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ROBUST CONTROLLER DESIGN FOR POSITION TRACKING OF NONLINEAR SYSTEM USING BACKSTEPPING-GSA APPROACH

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ABSTRACT

Electro-hydraulic actuator (EHA) system is highly non-linear system with uncertain dynamics in which the mathematical representation of the system cannot sufficiently represent the practical system. Nonlinearities of the system come from either the system itself or external disturbance signals. These dynamic characteristics are the reasons that cause the controller design for the system to be quite challenging. In this paper, back-stepping controller design for tracking purpose of this system is presented based on Lyapunov stability condition. Gravitational Search Algorithm (GSA) technique is then used to optimize the control parameters in order to achieve a predefined system performance. The performance is evaluated based on the tracking output and the tracking error between reference input and the system output. The results show that the system's output follow the reference input given but the tracking performance is influenced by the condition of the system and number of agents and iteration in the algorithm.

Keywords: backstepping, lyapunov function, disturbance, gravitational search algorithm, sum of squared error.

INTRODUCTION

Back-stepping control method permits to obtain global stability in the cases when the feedback linearization method only secures local stability (Anna, *et.al*, 2007). The fundamental concept of back-stepping method is introduced in (Kristic M, *et al*, 1995, Khalil, 2002). It is used as an observer (Nakkarat, *et al,* 2009, Payam, 2006), controller for electro-hydraulic system (Kaddissi, *et al,*2006,Sirouspour,*et.al,*2000, Ursu, *et.al,*2006), enhance the stability of power system (Karimi, 2005), as an adaptive method (Ji Min Le, *et al*, 2009, Qingwei Wang,*et.al*,2006) and controller for electro-pneumatic system (M.Smaoui,*et.al,*2006). The control parameter of back-stepping is important in order to achieve performance target. The value can be determined by several methods such as heuristic approach, artificial intelligent technique (Younes Al-Younes,*et.al,*2006) and optimization algorithm (Chao-Kuang Chen, *et al, 2010*, Anna, *et al*, 2007,Chao-Yong Li, *et al,* 2009, Ali Karimi, *et al,* 2005, Yu Hong, *et al,* 2004, R.J. Wai, *et al*, 2010, Faa-Jeng Lin, *et al,* 2010).

This research work focused on designing back-stepping controller for position tracking of electro hydraulic actuator system (EHA). The control parameters of back-stepping controller are then tuned by using Gravitational Search Algorithm (GSA) technique in order to acquire the suitable values for accurate tracking response. The performance of the designed controller with this technique is evaluated in terms of tracking output and tracking error. Sum of Squared Error (SSE) is used as an objective function for this algorithm. The pattern of SSE value is observed by increasing number of agent and iteration in the simulation process such that the information on the optimum parameters of the controller algorithm which generates optimum output can be attained. The effectiveness of the back-stepping controller is verified in simulation environment under various system set-up subjected to different type of external disturbance given to its actuator.

PROBLEM FORMULATION

Consider a state-space model of EHA system is given as follow [10]:

$$\begin{aligned} \dot{x_1} &= x_2 \\ \dot{x_2} &= -\frac{k}{m}x_1 - \frac{f}{m}x_2 + \frac{S}{m}x_3 - \frac{F_L}{m} \\ \dot{x_3} &= -\frac{S}{k_c}x_2 - \frac{k_l}{k_c}x_3 + \frac{c}{k_c}\sqrt{\frac{p_a - x_3}{2}}\,k_v u \end{aligned} \quad (1)$$

$x_1$is displacement of the load, x_2 is load velocity and $x_3$is the pressure difference between the cylinder chambers caused by load. $F_L$is an external disturbance given to the system and it can be constant or time varying. The control signal for the system based on Lyapunov stability is given as

$$u = \frac{k_c}{\rho_3 c k_v}\sqrt{\frac{2}{P_a - x_3}}\left[-\frac{\rho_2}{m}Se_2 + \frac{\rho_3}{k_c}Sx_2 + \frac{\rho_3}{k_c}k_l x_3 + \rho_3 \dot{x}_{3d} - k_3 e_3\right] \quad (2)$$

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$$x_{3d} = \frac{1}{s}[kx_1 + fx_2 - \frac{\rho_1}{\rho_2}me_1 + m\dot{x_{2d}} - \frac{k_2}{\rho_2}me_2 + F_o] \quad (3)$$

$$x_{2d} = \dot{x_{1d}} - k_1 e_1 \quad (4)$$

SIMULATION RESULTS AND DISCUSSION

The parameter of the testing system is given as $m = 0.33Ns^2/cm$, $S = 10cm^2$, $f = 27.5Ns/cm$, $k = 1000N/cm$, $w = 0.05cm$, $P_a = 2100N/cm^2$, $c_d = 0.63$, $k_l = 2.38 \times 10^{-3}cm^5/Ns$, $k_v = 0.017cm/V$, $k_c = 2.5 \times 10^{-4}cm^5/N$ and $\rho = 8.87 \times 10^{-7}Ns^2/cm^4$. For presentation of results in this chapter, the output plot yielded by 10 agents within 20 iterations, 15 agents within 30 iterations and 25 agents within 50 iterations are chosen for GSA in order to observe the performance of the designed controller with small, medium and bigger number of agents and iterations. Two dissimilar type of signal is given as an external perturbation to the system.

Case 1

In this case, constant value of signal $F_L = 10000$ is added as perturbation to system's actuator. Figure 1, 2 and 3 show the system's output, tracking error and SSE obtained from back-stepping-GSA with 10 agents within 20 iterations, 15 agents within 30 iterations and 25 agents within 50 iterations respectively.

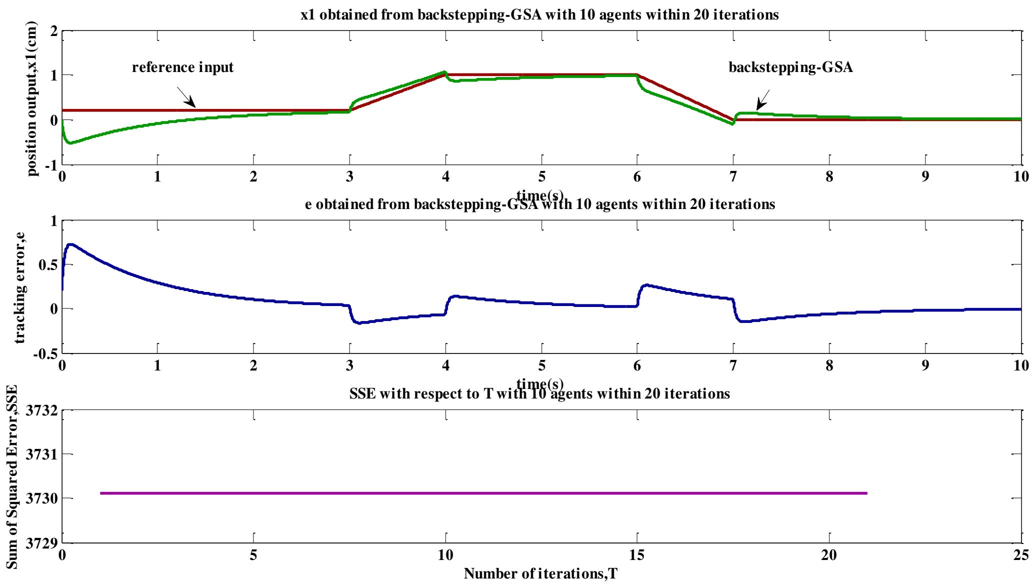

Figure-1. Position output, tracking error and SSE obtained from backstepping-GSA with 10 agents within 20 iterations.

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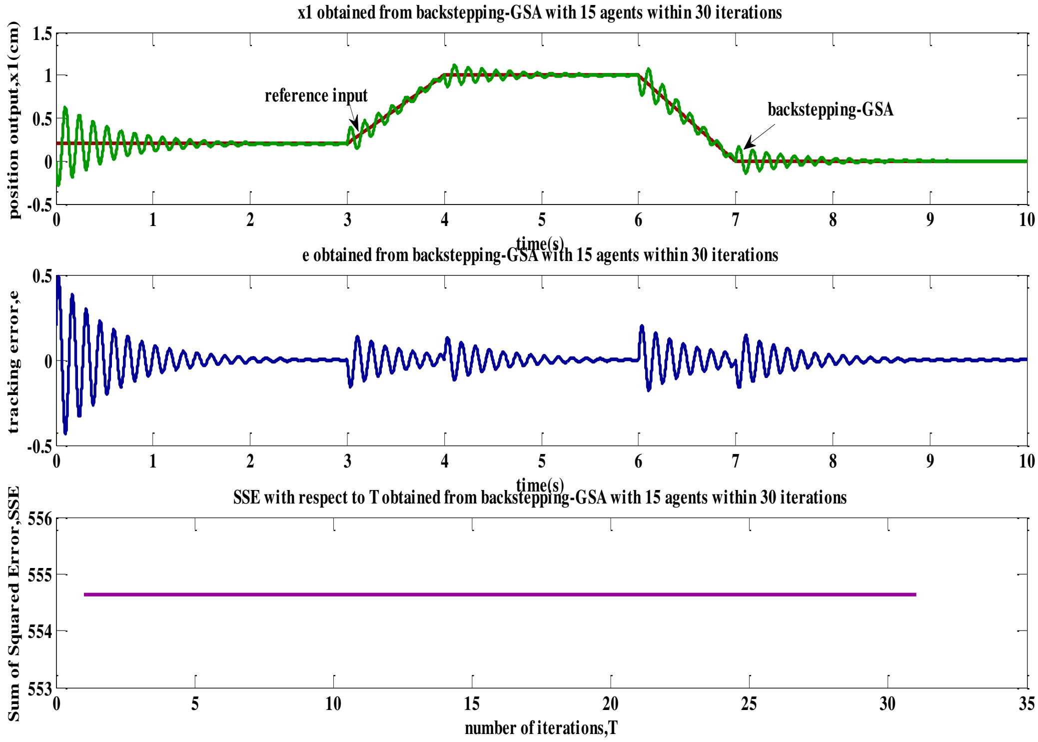

Figure-2. Position output, tracking error and SSE obtained from backstepping-GSA with 15 agents within 30 iterations.

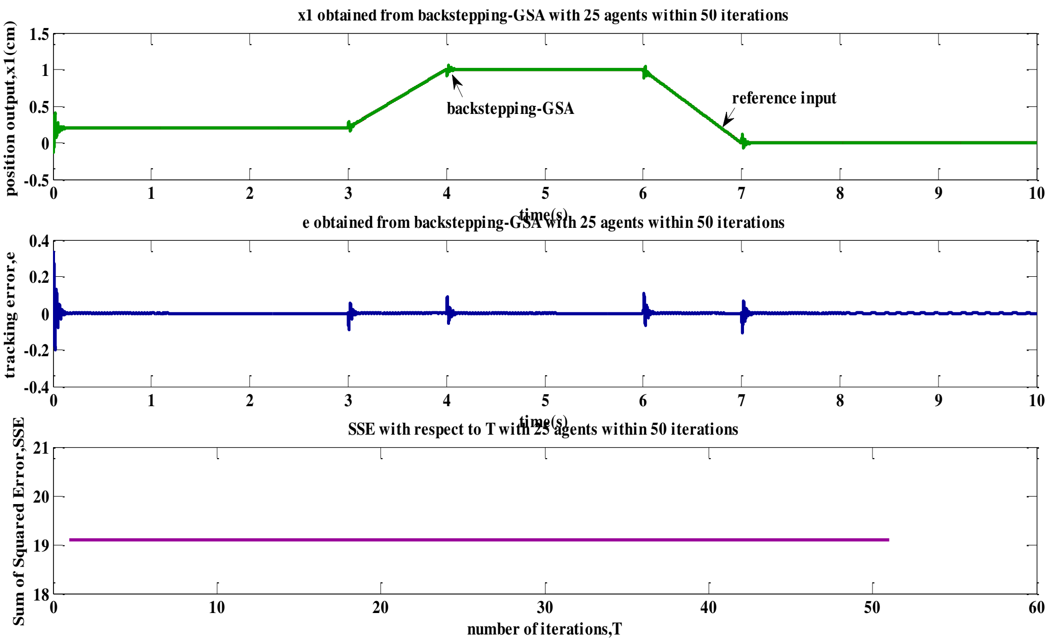

Figure-3. Position output, tracking error and SSE obtained from back-stepping-GSA with 25 agents within 50 iterations.

Referring to these Figures, the top plot illustrates the output yielded by back-stepping-GSA, the middle plot shows its tracking error while the SSE is presented by the bottom plot. Based on these three figures, the tracking output and error of the system is bigger when the system is operates with smaller agents and iterations. However, the values of these parameters are improved with the increment of agents and iterations. Better output performance is produced when the system simulates with more agents within long iterations.

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Case 2

In this case, time-varying signal is given to replace the signal disturbance to the system's actuator. Figure 4, 5 and 6 respectively show system output, tracking error and SSE for incorporation of back-stepping with GSA with 10 agents within 20 iterations, 15 agents within 30 iterations and 25 agents within 50 iterations. By looking at these figures, similar as previous case, the system's output and its tracking error is bigger when smaller agents within short iterations are given to the system. On the other hand, the output and tracking error is improved when the system operates with bigger number of agents within longer iterations.

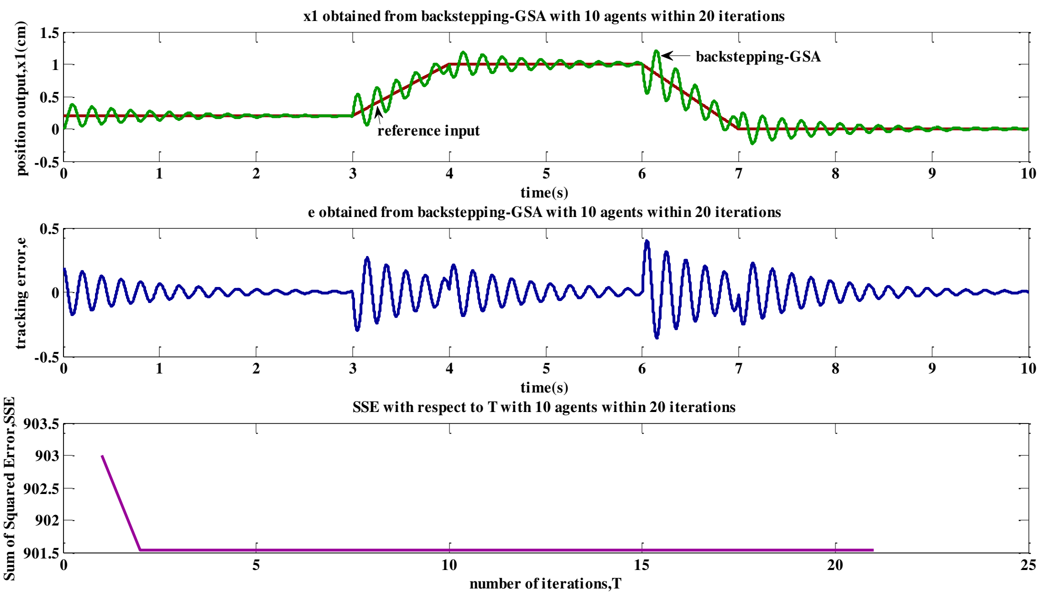

Figure-4. Position output, tracking error and SSE obtained from backstepping-GSA with 10 agents within 20 iterations.

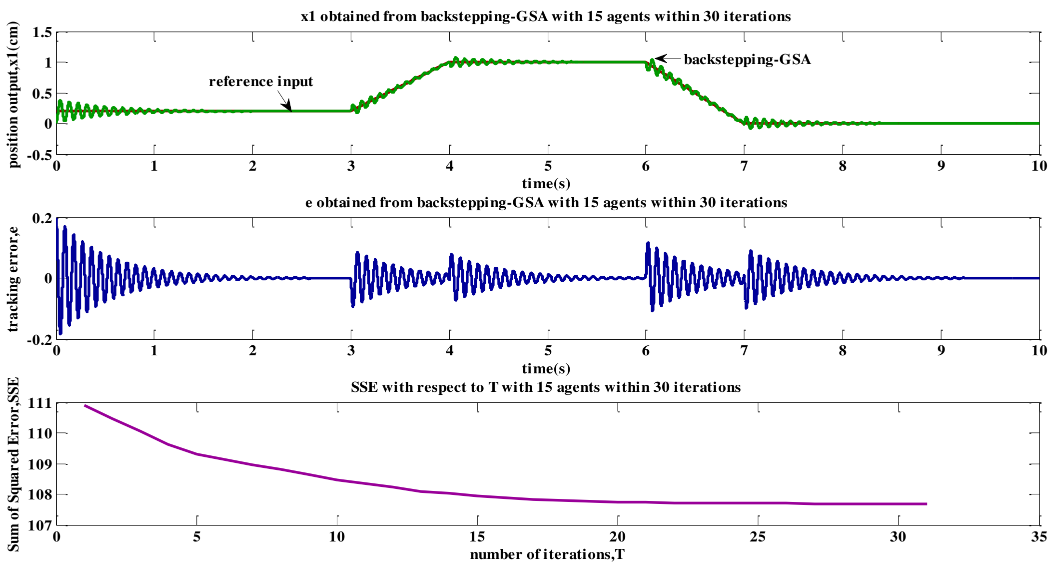

Figure-5. Position output, tracking error and SSE obtained from backstepping-GSA with 15 agents within 30 iterations.

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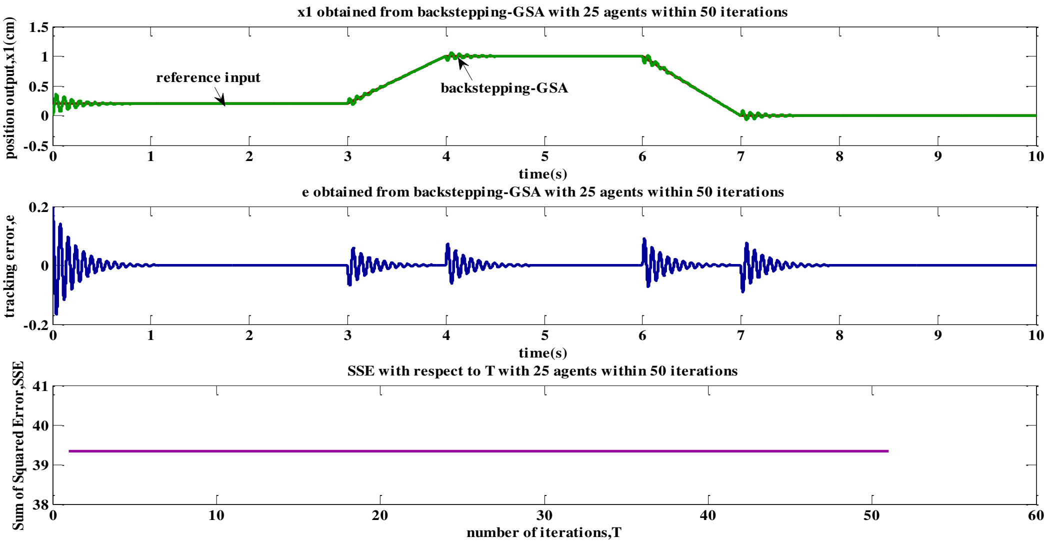

Figure-6. Position output, tracking error and SSE obtained from backstepping-GSA with 25 agents within 50 iterations.

CONCLUSIONS

Generally, the proposed back-stepping controller has mathematically fulfilled the requirement of stability of control system. External perturbation injected to the system's actuator is considered as nonlinearities in the chosen system. Since the performance of the designed controller relies on its control parameters, specific method should be determined in order to obtain the suitable value of these parameters such that good tracking performance is achieved. Although the trial and error method is good enough to set the value of control parameters such that the system's output tracked the reference input given, this manual method consumes a lot of time and require good experience and knowledge of the user to fix it on certain value and condition. Thus, Gravitational Search Algorithm (GSA) technique is integrated with back-stepping controller so that the controller has the own capability to tune its control parameters automatically in any condition of the system. Although back-stepping-GSA applied on the chosen system cannot completely tracked the reference input given smoothly, the performance of this integration of controller still can be improved by providing bigger number of agents and iterations for optimization algorithm. It can be concluded in each case, additional number of agents and iterations of GSA produced better tracking performance with smaller tracking output and oscillation of the system. SSE value generated by the similar algorithm with more number of agent and iteration is also reduced.

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