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Particle Swarm Optimization Based Tuning of PID Controller for Robot Arm Joint Control

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ABSTRACT: Most fuzzy controllers have been treated and utilized as ebony-box controllers in the sense that their analytical structures are unknown. Kenning the explicit structure information will enable one to insightfully understand how a fuzzy control works. In this paper analytical structure of fuzzy PID controller is developed with minimum number of regions and rules compared to already subsisting methods. The efficacy of the controller is tested on Robot arm. Results are compared with the conventional controller.

KEYWORDS: Fuzzy controller, Robot arm. Triangular fuzzy sets.

I.INTRODUCTION

Fuzzy controllers are constructed via soi-disant perspicacious system approaches as opposed to the mathematical approaches exclusively utilized in conventional control. The fuzzy controllers have been treated and utilized as ebony box controllers. Without analytical structure information, precise and efficacious mathematical analysis and design are very arduous to achieve. Availability of the structure information may lead to less trail and error effort and engender better control performance.

The fuzzy AND operators that are widely used are Product AND operator and Zadeh AND operator. Deriving analytical structure of the fuzzy controller that utilizes the former operator is not arduous, regardless of the shape of the input fuzzy sets. This is because it is straightforward to carry out multiplication of multiple membership functions in a fuzzy rule. However, revealing the analytical structure of a fuzzy controller that utilizes Zadeh AND operator is far more arduous even for triangular input fuzzy sets, which are simplest fuzzy sets because this operator requires the comparison of membership functions. In 1990 a technique in the literature to cover Zadeh AND operator and a particular class of symmetric trapezoidal fuzzy sets [1] is developed. That method is widely used (e.g. [2], [3] and [4]). Later it is generalized to cover arbitrary trapezoidal fuzzy sets [5]. Then a technique of deriving input output structure applicable to arbitrary types of input fuzzy sets is withal developed [6]. Recently that is elongated to derive the relationship between input space divisions needed due to the utilization of Zadeh AND operator and input fuzzy sets [7] [8] [9].The incrementing demand on robotic system performance leads to the utilization of advanced control strategies. It has been reported that authentic-time control of a manipulator predicated on a detailed mathematical model is arduous to achieve, as the model is both involute and nonlinear. In such situations fuzzy controllers do well. In this paper the robotic arm control is simulated to ken the efficacy of the fuzzy controller utilizing symmetrical input membership functions.

II. DEVELOPMENT OF A GENERAL TECHNIQUE

Most of the popular fuzzy controllers developed so far take two inputs, such as error and rate of change of error (rate for short) about a set point. However, the nonlinear fuzzy PID controller proposed in this paper has a supplemental input designated expedited rate of change of error (acc for short) to amend the transient replication of nonlinear dubious systems. The configuration of the FLC suggested is shown in Fig. 1.

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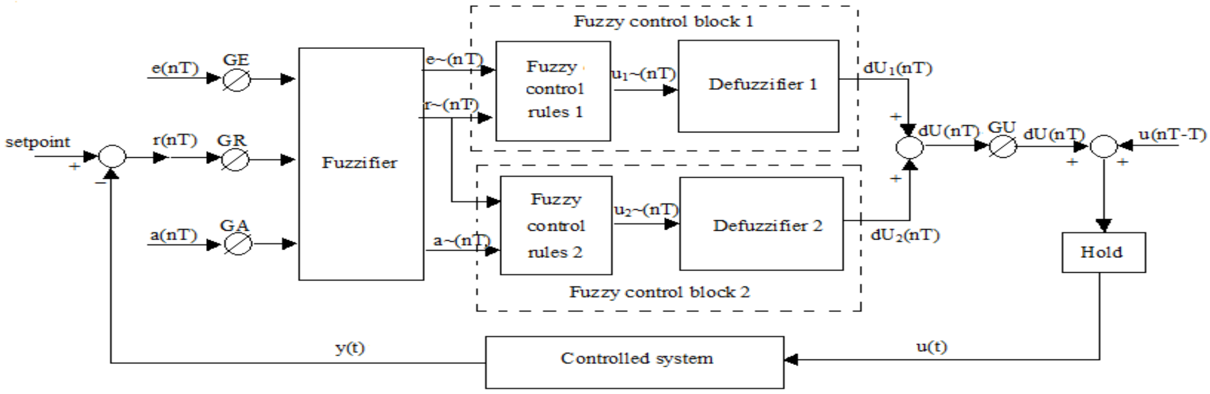

Fig 1: The structure of FPID Controller

With these three inputs the structure of the FLC is compared of two independent parallel fuzzy control blocks, each of which contains the corresponding fuzzy control rules and a defuzzifier. The incremental output of the FLC is composed by algebraically integrating the outputs of the two fuzzy control blocks. The following notations are employed.

$e(t)$= set point-$y(t)$, $e(nT)$ = sample $[e(t)]$

$\tilde{e}(nT) = F(e^*)$, $e^*=GE \times e(nT)$

$r(nT) = [e(nT)-e(nT-T)]/T$

$\tilde{r}(nT) = F(r^*)$, $r^* = GR \times r(nT)$

$a(nT) = [r(nT)-r(nT-T)]/T$
$= [e(nT)-2e(nT-T)+e(nT-2T)]/T^2$

$\tilde{a}(nT) = F(a^*)$, $a^* = GA \times a(nT)$

$u(nT) = du(nT)+u(nT-T)$

$du(nT) = GU \times dU(nT)$

$dU(nT) = dU_1(nT)+dU_2(nT)$

Where n is positive integer and T is the sampling period. y(nT), e(nT), r(nT) and a(nT) denote process output, error, rate and acc at sampling time nT, respectively. GE (gain for error) is the input scalar for rate, GA (gain for acc) the input scalar for acc and GU (gain for controller output) the output scalar of the FLC. F(.) describes the fuzzification of the scaled output of the FLC at sampling time nT.dUi(nT) (i=1,2) designate the incremental output of the fuzzy control block i from the defuzzification of the fuzzy set 'output i' ui~(nT) at sampling time nT. Thus the FLC includes the following components.

(1) Input scalars GE, GR, GA and output scalar GU
(2) Fuzzification algorithms for scaled error e*, scaled rate r*, scaled acc a* and output of each control block.
(3) Fuzzy control rules for each control block.
(4) Fuzzy decision-making logic to evaluate the fuzzy control rules for each control block.
(5) A defuzzification algorithm to obtain the crisp output of each control block for the control of process.

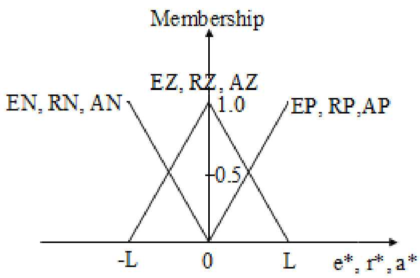

Fig. 2 Inputs e*, r* and a* of FPIDC

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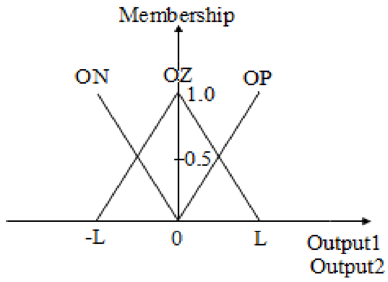

Fig. 3 Output of fuzzy control block 1 and 2

A. Fuzzification Algorithms: The fuzzification for scaled inputs is shown in Fig. 2. The fuzzy set 'error' has three membership EP(error positive), EZ(error zero) and EN(error negative), the fuzzy set 'rate' has three members RP(rate positive), RZ(rate zero) and RN(rate negative), the fuzzy set 'acc' also has three members AP(acc positive), AZ(acc zero) and AN(acc negative). The fuzzy set 'output1 and output2' has three members OP(output positive), OZ(output zero) and ON(output negative) as shown in Fig.3.

B. Fuzzy Control Rules

For the fuzzy control rules for each fuzzy control block 1, nine control rules are given as:

$(R1)_1$: IF error = EN and rate = RN THEN output = ON, h_{-2}
$(R2)_1$: IF error = EZ and rate = RN THEN output = ON, h_{-1}
$(R3)_1$: IF error = EP and rate = RN THEN output = OZ, h_0
$(R4)_1$: IF error = EN and rate = RZ THEN output = ON, h_{-1}
$(R5)_1$: IF error = EZ and rate = RZ THEN output = OZ, h_0
$(R6)_1$: IF error = EP and rate = RZ THEN output = OP, h_1
$(R7)_1$: IF error = EN and rate = RP THEN output = OZ, h_0
$(R8)_1$: IF error = EZ and rate = RP THEN output = OP, h_1
$(R9)_1$: IF error = EP and rate = RP THEN output = OP, h_2

For the fuzzy control block 2, nine control rules, are given as:

$(R1)_2$: IF rate = RN and acc = AN THEN output = ON, h_{-2}
$(R2)_2$: IF rate = RZ and acc = AN THEN output = ON, h_{-1}
$(R3)_2$: IF rate = RP and acc = AN THEN output = OZ, h_0
$(R4)_2$: IF rate = RN and acc = AZ THEN output = ON, h_{-1}
$(R5)_2$: IF rate = RZ and acc = AZ THEN output = OZ, h_0
$(R6)_2$: IF rate = RP and acc = AZ THEN output = OP, h_1
$(R7)_2$: IF rate = RN and acc = AP THEN output = OZ, h_0
$(R8)_2$: IF rate = RZ and acc = AP THEN output = OP, h_1
$(R9)_2$: IF rate = RP and acc = AP THEN output = OP, h_2

In this way, the membership values are given as

$$\mu_{EN} = [-e^*/L] = [-GE \times e(nT)]/L \qquad -L \leq e^* \leq 0$$

$$\mu_{EZ} = [e^*+L]/L = [GE \times e(nT)+L]/L \qquad -L \leq e^* \leq 0$$
$$= -[e^*-L]/L = -[GE \times e(nT)-L]/L \qquad 0 \leq e^* \geq L$$

$$\mu_{EP} = [e^*/L] = [GE \times e(nT)]/L \qquad 0 \leq e^* \leq L$$

$$\mu_{RN} = [-r^*/L] = [-GR \times r(nT)]/L \qquad -L \leq r^* \leq 0$$

$$\mu_{RZ} = [r^*+L]/L = [GR \times r(nT)+L]/L \qquad -L \leq r^* \leq 0$$

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$= -[r^*-L]/L = -[GR \times r(nT)-L]/L \quad 0 \le r^* \le L$

$\mu_{RP} = [r^*/L] = [GR \times r(nT)]/L \quad 0 \le r^* \le L$

$\mu_{AN} = [-a^*/L] = [-GA \times a(nT)]/L \quad -L \le a^* \le 0$

$\mu_{AZ} = [a^*+L]/L = [GA \times a(nT)+L]/L \quad -L \le a^* \le 0$

$= -[a^*-L]/L = -[GA \times a(nT)-L]/L \quad 0 \le a^* \le L$

$\mu_{AP} = [a^*/L] = [GA \times a(nT)]/L \quad 0 \le r^* \le L$

$\mu_{EP} + \mu_{EN} = 1$
$\mu_{RP} + \mu_{RN} = 1$
$\mu_{AP} + \mu_{AN} = 1$

C. Defuzzification Algorithm:

Thus the defuzzified output of a fuzzy set is defined as

$$dU = \frac{\Sigma(membership\ of\ member) \times (value\ of\ member)}{\Sigma(membership)}$$

For $(IC1)_1$ and $(IC2)_1$
If $GR \times |r(nT)| \le GE \times |e(nT)| \le L$,

$$dU1(nT) = \frac{-e*(h_{-2}+h_{-1}+h_1)+r*(-h_{-1}-h_1+h_2)+2Lh_1}{1-4e^*-3r^*+3L}$$

For $(IC3)_1$ and $(IC4)_1$
If $GE \times |e(nT)| \le GR \times |r(nT)| \le L$,

$$dU1(nT) = \frac{-r*(h_{-2}+h_{-1}+h_1)+e*(-h_{-1}-h_1+h_2)+2Lh_1}{1-4r^*-3e^*+3L}$$

For $(IC5)_1$ and $(IC6)_1$
If $GR \times |r(nT)| \le GE \times |e(nT)| \le L$,

$$dU1(nT) = \frac{-r*(h_{-2}-h_{-1}-h_1)+e*(h_{-1}+h_1+h_2)+2Lh_1}{1+5e^*+2r^*+3L}$$

For $(IC7)_1$ and $(IC8)_1$
If $GE \times |e(nT)| \le GR \times |r(nT)| \le L$,

$$dU1(nT) = \frac{-e*(h_{-2}-h_{-1}-h_1)+r*(h_{-1}+h_1+h_2)+2Lh_1}{1+2r^*+5e^*+3L}$$

The incremental output of fuzzy control block 2 at sampling time nT, dU2(nT), can be given by the following two equations. For $(IC1)_2$ and $(IC2)_2$
If $GA \times |a(nT)| \le GR \times |r(nT)| \le L$,

$$dU2(nT) = \frac{-r*(h_{-2}+h_{-1}+h_1)+a*(-h_{-1}-h_1+h_2)+2Lh_1}{1-4r^*-3a^*+3L}$$

For $(IC3)_2$ and $(IC4)_2$
If $GR \times |r(nT)| \le GA \times |a(nT)| \le L$,

$$dU2(nT) = \frac{-a*(h_{-2}+h_{-1}+h_1)+r*(-h_{-1}-h_1+h_2)+2Lh_1}{1-4a^*-3r^*+3L}$$

For $(IC5)_2$ and $(IC6)_2$
If $GR \times |r(nT)| \le GA \times a(nT)| \le L$,

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$$dU2(nT) = \frac{-a*(h_{-2}-h_{-1}-h_1)+r*(h_{-1}+h_1+h_2)+2Lh_1}{1+5r^*+2a^*+3L}$$

For $(IC7)_2$ and $(IC8)_2$

If $GA\times|a(nT)|\leq GR\times|r(nT)|\leq L$,

$$dU2(nT) = \frac{-r*(h_{-2}-h_{-1}-h_1)+a*(h_{-1}+h_1+h_2)+2Lh_1}{1-4r^*-3a^*+3L}$$

$$dU(nT) = dU_1(nT)+ dU_2(nT)$$

Conclusively, the output of the FLC can be divided into four different forms according to the following conditions:

(1) If $GR\times|r(nT)|\leq GE\times|e(nT)|\leq L$, and

$GA\times|a(nT)|\leq GR\times|r(nT)|\leq L$,

$$dU(nT) = -e^*\frac{(h_{-2}+h_{-1}+h_1)}{1-4e^*-3r^*+3L} - r^*\left[\frac{(h_{-1}+h_1-h_2)}{1-4e^*-3r^*+3L}+\frac{(h_{-2}+h_{-1}+h_1)}{1-4r^*-3a^*+3L}\right] - a^*\frac{(h_{-1}+h_1-h_2)}{1-4r^*-3a^*+3L}$$

(2) If $GR\times|r(nT)|\leq GE\times|e(nT)|\leq L$, and

$GR\times|r(nT)|\leq GA\times|a(nT)|\leq L$,

$$dU(nT) = -e^*\frac{(h_{-2}+h_{-1}+h_1)}{1-4e^*-3r^*+3L} - r^*\left[\frac{(h_{-1}+h_1-h_2)}{1-4e^*-3r^*+3L}+\frac{(h_{-2}+h_{-1}+h_1)}{1-4a^*-3r^*+3L}\right] - a^*\frac{(h_{-2}+h_{-1}+h_1)}{1-4a^*-3r^*+3L}$$

(3) If $GE\times|e(nT)|\leq GR\times|r(nT)|\leq L$, and

$GA\times|a(nT)|\leq GR\times|r(nT)|\leq L$,

$$dU(nT) = -e^*\frac{(h_{-1}+h_1-h_2)}{1-4r^*-3e^*+3L} - r^*\left[\frac{(h_{-2}+h_{-1}+h_1)}{1-4r^*-3e^*+3L}+\frac{(h_{-2}+h_{-1}+h_1)}{1-4r^*-3a^*+3L}\right] - a^*\frac{(h_{-1}+h_1-h_2)}{1-4r^*-3a^*+3L}$$

(4) If $GE\times|e(nT)|\leq GR\times|r(nT)|\leq L$, and

$GR\times|r(nT)|\leq GA\times|a(nT)|\leq L$,

$$dU(nT) = -e^*\frac{(h_{-1}+h_1-h_2)}{1-4r^*-3e^*+3L} - r^*\left[\frac{(h_{-2}+h_{-1}+h_1)}{1-4r^*-3e^*+3L}+\frac{(h_{-1}+h_1-h_2)}{1-4r^*-3a^*+3L}\right] - a^*\frac{(h_{-2}+h_{-1}+h_1)}{1-4r^*-3a^*+3L}$$

An important fact described as below

$dU(nT) = K_i\, e(nT)+ K_p\, r(nT)+ K_d\, a(nT)$

Let

$$K_i = \frac{(h_{-2}+h_{-1}+h_1)}{1-4r^*-3e^*+3L}$$

$$K_p = -\left[\frac{(h_{-1}+h_1-h_2)}{1-4e^*-3r^*+3L}+\frac{(h_{-2}+h_{-1}+h_1)}{1-4r^*-3a^*+3L}\right]$$

$$K_d = -\frac{(h_{-1}+h_1-h_2)}{1-4r^*-3a^*+3L}$$

Then the following equation can be written and fuzzy controller in this work can be considered as a PID type controller with gains K_p, K_i and K_d which are changed nonlinearly according to the error, rate and acc. That is,

$$dU(nT) = K_i\, e(nT)+ K_p\, r(nT)+ K_d\, a(nT)$$

This nonlinear type PID controller may be named a nonlinear fuzzy PID controller, where K_p is defined a proportional gain, K_i an integral gain and K_d a derivative gain. In a similar fashion, K_p, K_i and K_d can be obtained for other regions.

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III. ROBOT ARM JOINT MOTION CONTROL USING FUZZY PID CONTROLLER

The block diagram of the system under consideration is given by Fig 7. The parameter values are [10], A= 10, Ra= 1.64 Ω (including brush resistance), Kt= 10.02 o.z-in./A, Ke= 0.0708 V/rad/s, La = 3.39 mH, B= 9.55 e -4 o.z-in./rad/s, J_m=0.0038 o.z-in.-s^2, T = 1/6280.

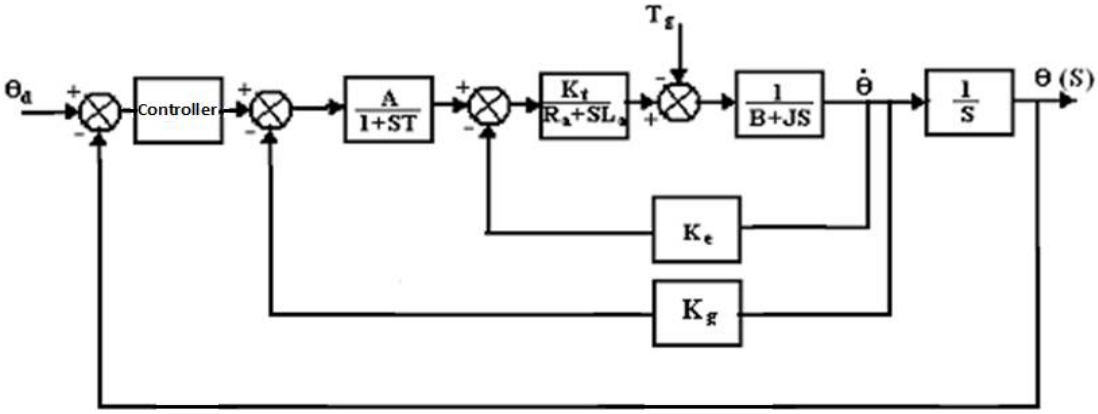

Fig. 4 Block diagram of robot arm with compensators

To see more clearly the effects of the gravity disturbance on robot arm joint consider Fig. 4. It is observed that initially when the joint is at $\theta = 0$ rad, the gravitational force produces no additional load on the axis motor. However as θ increases with time due to the command signal, the gravitational disturbance also increases and is proportional to the sine of θ . For particular joint geometry, we will assume that the magnitude of this disturbance is 21oz-in. so that the time variation of gravitational torque will be

$$T_{gr} = 21 sin\theta$$

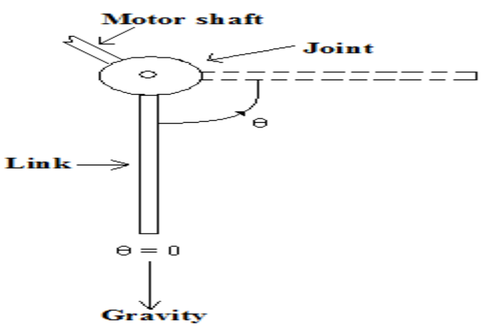

Fig. 5 Joint showing the effect of gravity as a function of θ

Let the joint be initially at θ = 0 rad, and the desired final position of the joint be π/2 radians, so that θ_d = π/2 rad = 1.57 rad.

Overview of the particle swarm optimization (PSO)

PSO is nature-inspired heuristic optimization method which first proposed by Kennedy and Eberhart. It belongs to the category of Swarm Intelligence methods. Its development was based on mimicking the movement of individuals within a swarm (i.e., fishes, birds, and insects) in an effort to find the optima in the problem space. It has been noticed that members of the swarm seem to share information among them. This communication fact leads to increase efficiency of the swarm. The PSO algorithm searches in parallel using a group of individuals similar to other population-based heuristic optimization techniques. PSO technique conducts search using a population of particles, corresponding to individuals. Each particle represents a candidate solution to the problem at hand. In a PSO system, particles change

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their positions by "flying" around in a multidimensional search space. Particle in a swarm adjust its position in search space using its present velocity, own previous experience, and that of neighbouring particles. Therefore, a particle makes use of best position encountered by itself and that of its neighbours to steer toward an optimal solution. The performance of each particle is measured using a predefined fitness function, which quantifies the performance of the optimization problem. The mathematical expressions for velocity and position updates are given by

$$v_{ij}^{k+1} = wv_{ij}^{k} + c_1 r_1 (Pbest_{ij} - x_{ij}^{k}) + c_2 r_2 (Gbest_j - x_{ij}^{k})$$

$$x_{ij}^{k+1} = x_{ij}^{k} + v_{ij}^{k+1}$$

$$\text{where}, 1 \le i \le I, 1 \le j \le J, 1 \le k \le K$$

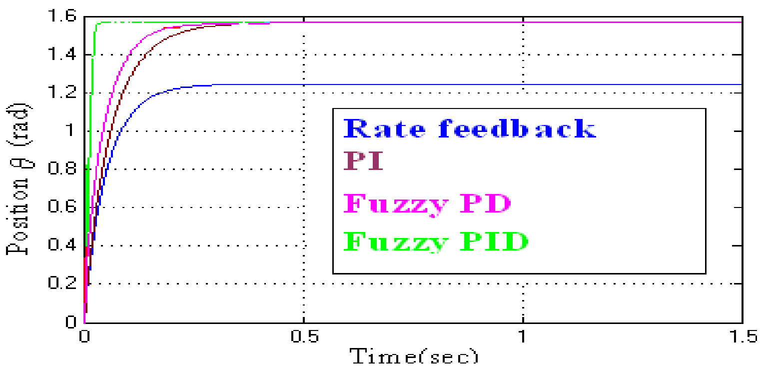

Fig. 6 Responses for all controllers with disturbance

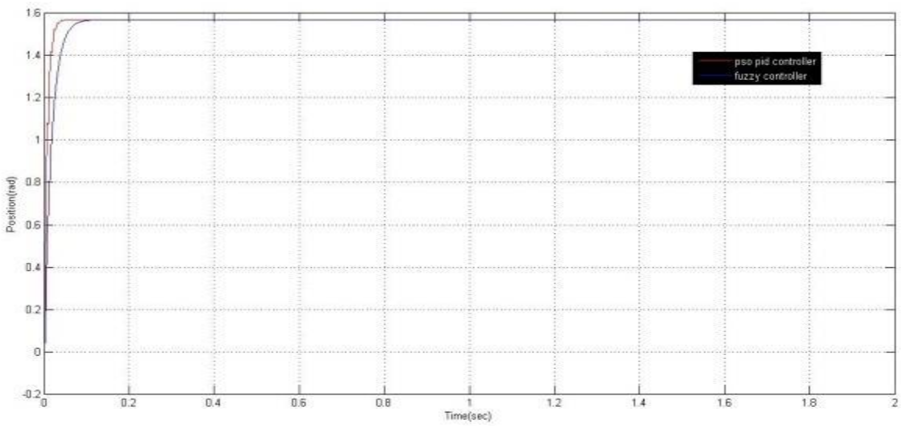

Fig. 7 Response with PSO PID controller

IV. CONCLUSIONS

In this paper an alternative approach is adapted to derive the analytical structure of the Fuzzy PID controller with 3-membership functions for each of the inputs. The FPID controller is realized with two two-input Fuzzy controllers working in parallel. The new configuration of 3 input FLC considered in this work requires only 8 regions, 4 conditions and whatever be the no of MFs the number of rules is equal to square of the MFs. Robot arm joint motion control problem with nonlinear disturbance is considered to test the effectiveness of this controller. Disturbance compensation is effective with both PID controllers. However if nonlinear structure is used the transient response improved a lot with both FPD,FPID controllers and Particle Swarm Optimization based tuning of PID Controller are compared to classical controllers.

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