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TRACKING ANALYSIS FOR AN OPTIMIZED ROBUST CONTROLLER IN HYDRAULIC SYSTEM

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ABSTRACT

Tracking accuracy is very crucial in production industries such as automotive industrial that heeds high-precision. A slight deviation might cause severe consequences in terms of squandering. The difficulties are increased when faced with the system that is naturally highly nonlinear with major uncertainties such as electro-hydraulic actuator (EHA) system. Therefore, control system is playing enormous roles to significantly improve the EHA system positioning tracking accuracy by lessening the error caused by nonlinear and uncertain characteristics. This paper introduced the conventional proportional-integral-derivative (PID) controller, as a trademark to the improved fractional-order PID (FOPID) controller. Which are both optimized by using the particle swarm optimization (PSO) algorithm. To analyse the positioning tracking capability of the designed controllers, sinusoidal reference trajectory is first implemented. More attentive analyse based on multiple sinusoidal reference trajectory is conducted. Based on the output response, it is observed that the FOPID controller outperforms the PID controller.

Keywords: positioning tracking analysis, electro-hydraulic actuator (EHA), robust control design.

1. INTRODUCTION

The control of the electro-hydraulic actuator system usually focuses on two main types, which are force and positioning control. Force control, however, required an external force sensor that raises the manufacturing cost [1]. Thus, positioning control is usually done in the past decades. Compared to positioning control, due to the high force produced by the hydraulic system, force control will be a challenging task compared with the positioning control. Accurate positioning control is a common requirement in the construction machinery including robotic applications [2], aerodynamic system [3], and manufacturing industries [4].

Sinusoidal response is specifically used in the positioning tracking analysis [5]. Real-time application, such as the electro-hydraulic actuator will be extended and retracted in a full-wave cycle of the sinusoidal response depicted in Figure-1. It is noted that the output response can only be performed as in Figure-1 with the support of the control system. The examination of the sinusoidal trajectory for a particular system, also known as bandwidth test is to identify the frequency and amplitude that the designed controller can accurately track [6]. Output response is thus showing the capability and limitation of the system with or without the assistance of the controller.

By referring to the amplitude of the sinusoidal response, varied velocity and acceleration can be obtained in a full-wave cycle. The low-velocity to high-velocity can be obtained in a full-wave cycle. In the EHA system, the backlash and friction usually occurred in the low-velocity condition, or when reversing the actuator motion.

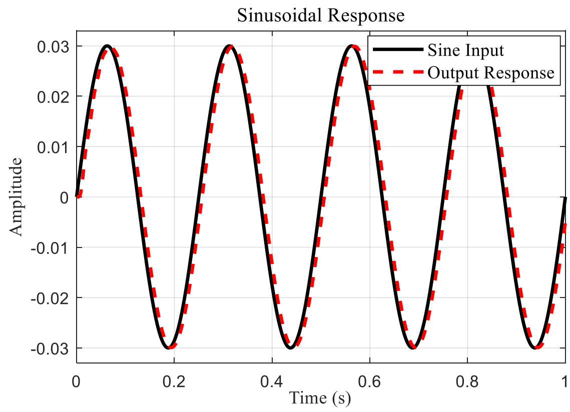

Figure-1. Sinusoidal reference trajectory.

In the positioning tracking examination implemented in the EHA system, several researchers have used the sinusoidal response in their study [7]–[10]. Based on Figure-1, the generally expected output response with the support of the control system is as near as possible to the reference response. Additionally, it is well-known the performance of the particular system varied over time. Thus, a well-constructed control system is expected to be able to cope with any disturbance occurred along the process.

To properly expose the character of a particular system, multi-types of trajectories can be composed together that capable of extracting various information from the response. This is the so-called multiple sinusoidal trajectories that able to extract more information to

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achieve higher tracking capability of a particular system. This method has been applied by several researchers in the examination of the high accuracy of the EHA system [6], [11]-[13].

For the reference of the multiple-sinusoidal response, the response in Figure-2 has been designed. Refer to the figure, the expected response of a particular system with the assistance of controller is produced by controller B, where more consistent tracking performance is pointed out by the controller B. Referring to the response generated by controller A, it can be roughly seen that the controller is not robust enough toward the changes during the operation over time, where the response in the time between 11 to 13 seconds onward demonstrated longer time needed in the tracking performance. Thus, an appropriate control approach may be necessary to be designed to overcome the interruption or changes during the operation such as uncertainties and disturbances, and obtain the performance as accurately as possible in the entire operating hours.

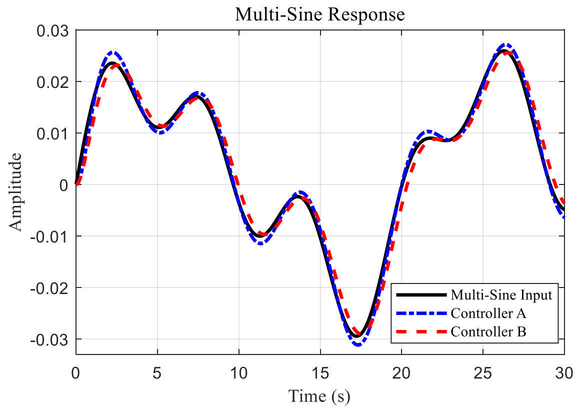

Figure-2. Multiple-sinusoidal reference trajectory.

2. METHODOLOGY

Particle Swarm Optimization (PSO) is well-known to be uncomplicated and able to be applied to various applications [14]. Basically, the implementation of the PSO algorithm can be summarized as in Figure-3.

The searching will always start with randomly distributed position and velocity values on the wide range searching area. All the particles will then share their information that composed of velocity and position information. The particle will be updated with new velocity and position information based on the formula as stated below [15].

$$v_{id}^{k+1} = v_{id}^{k} + c_1 rand_1^k (pbest_{id}^k - s_{id}^k) \cdots \\ + c_2 rand_2^k (gbest_{id}^k - s_{id}^k) \quad (1)$$

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1} \quad (2)$$

Searching will be ended when one of the criteria is fulfilled. The criteria are such as achievement of the minimum error, and maximum iterations are reached. Description for formula 1 and 2 are summarized in Table-1 [16].

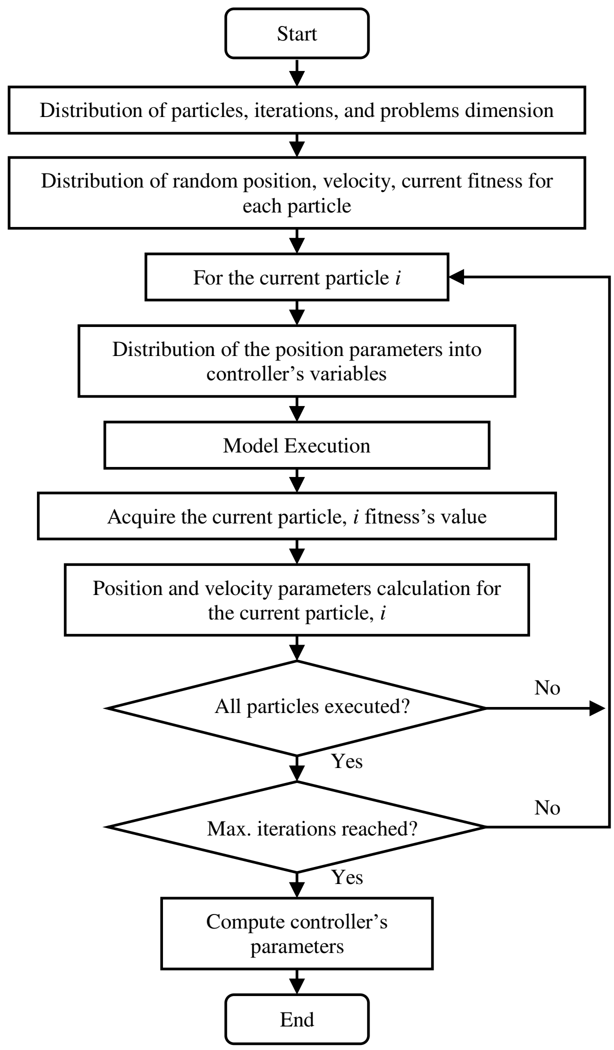

Figure-3. Summarized process of the PSO algorithm.

Table-1. Description of the PSO formula.

Terms	Description
v	Particle's velocity
k+1	Particle's future iteration
I	Particle's value, where *i* = 1, 2, 3, …, n
d	Problem dimension of particular system, where *d* = 1, 2, 3, …, n
k	Particle's iteration, where *k* = 1, 2, 3, …, n
$c_{1/2}$	c_1 = self-coefficient c_2 = group / swarm-coefficient
$rand_{1/2}$	*rand* = random value ranged from 0 to 1 $rand_1$ = random value of self-coefficient $rand_2$ = random value of group-coefficient
pbest	Particle's personal or self-best value
s	Searching point of the algorithm
gbest	Particle's group / swarm or global best value

3. OUTPUT PERFORMANCE

MATLAB/Simulink 2018 software is used to simulate the EHA model. As emphasized in the earlier section, positioning accuracy is extremely crucial in the production industries, where the involvement of the EHA system that is inherently nonlinear with numerous uncertainties doubled the challenge in achieving high-accuracy performance. Thus, a proper control system is required to elevating the success rate in achieving this goal. In this work, two control systems have been proposed which are PID, and the improved PID controller which is known as FOPID controller. PSO algorithm is used to obtain the controller gains of both controllers. All the gains are tabulated in Table-2.

To inspect the positioning tracking accuracy, sinusoidal and multiple-sinusoidal reference responses have been designed. As discussed earlier, sinusoidal waveform with more different amplitude and frequency can produce more information for the purpose of accuracy enhancement. To observe the aforementioned statement, the root means square error (RMSE) analysis is performed on the designed sinusoidal and multiple-sinusoidal reference responses. Figure-4 describes the tracking performance based on sinusoidal reference trajectory.

With the same parameters implemented in the PSO algorithm, including the particle size, stochastic accelerations, c_1 and c_2 and also maximum iteration, the parameters of the PID and FOPID controllers are obtained as tabulated in Table-3. From Figure-4, it is clearly seen the delay occurred when the PID controller is applied. FOPID showing great positioning tracking performance. These performances clearly indicated in the RMSE analysis in Table-3.

Table-2. Parameters obtained using PSO algorithm.

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

Table-3. Root mean square error for sinusoidal reference response.

Controllers	RMSE
FOPID	2.96876
PID	10.4471

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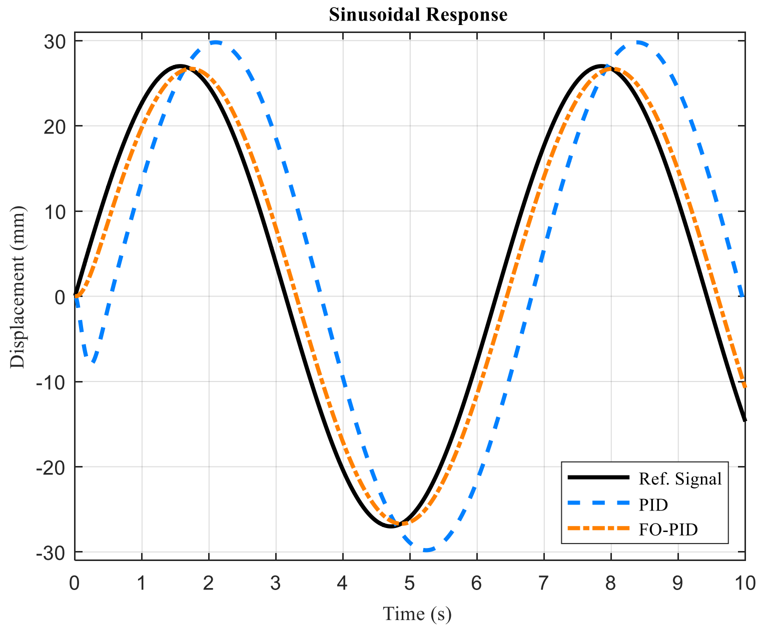

Figure-4. Output response of the sinusoidal reference response.

Further inspection conducted on the multiple-sinusoidal reference response. Figure-4 depicts the output performance of the multiple-sinusoidal reference response. Crucial feedback is obtained when multiple-sinusoidal reference response is applied. It is clearly seen the PID controller perform poorly in the condition of diverse amplitude and frequency. Conversely of the FOPID controller.

Therefore, to ensure the reliability of the designed controller, the multiple-sinusoidal reference response is a great choice to determine either the designed controller is capable of coping with diverse amplitude and frequency that represent difference situation.

Figure-5 illustrates the output performance of the PID and FOPID, when multiple-sinusoidal response is applied. The PID controller is seemed to be performed even worst in the multiple-sinusoidal reference response. The quantitative evidence in Table-4 clearly shows the performance of both controllers. Therefore, it can be identified the positioning tracking performance of the FOPID controller is greater than the performance of the PID controller.

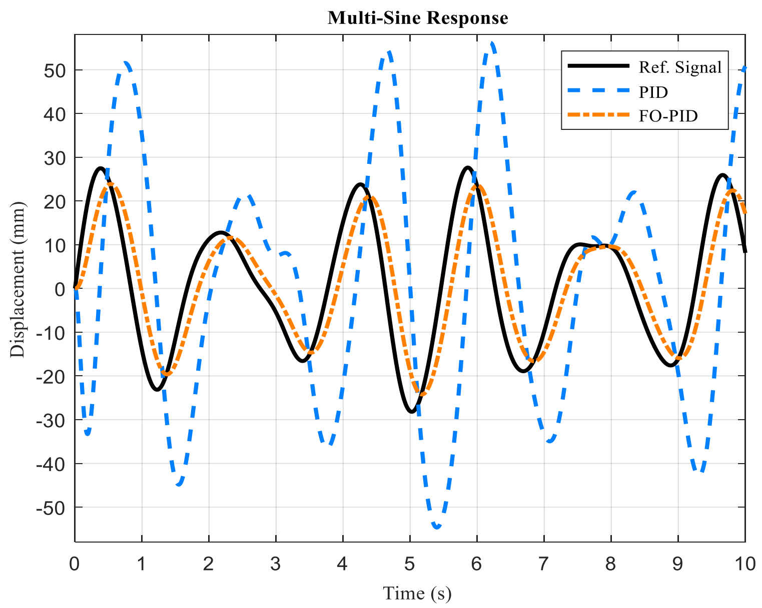

Figure-5. Output response of the multiple-sinusoidal reference response.

Table-4. Root mean square error for multiple-sinusoidal reference response.

Controllers	RMSE
FOPID	7.58353
PID	30.8148

4. CONCLUSIONS

The positioning or trajectory tracking of the designed PID and FOPID is thoroughly examined based-on sinusoidal and multiple-sinusoidal reference responses. The simple and industrial's favourite controller, which is PID controller is first designed under the nonlinear and the uncertain characteristics of the EHA system. Followed by the enhanced PID controller with the so-called FOPID controller is designed. The controller's gains are obtained using PSO algorithm. Based on the sinusoidal and multiple-sinusoidal reference responses, the positioning tracking capability of the FOPID controller is greatly surpassed the PID controller.

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