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Implementation of PID based controller tuned by Evolutionary Algorithm for Double Link Flexible Robotic Manipulator

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***Abstract*—The paper investigates the development of intelligent hybrid collocated and non-collocated PID controller for hub motion and end point vibration suppression of double-link flexible robotic manipulator. The system was modeled using multi-layer perceptron neural network structure based on Nonlinear Autoregressive Exogenous (NARX) model. The hybrid controllers are incorporated with optimization algorithm that is ABC and PSO to find out the parameters of the PID controllers. Numerical simulation was carried out in MATLAB/Simulink to evaluate the system in term of tracking capability and vibration suppression for both links. Performance of the controllers are compared with the hybrid PID-PID Ziegler Nichols (ZN) controller in term of input tracking and vibration suppression. The results show that PSO revealed the superiority over ABC in controlling the system. The system managed to reach desired angle for both hub at lower overshoot using proposed method. Meanwhile, the vibration reduction shows great improvement for both link 1 and 2. This signifies that, the PSO algorithm is very effective in optimizing the PID parameters.**

Keywords—Flexible Manipulator, Neural Network, Particle Swarm Optimization, Artificial Bees Algoritmn, Vibration suppression

I. Introduction

Despite various advantages shown by flexible manipulator such as offers cost reduction, lower power consumption, improved dexterity, better maneuverability, safer operation and light-weight, the undesirable vibration is the common shortcoming occurred in the structure. In order to satisfy the conflicting requirements, number of researches on improving the control methods have been carried out.

Among available wide range controllers, PID controller is still the most widely used in the industrial environment for MIMO systems because they are capable of providing a satisfactory performance in spite of their simple structure and intuitiveness. The main issue of PID controllers is to tune the gains. Other than that, PID controller is still significant because of its robustness performance in a wide range of operating condition and easy to implement.

There is few researches that consider double link flexible robotic manipulator (DLFR) using PID controller. The decentralized PI-PID controller for DLFR have been proposed in [1-2] by employing manual tuning for both PD and PID whereby the parameters of the first link was carried out followed by the second link. The overall system performance has been improved by introducing ILC and adaptive control respectively which were proven in the simulation. Another tuning method that has been implemented in flexible manipulator is simultaneous equation solving method. The Linear matrix inequalities (LMI) based PID control of a nonlinear DLFR incorporating payload have been presented in [3]. Another researcher proposed a class of stabilizing decentralized proportional integral derivative (PID) controller by incorporating bounding parameters of interconnection terms in LMI formulation for an n-link robot manipulator system [4]. Meanwhile, Neural Network (NN) is being utilized to approximate the ZN-PID for each link of DLFR in [5] which can be categorized under Independent method.

Evolutionary Algorithms have been used in various areas including in developing tuning method of PID controller for flexible manipulator. For instance, hybrid PD-PD/Iterative learning Algorithm (ILA) tuned by Genetic Algorithm for single-link flexible manipulator (SLFM) is presented in [6], a multi-objective optimization using Differential Evolution (MODE) for PID controller of SLFM studied in [7], an improved Bacterial Foraging Algorithms (BFA) to tune the PID controller of SLFM is proposed in [8], Bee Algorithm is used to optimize the hierarchical PID parameter of SLFM in [9] and particle swarm optimization (PSO) algorithm to tune parameter of one PID controller of SLFM in [10].

In this paper, a hybrid PID-PID controller is developed for double link flexible robotic manipulator (DLFR) based on the NARX model plant as elaborated in [11]. The global search of ABC and PSO are utilized to optimize all the PID controllers' gains.

II. SYSTEM CONTROLLER

A. Control Scheme

The control scheme is shown in Fig.1. The PID_{i1} controller is developed for hub angle motion while PID_{i2} controller is applied for flexible body motion. The two loops of each link ($i=1,2$) are combined together to give control inputs that work simultaneously for the double link flexible robotic manipulator system.

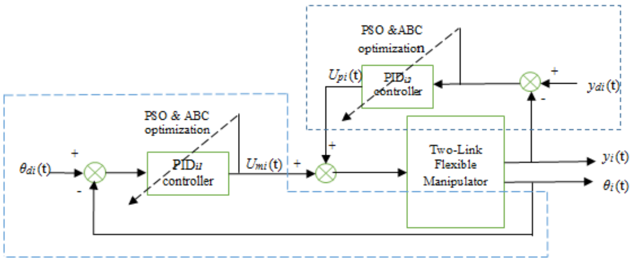


Fig. 1. Hybrid controller structure of double link flexible robotic manipulator.

B. Control Design

For the hub angle motion, θ_{di} , and $\theta_i(t)$ represents reference hub angle and actual hub angle of the system respectively. By referring to Fig. 2, the close loop signal of U_{mi} can be written as;

$$U_{mi}(t)= A_{mi}\left[\left(K_{Pi}[\theta_{id}(t)-\theta_i(t)]+K_{Ii}\int\theta_i dt+K_{Di}\frac{d\theta_i}{dt}\right)\right] \quad (1)$$

where U_{mi} is PID control input, A_{mi}, K_{Pi}, K_{Ii} *and* K_{Di} are motor gain, proportional, integral and derivative gain respectively. The error function of the system defined as in Eq. (2);

$$e_i(t)=[\theta_{di}(t)-G_m\theta_i(t)] \quad (2)$$

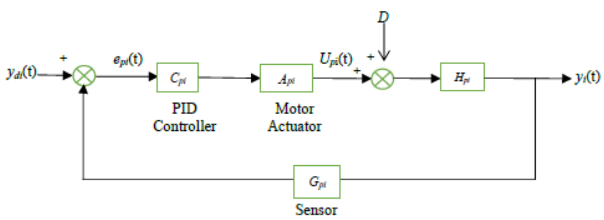


Fig.2. Block diagram of rigid body motion

The block diagram shown in Fig. 3 is for the flexible motion. Thus, the close loop signal for the control input is given by;

$$U_{pi}(t)= A_{pi}[(K_{Pi}+K_{Ii}\int dt+K_{Di}(d/dt))*e_{vi}(t)] i=1,2 \quad (3)$$

where U_{pi} is PID control input, A_{pi}, K_{Pi}, K_{Ii} *and* K_{Di} are piezoelectric gain, proportional, integral and derivative gain respectively. The reference endpoint displacement $y_{di}(t)$ is set to zero. Thus e_i is defined as;

$$e_{vi}(t)=[0-G_A y_i(t)] \quad (4)$$

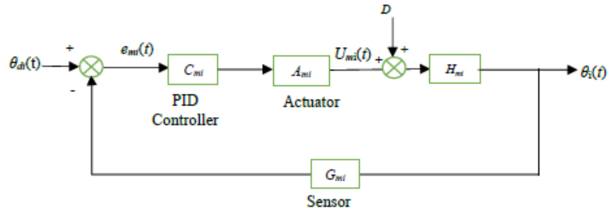


Fig. 3. Block diagram of flexible body motion

All the parameters of K_{Pi}, K_{Ii} and K_{Di} were tuned using global optimization method so that U_{Mi} and U_{pi} provide acceptable performance of DLFR. The performances of the algoritmn in tuning the PID controller was based on minimizing the MSE value.

III. OPTIMIZATION METHOD

The proposed control structure using novel evolutionary algorithms of PSO and ABC are adopted to tune the PID controllers' parameters. The objective functions of optimization are formulated based on the MSE of the hub angle error and end point vibration suppression. The details of algorithm as follow.

A. Particle Swarm Optimization (PSO)

PSO is initialized with a group of random particles and then searches for optimum by updating generations. The particle updates its velocity and positions with following Eq. (5) and (6).

$$V_{id}^{k+1}=W\ *V_{id}^{k}+C_1*R_1*(Y_{id}^{k}-X_{id}^{k})+C_2*R_2*(Y_{id}^{k}-X_{id}^{k}) \quad (5)$$

$$X_{id}^{k+1}=Y_{id}^{k}-X_{id}^{k} \quad (6)$$

where V= particle velocity, X= particle position, W= Inertia weight, R_1, R_2 = random number and C_1, C_2 = learning factors. In this research, C_1 = C_2 is chosen as 2 and R_1, R_2 is between 0 and 1. The starting and end point of inertia weight, W set as 0.9 and 0.25. The flowchart of PSO algorithm is shown in Fig. 4.

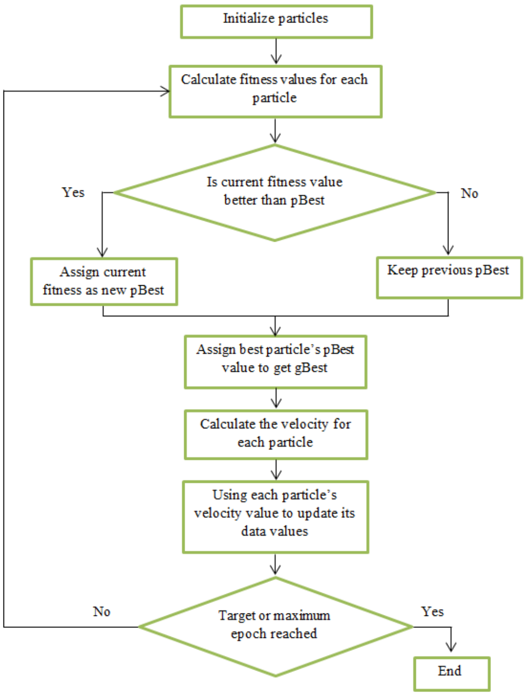


Fig. 4. Flow chart of Particle Swarm Optimization Algorithm

B. *Artificial Bees Colony Algorithm (ABC)*

ABC is inspired by intelligent behavior of honey bees to look for the best food location.

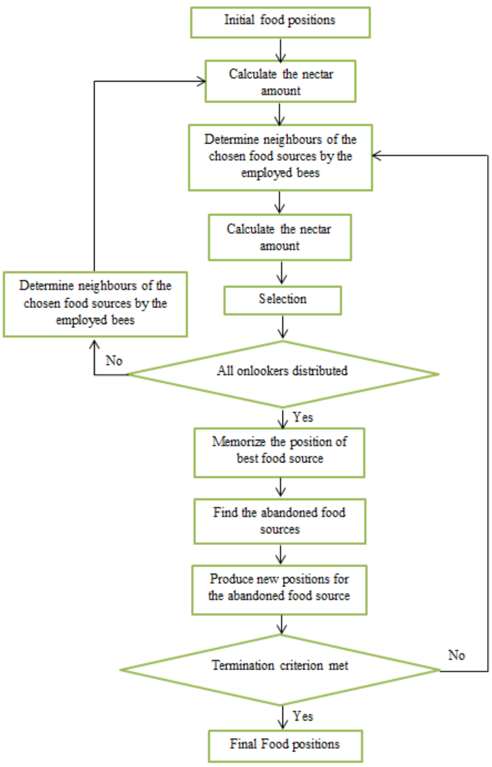


Fig. 5. Flowchart of Artificial Bees Colony Algorithm

The fitness is calculated by the following formula (7), after that a greedy selection is applied between x_m and v_m.

$$fit_m(x_m) = \frac{1}{1+f_m(x_m)}, f_m(x_m) > 0$$

$$fit_m(x_m) = 1 + |f_m(x_m)|, f_m(x_m) < 0 \quad (7)$$

where, f_m (x_m) is the objective function value of x_m. The quantity of a food source is evaluated by its profitability. P_m is determined by the formula;

$$P_m = \frac{fit_m(x_m)}{\sum_{m=1}^{SN} fit_m(x_m)} \quad (8)$$

where, $fit_m(x_m)$ is the fitness of x_m.The procedure of ABC algorithm is illustrated in the flowchart in Fig. 5.

IV. RESULTS AND DISCUSSION

Results of the simulation are divided into two sections that are hub angle control and flexible motion control.

A. *Hub angle control*

The hub angles were controlled by the collocated PID controller individually. The DLFR system is required to follow a step input of 2.1 rad and 1.1 rad to test the hub tracking input of link 1 and 2 respectively. The hub angle response for both links are shown in Fig. 6.

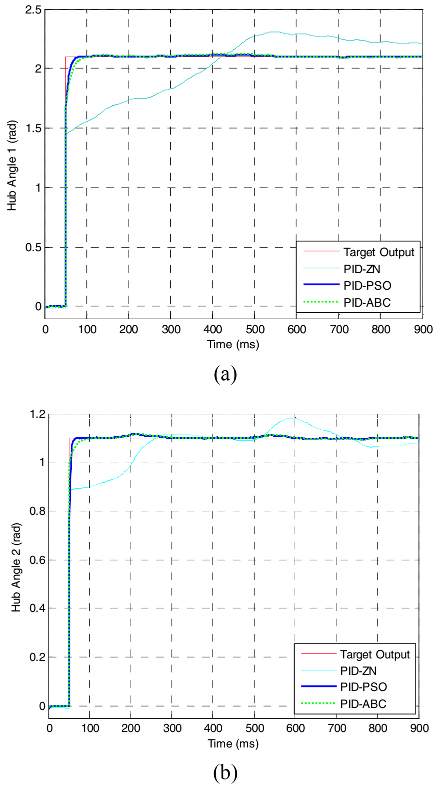


Fig. 6. (a) Input tracking for Hub 1 (b) Input tracking for Hub 2

PSO and ABC controller achieved a very significance improvement in term rise time, steady state error and overshoot as compared to Ziegler-Nichols (ZN).
Table I shows that the rise time, steady state error and overshoot value of the PID-PSO controller for link 1are recorded at the lower value compared to ABC-based control. Though ABC-based control provides slightly lower settling time, but the overshoot value is almost double the overshoot

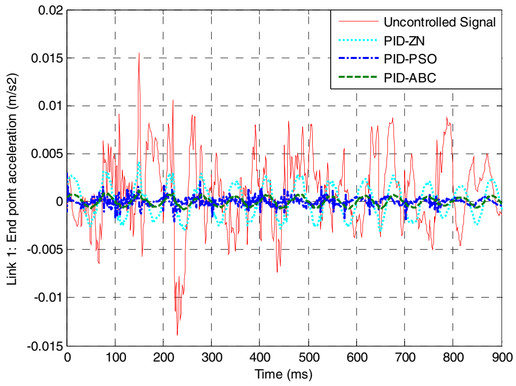
value of PSO-based control. Referring to [10], there should be a trade-off between minimum overshoot and settling time. For link 2, PID-PSO controller gives shorter rise time, lower settling time, lower overshoot value and steady state error in comparison with each other. Overall, the results showed PSO-based controller supersede ABC-based controller in all aspect of system response. In general, both the proposed controllers used in this work achieved satisfactory hub angle response. However, in overall PSO lead the ABC in giving better results.

TABLE I. PARAMETERS AND PERFORMANCE OF HUB INPUT TRACKING FOR DLFR SYSTEM

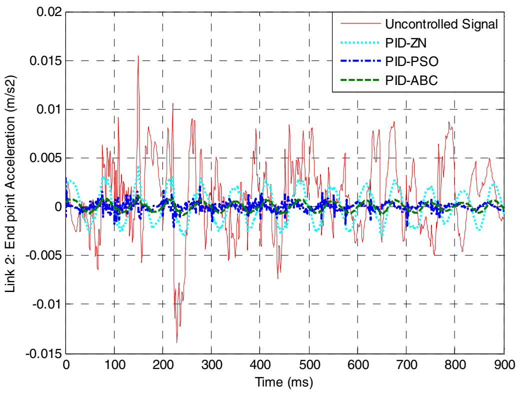
		Parameters			Rise Time (s)	Sett. Time (s)	Over shoot (%)	SSE
		K_P	K_I	K_D				
ABC	L 1	6.54	20.5	49.43	0.076	1.08	1.94	0.007
	L 2	5.48	28.3	13.72	0.099	5.64	3.19	0.002
PSO	L1	3.65	57.9	3.46	0.058	1.16	0.89	0.003
	L 2	2.19	88.2	0.79	0.043	0.59	1.64	0.002
ZN	L1	2.09	0.54	2.01	2.97	7.15	4.69	0.681
	L2	4.15	1.3	3.32	1.46	5.45	5.45	0.284

B. *Flexible motion control*

The non-collocated PID controllers were implemented to DLFR system to actively suppress the vibration at the end point of link 1 and 2 individually. The simulation results of vibration suppression are presented in Fig. 7.



(a)



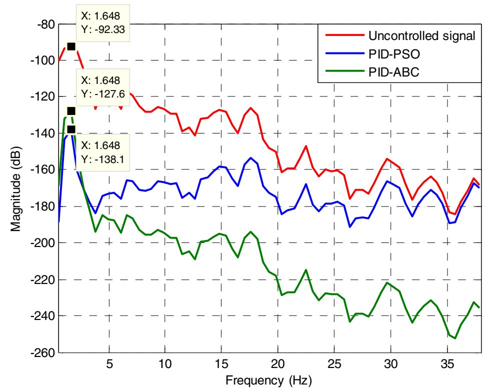
(b)

Fig. 7. (a) End point vibration suppression of Hub 1(b) End point vibration suppression of Hub 2

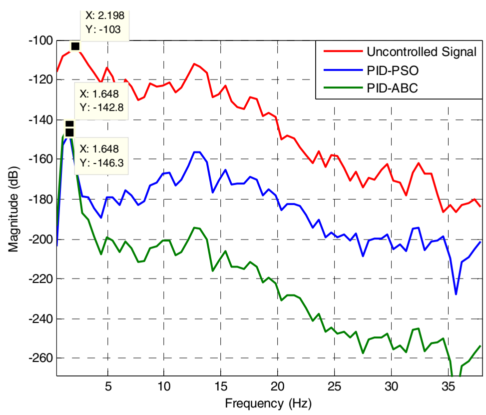
The vibration can be further suppressed by employing the ABC and PSO controller as compared to ZN. It can be observed from Fig. 7 that the responses from ABC and PSO tuning methods are having almost the same amplitude of vibration. Numerical results presented in Table II shows that the MSE value of the PID-PSO controller is recorded at the lower value in comparison to PID-ABC controller. This could be further investigated from frequency domain result as shown in Fig.8. PSO-based control provides the highest attenuation value of mode 1, meanwhile ABC-based control gives highest attenuation value of mode 2 and 3. However, the first mode is dominant and contributes substantial effect to the system. Overall, PSO shows the superiority over ABC

TABLE II: PARAMETERS AND PERFORMANCE OF VIBRATION SUPPRESSION FOR DLFR SYSTEM.

		Parameters			MSE	Attenuation of amplitude at natural frequency (dB)		
		K_P	K_I	K_D		1st	2nd	3rd
ABC	L1	30.03	56.07	88.95	7.919e-07	35.27	67.7	67.6
	L2	50.1	46.96	23.62	8.432e-08	39.8	82.2	83.4
PSO	L1	2.07	498.1	2.04	3.948e-08	45.8	27	12
	L2	8.06	817.9	1.03	4.315e-08	43.3	44.4	32.6
ZN	L1	7.2	21.176	0.612	2.822e-06	8.9	41	40.9
	L2	16	55.082	1.281	7.564e-07	11.8	53.3	54.4



(a)



(b)

Fig. 8.Comparison of spectral density of PID-PSO and PID-ABC controller (a) Link 1 (b) Link 2

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CONCLUSION

In this work, the intelligent Hybrid PID-PID controllers have been developed for DLFR. The controllers have been compared with hybrid PID-ZN controller. The proposed control schemes have been tested through simulation in Matlab/Simulink environment. The proposed controllers are able to follow the reference trajectory and the vibration of the system is eliminated simultaneously through end point acceleration feedback. The system managed to reach desired angle at lower overshoot using proposed method that is with the improvement of 80.85% and 69.89% respectively as compared with the ZN. And the settling time is very much faster that is from 2.97 s to 0.05 s for hub 1 and from 1.46 s to 0.043 s for hub 2. Meanwhile, the vibration reduction shows great improvement that is about 96.01% for link 1 and 90.67% for link 2. Overall, it is revealed that PSO controllers offer the best outcomes compared to ABC.

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