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Optimization of PID for industrial electro-hydraulic actuator using PSOGSA

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Abstract

The Electro-hydraulic actuator (EHA) systems known to be extremely nonlinear due to its dynamic characteristics and these existing nonlinearities and uncertainties yield to the constraint in the control of EHA system, which influences the position tracking accuracy and affect the occurrences of leakage and friction in the system. The purpose of this work is to develop the mathematical model for the industrial electrohydraulic actuator, then to design a controller by proportional-integral-derivative (PID) and optimize the parameters using Particle Swarm Optimization-Gravitational Search Algorithm (PSOGSA). A few controllers such as conventional PID (CPID) and model reference adaptive control (MRAC) designed for comparison. The performance of PID, PID-PSOGSA and modern controller MRAC will be compared in order to determine the most efficient controller. Despite all controllers are capable to provide good performance, PID-PSOGSA control methods generate good response compared to PID and MRAC in term of positioning.

Keywords: *EHA system, MRAC, PID controller, PSOGSA algorithm*

1. Introduction

EHA systems are important actuators in modern industries, principally because it offers many preferences such as high-power thickness, quick and smooth reaction attributes, and great ability in positioning. Because of its ability in positioning, it has been used in many applications for position control in modern equipment's such as aerospace, production assembly lines, industrial robots, aircrafts equipment's, machine tools, and submarine operations [1], and it has given a critical effect in the results. These applications required the highest performance of the electro-hydraulic actuator in term of positioning. The system inherently suffers from uncertainties and nonlinearities due to that many studies have been conducted recently, related to the EHA system problems to surmount thefise issues such as [2, 3]. One of the ways was optimizing the system controller performance. As optimization technique becomes popular nowadays, it can be utilized to optimize various types of controllers such as PID controller [4], MRAC and many more. However, position tracking performance of an EHA can be assured when its robustness and tracking accuracy are guaranteed. Therefore, the development of a suitable controller, which could reflect robustness and tracking accuracy, is very significant [5]. Currently, there are various controllers that can be used. Anyhow, one of the controllers that are very simple and effective is PID controller.

The advantages of a PID controller is that it can provide robust performance for a wide range of operating conditions [6]. It can also reduce the dynamic range error, eliminate the steady-state error and improve in the transient response of the loopback functions system. In the literature, there are some studies have been done regarding the optimization for the PID controller using PSO algorithm [7, 8]. In the latest study, the PID controller that has been optimized by PSO algorithms shown some improvements. However, it could not surmount the nonlinearity issues of EHA, efficiently. In order to overcome the time consuming of the piston in order to stabilize, PSOGSA algorithm has been chosen in this study as the optimisation method to improve the response efficiency of the piston positioning of the EHA system. Moreover, as a comparison, an adaptive controller MRAC has been used since it has the ability to adjust itself to any parameter

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variations occurring in a control system [9]. This two types of controllers have been used together with POSGSA, in order to get the best result of controlling the position of the EHA. Comparative assessment of both control schemes to the system performance is presented and discussed.

2. Research Method

The actuator dynamic equation of electro-hydraulic actuator servo system is expressed as in [10]:

$$m\ddot{x}_p = SP_L - f\dot{x}_p - kx_p - F_L \quad (1)$$

where, m is load at the rod of the system, x_p is the displacement of the piston, *S* is the piston area, P_L is the difference in pressure between the chambers, f is the coefficient of thick contact, is the coefficient of aerodynamic elastic force, F_L is the external disturbance injected into the system's actuator. Servo valve is used in the system with the assumption of having a high response, the controller connected to the arrangement of the spool valve will be corresponding to the spool position and it is given by the following equation:

$$x_v = k_v u \quad (2)$$

here the opening valve is expressed by x_v, the coefficient of the servo valve is expressed by k_v, and the input voltage by our system is having a double acting cylinder by assuming it is a symmetrical piston area and volume for each port are similar. Thus, the dynamic of cylinder oil flow is given by the following equation:

$$Q_L = \dot{P}_L + \frac{2\beta s}{v}\dot{x}_p \quad (3)$$

where, Q_L is the difference between supplied flow rate to the chambers, β is the effective bulk modulus of the fluid and v is the volume of the chamber. Thus, the difference of the flow rate Q_L to the chambers is given as the following:

$$Q_L = \frac{2\beta}{v}\left[c_d w\sqrt{\frac{P_a - P_L}{\rho}}x_v - k_l P_L\right] \quad (4)$$

The coefficient of the volumetric stream of the valve port is expressed by c_d, the supply pressure expressed by P_a , the oil density is expressed by ρ and the coefficient of internal leakage between the cylinder chambers by k_l. Let,$x_1 = x_p$, $x_2 = \dot{x}_p$ and $x_3 = P_L$

$$\dot{x}_1 = \dot{x}_p = x_2 \quad (5)$$

$$\dot{x}_2 = \ddot{x}_p \quad (6)$$

referring to (1),

$$\ddot{x}_p = \frac{S}{m}P_L - \frac{f}{m}\dot{x}_p - \frac{k}{m}x_p - \frac{F_L}{m} \quad (7)$$

thus,

$$x_2 = \frac{S}{m}P_L - \frac{f}{m}\dot{x}_p - \frac{k}{m}x_p - \frac{F_L}{m} \quad (8)$$

$$\dot{x}_3 = \dot{P}_L \quad (9)$$

from (3),

$$P_L = Q_L - \frac{2\beta s}{v}\dot{x}_p \quad (10)$$

substituting (4) into (10)

$$P_L = \frac{2\beta s}{v} c_d w \sqrt{\frac{P_a - P_L}{\rho}} x_v - \frac{2\beta s}{v} k_l P_L - \frac{2\beta}{v} \dot{x}_p \quad (11)$$

from the previous equations we can get that the differential equations governing the dynamics of electro-hydraulic actuator servo system with external disturbance injected to its actuator is given as the following:

$$\dot{x}_1 = x_2 \quad (12)$$

$$\dot{x}_2 = -\frac{k}{m} x_1 - \frac{f}{m} x_2 + \frac{S}{m} x_3 - \frac{F_L}{m} \quad (13)$$

$$\dot{x}_3 = -\frac{s}{k_c} x_2 - \frac{k_l}{k_c} x_2 + \frac{c}{k_c} \sqrt{\frac{P_a - P_L}{\rho}} k_v \quad (14)$$

F_o is the external disturbance given to the system and it can be constant or a time varying signal. Table 1 shows the parameters of electro hydraulic actuator system.

Table 1. EHA system parameters [11]

Symbol	Description	Value
m	Load at the EHA rod	0.33 Ns^2/cm
s	Piston Area	10 cm^2
f	Coefficient of vicious friction	27.5 Ns/cm
k	Coefficient of aerodynamic elastic force	1000 N/cm
w	Valve port width	0.05 cm
P_a	Supply pressure	2100 N/cm^2
c_d	Coefficient of volumetric flow of the valve port	0.63
ρ	Oil density	8.87× 10^{-7} Ns^2/cm^4
k_l	Coefficient of internal Leakage	2.38× 10^{-3} cm^5/Ns
k_v	Coefficient of servo valve	0.017 cm/N
k_c	Coefficient involving bulk modulus and EHA volume	2.5× 10^{-4} cm^5/N
F_o	External disturbance	3500 N

2.1. Controller Design and Simulation

In this section, three controller schemes PID, PID-PSOGSA and MRAC are proposed and described. The following controllers designed requirements have been made to examine the performance of the controller strategies for the displacement of the pistonpiston x_1, when there is an external disturbance injected to the system. F_o is an external disturbance that will be injected to the system's actuator as perturbations to the EHA system. The signal of F_o is used to examine the response of the controllers. Constant value of signal F_o=3500 N is added as a perturbation to the system actuator.

2.1.1. PID Controller

The popularity of PID controller can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity [12], which allows engineers to operate them in a simple, straightforward manner. PID algorithm consists of three basic coefficients, K_P proportional, K_i integral and K_d derivative which are varied to get optimal response. In order to get better performance of the PID controller in any system the three parameters of the controller K_P ,K_i and K_d must be tuned. This classical method for determining the parameters of the PID controller was presented by Ziegler and Nichols in 1942, and it is still widely used until today [13]. Figure 1 shows the simulation model of the EHA system with PID controller.

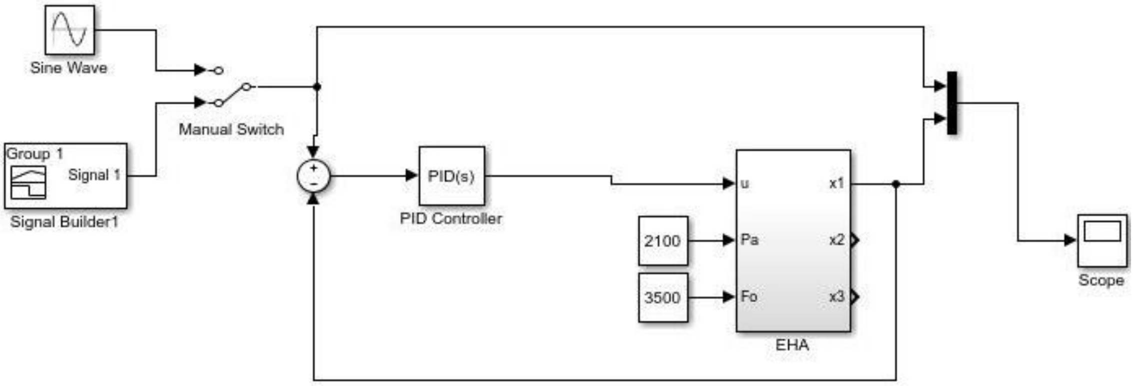

Figure 1. The simulation model of the EHA with PID controller

2.1.2. MRAC Controller

MRAC is one type of the adaptive controllers. It is been initially proposed to take care of an issue, where the details are given in terms of a reference model that characterize the wanted behaviour of the closed-loop system. This is a necessary approach for adaptive control. Figure 2 shows the simulation model of the EHA system with MRAC.

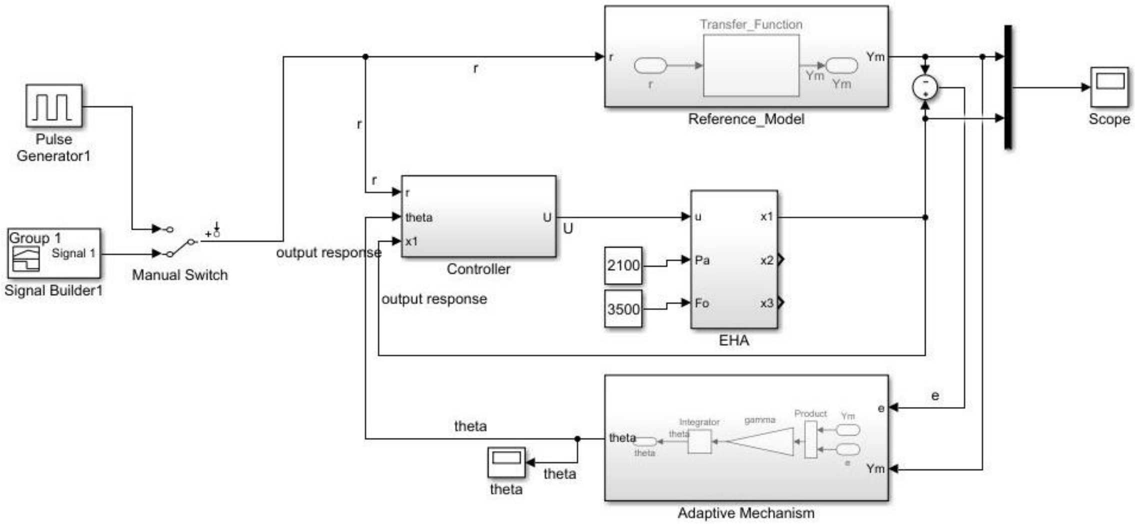

Figure 2. The simulation model of the EHA with MRAC

2.2. PSOGSA Algorithm

The main goal of PSOGSA algorithm is to locate the best outcome among all the conceivable arrangements in the result (optimal solution) [14]. PSOGSA algorithm is a combination of two algorithms which are Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA). The main idea is to integrate the ability of exploitation in PSO with the ability of exploration in GSA to synthesize both algorithms strength [15].

2.2.1. PSO Algorithm

It has proposed by Kennedy and Eberhart 1995, as an evolutionary computation technique [16]. It is based on a randomly initialized population and searches for optimal iteration-to-iteration updating. In the literatures there are some studies done the optimization for PID controller using PSO algorithm [17, 18]. In order to solve many problems in various systems one of those problems is nonlinearity issues of the EHA system such as the internal leakage, fluid flow expression through the servo valve and the friction. Most of the researchers and engineers prefer to use PID controllers in control applications because it could develop many features in the execution of the system, for example, rise time, settling time, overshoot, and the unfaltering state mistake, which makes the system more effective. Figure 3, shows the general process flowchart of the PSO technique [19].

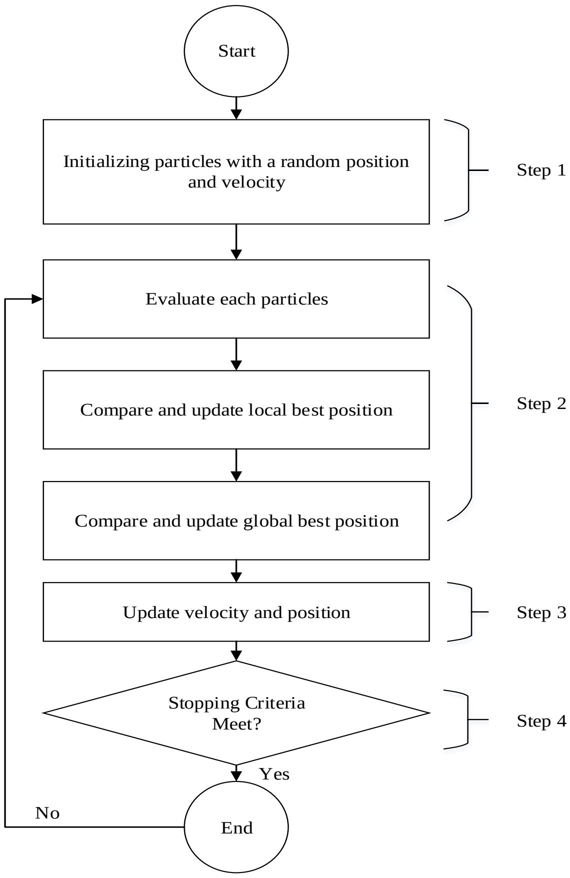

Figure 3. Flowchart of the PSO technique

The arrangement of the procedure is expressed as follows. To begin with, the generation of beginning conditions for looking point, the state of each particle and the speeds V_i produced randomly inside the predetermined range, now Pbest will be considered for the best searching point in the particles.While the best-assessed parameter of Pbest will be set to Gbest and the put away parameter will be the molecule number with the best parameter as in Step 1.

2.2.2. GSA Algorithm

It is based on Newton's Law of Gravity and mass interaction [20]. In this algorithm, the searcher agents survey the masses that interact with each other using the law of gravity and law of motion. Moreover, the gravitational constant decreased with time to arrange the accuracy of the search, which defined as the most significant feature of the GSA [21]. Figure 4, shows the general process flowchart of the GSA technique.

The arrangement of the procedure expressed as follows; the places of the N number of operators introduced arbitrarily. For minimization or boost issues, the wellness advancement performed by assessing the best and most exceedingly bad wellness for all specialists at every emphasis [22]. Gravitational constant *G* is computed at iteration *t*. Gravitational and idleness masses for every specialist are computed at emphasis *t*. Acceleration of the i^{th} operators at cycle *t* is determined, position and the velocity of the agents at the next cycle (t+1) are determined, stages 2 to 6 are repeated until the cycles reaches them maximum limit and wellness value at the last iteration is figured as the worldwide wellness while the position of the comparing operator at determined measurements is figured as the worldwide arrangement of that specific issue.

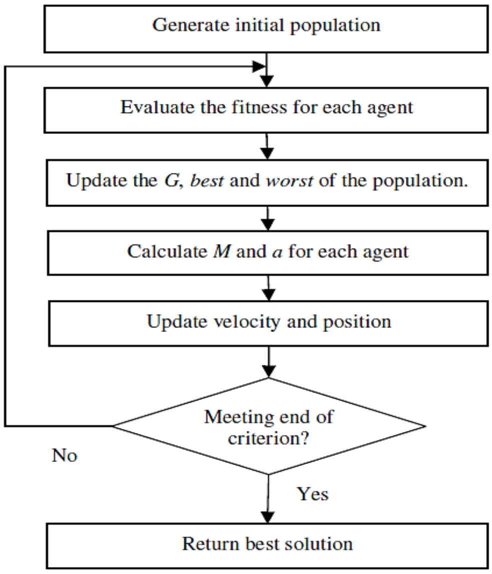

Figure 4. Flowchart of the GSA technique

2.2.3. PSOGSA Algorithm

Figure 5, shows the general process flowchart of the GSA technique and the arrangement of the procedure expressed as the follows, all agents haphazardly introduced. Each agent considered as an applicant arrangement after initialization, Gravitational power, gravitational steady, and resultant powers among specialists are determined, from that point forward, the increasing speeds of particles are characterized [23]. In every cycle and the best solution so far will be updated, then the velocities of all agents will be determined with the position as well finally the process of updating velocities and positions will be stopped by meeting an end criterion [24, 25]. The parameters used in the PSOGSA are as follows:

- Number of particles: 25,
- Dimension of the problem: 3,
- Number of maximum iterations: 50,

Figure 6 illustrates the block diagram of the PID controller with PSOGSA algorithm.

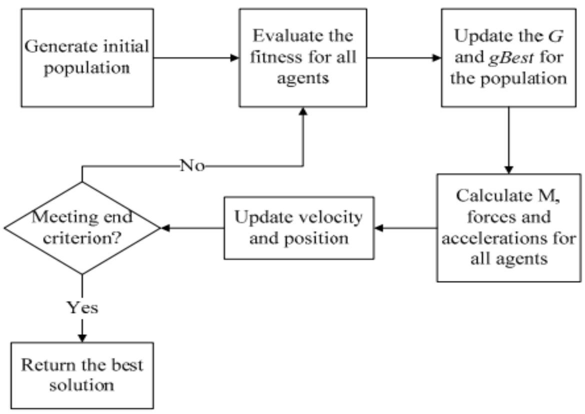

Figure 5. Flowchart of the PSOGSA technique

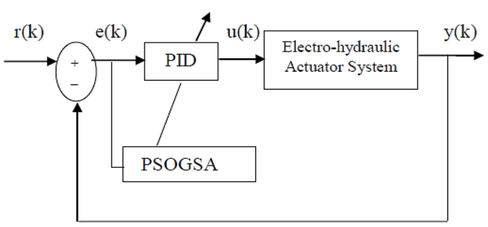

Figure 6. PID controller tuning based on PSOGSA algorithm for EHA system

3. Results and Analysis

PID controller has been applied to the Electro-hydraulic actuator system, where it was tuned using the Ziegler-Nichols method. An external disturbance was applied to the system too (F_o= 3500 N), to examine the robustness of the controller in piston x_1 positioning, the output response of the system is shown in Figure 7.

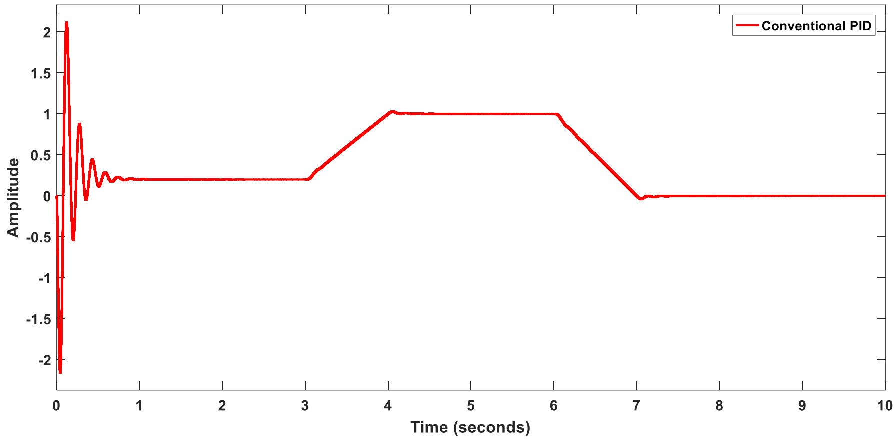

Figure 7. Conventional PID response when F_o = 3500N

In Figure 7, the system is not showing an efficient response where it has shown that in the beginning there was an oscillation. Moreover, when the system is changing from one point to another one the response does not follow the reference trajectory perfectly, it is showing some instability in the system. To see how PSOGSA is efficient some remarks were noted as follow. In PSOGSA, the quality of solutions (fitness) is considered in the updating procedure. The iterations near to good solutions try to attract the other iteration, which is exploring the search space. When all iterations are near to a good solution, they move very slowly. In this case, the GBest help them to exploit the global best. PSOGSA use a memory (GBest) to save the best solution has found so far, so it is accessible. This paper aimed to optimize the system with different values of iteration (T) and particles (N) to see clearly to performance of the system and the changes that will happen to the system response when an external disturbance is applied to the system, where the external disturbance value that been used here is F_o = 3500 N, the responses of the system are showing in Figures 8, 9 and 10. The optimization for the system started with a small number of particles and iterations, where the system response has shown a good improvement compared to the conventional PID response. However, it is still not an efficient response where it is still has some over and under shoots. Moreover, it produces errors when the position of the system changed.

As shown in Figure 9, the system response has improved more than the previous one where the overshoot minimized to zero and the settling time becomes faster that means when the number of particles and iterations increased the system response becomes more stable and accurate. When the number of iteration and particles increase the optimization algorithm will have a bigger search space to find the best solution so far for the system (Global optimum), but also it has some noise appears when the system response changes from one position to another one.

In Figure 10, the response of the system in the last experiment has shown the system becomes more accurate and the performance has improved by minimizing the overshoot, settling time, and rise time. Moreover, it has a better tracking performance in following the reference trajectory. In this paper, two controllers have been used which are PID and adaptive MRAC. The PID controller was applied to the electrohydraulic actuator (EHA) system two times first as Conventional PID tuned by Ziegler-Nichols method and the second time using PSOGSA Algorithm. Where an adaptive controller MRAC has been used with the EHA system for comparison with the PID controller, the responses of the controllers and the comparison is shown in Figure 11.

Figure 11 shows that all the controllers ha ve the capability to control the piston position of the EHA system but with different level of noise, osculation and instability, overall it shows that the best performance was done by the PID-PSOGSA where it shows a better response than other controllers with a less overshoot, undershoot, rise time and settling time also with a fast response for the system when it is changed from one position to another one.

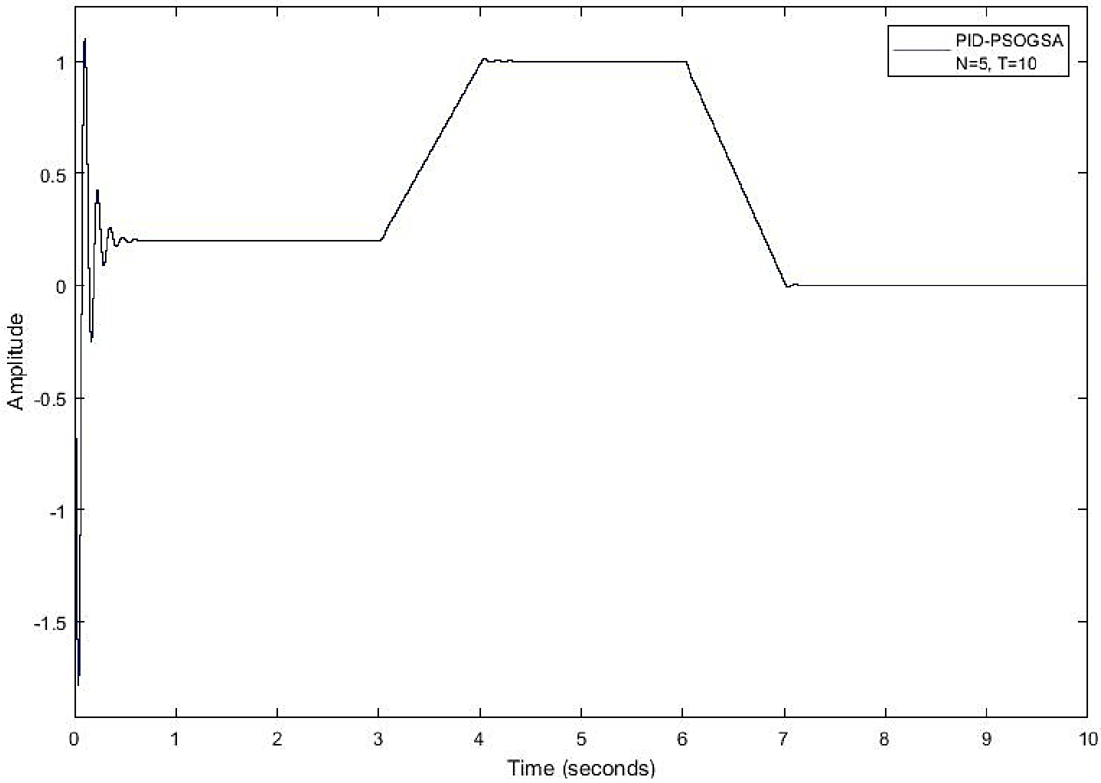

Figure 8. The response of the system with PID-PSOGSA
when the Particles=5 and iterations=10

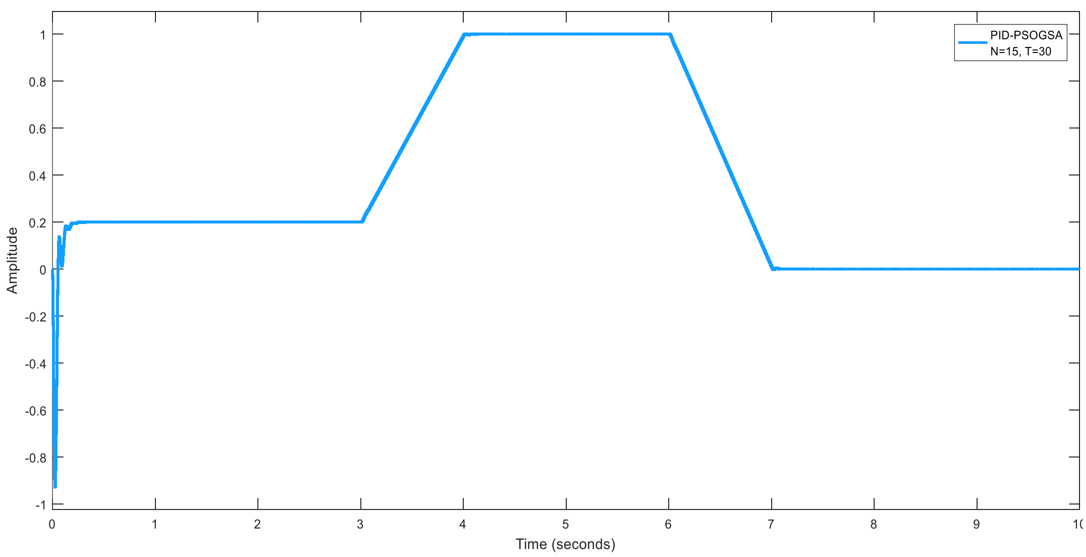

Figure 9. The response of the system with PID-PSOGSA
when the Particles=30 and iterations=15

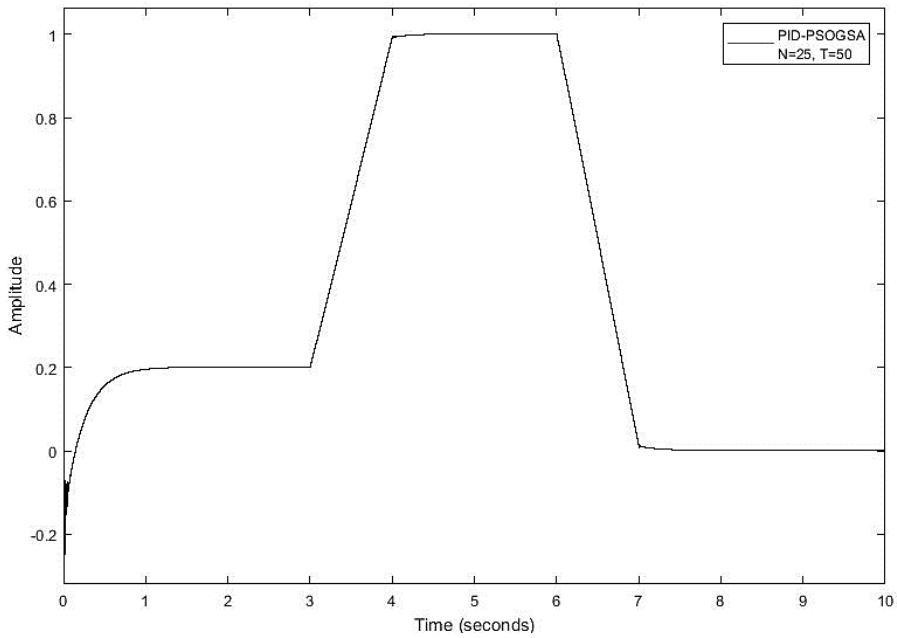

Figure 10. The response of the system with PID-PSOGSA when the Particles=25 and iterations=50

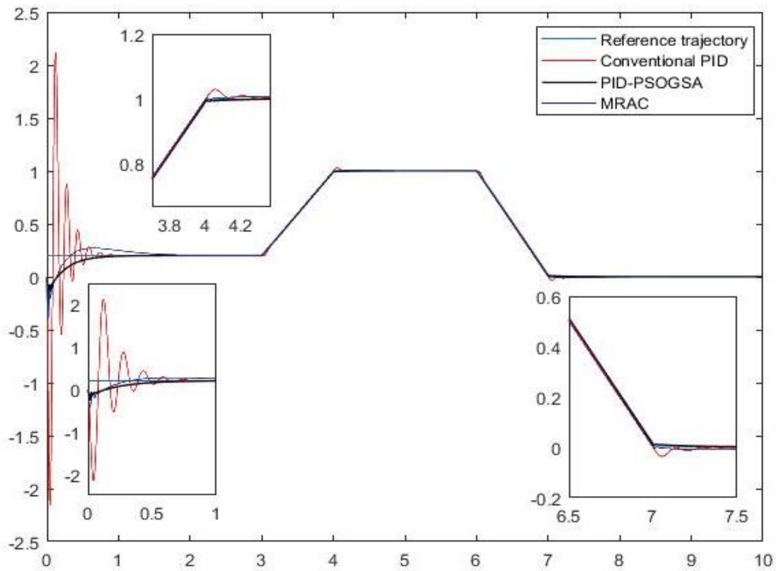

Figure 11. Response of the system with CPID, PID-PSOGSA and MRAC when F_o = 3500 N

The optimization procedure started with 5 particles 10 iterations, then increased to 15 particles 30 iterations and lastly 25 particles and 50 iterations. The reason for increasing the number of particles and iterations is to get the optimal solution for the system. Moreover the idea of the particles and iterations is that for each 5 particles, 10 iterations are going to move around it in the search space then it will take the best solution so far among them and continue the same process until it gets the global best fitness of the system overall as it is shown in the following SSE Table 2. In the SSE table, the values of the Global best fitness are shown in each optimization loop as it is illustrated.

Table 2. SSE Particles

T N	5	10	15	20	25
10	1.6974	1.8437	1.1818	9.5420	1.5201
20	2.2395	1.2720	1.3165	4.3583	4.1127
30	1.6654	1.3324	3.4051	6.1781	2.3875
40	1.5356	5.4396	8.8156	2.7457	1.6182
50	2.3414	7.7045	5.9921	2.4633	1.6477

4. Conclusion

In this paper, three controllers such as PID, PID-PSOGSA and MRAC are successfully designed. Based on the results and the analysis, a conclusion has been made that comparison of CPID, PID-PSOGSA and MRAC controllers in term of the best performance by responding to the changes of the system positions with external disturbance controllers have shown the ability of controlling the nonlinear electro-hydraulic actuator displacement of the piston and fulfilled all the design requirements. The responses of each controller were plotted in one window. Simulation results in Figure 10 and Figure 11 shows that PID-PSOGSA controller has better performance compared to the PID and MRAC controllers. The PSOGSA algorithm has made a significant improvement in the system. Further improvement needs to be done for the modern controller MRAC by optimizing it using PSOGSA algorithm in order to improve the response of the EHA systems.

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