controllers are seem to be significantly increased compared with time at 6 seconds. This phenomenon indicates the traking capability of the PID and FO-PID controller reduced over time. The degradation might be worst in long operation hours which appeared to be a core manner in the industrial process.

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ARPN Journal of Engineering and Applied Sciences

While SMC seems to be able to sustain its efficiency over time. This phenomenon verified the theoritical treatise of the SMC control.

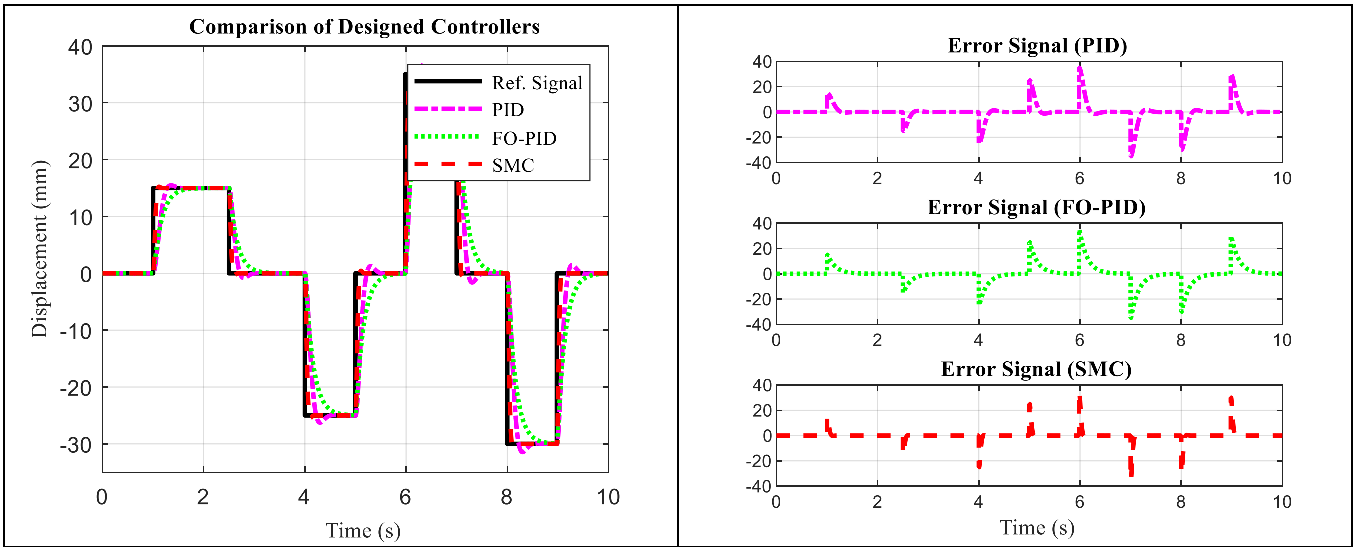

Figure-2. Multi-step trajectory tracking for PID, FO-PID and SMC controllers.

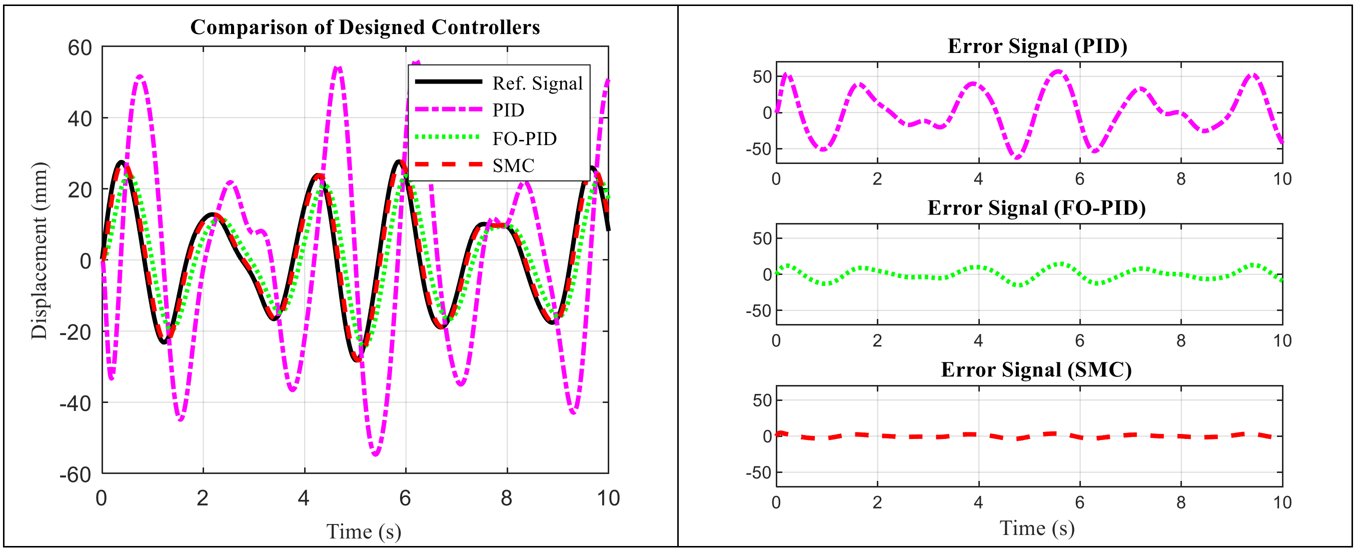

Figure-3. Multi-sine trajectory tracking for PID, FO-PID and SMC controllers.

Table-1. Parameters obtained using PSO algorithm.

Controller	Parameter				
	K_p	K_i	K_d	λ	δ
SMC	-	-	-	87.6240	395.7009
FO-PID	34.8991	0.7052	8.5401	2.0296	8.1205
PID	10.0910	0.0013	-4.6985	1	1

On the other side in multi-sine result, significant differences are achieved by these controllers according to the Figure-3. It can be seen in the error signal generated by these controllers, PID controller showing unacceptable response which indicates the tracking capability of the PID controller in dealing with inconstant frequency in the sine wave.

Noted that all the controller's parameters are obtained using PSO algorithm as listed in Table-1.Clearer numerical data with respect to Root Mean Square Error (RMSE) obtained in multi-step and multi-sine wave form are tabulated in Table-2 and Table-3 respectively. The smaller the error, the better the tracking performance. Referring to the Table 2 and Table-3, SMC is capable to delivered better results compared to the PID and the FO-PID controllers.

Table-2. RMSE for the multi-step input reference signal.

Controllers	**Root Mean Square Error** (Multi-Step)
SMC	11.1939
FOPID	14.7745
PID	14.8041

Table-3. RMSE for the multi-sine input reference signal.

Controllers	**Root Mean Square Error** (Multi-Sine)
SMC	1.95785
FOPID	7.49155
PID	30.1319

4. CONCLUSIONS

This paper aims to evaluate the positioning or trajectory tracking of the designed PID, FO-PID, and SMC controllers. Mathematical modelling of the EHA system is presented in the study. Then, the controller is designed under the nonlinear and the uncertain characteristics of the EHA system. The precision in the positioning tracking is well-known to be crucial, which simultaneously affect the outcome of the end product. Based on the results, SMC is capable to achieved smaller error, which indicate its tracking capabilities in delivering better outcome compared to the PID and the FO-PID controllers.

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