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A new co-ordinated hybrid fuzzy logic and particle swarm optimization based PID controller for speed control of DC servomotor

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Abstract:

The speed control is an interesting and important term in control system engineering. Speed of the DC servomotor has to be varied according to application requirement. According to requirement suitable controllers and algorithm are use to achieve best control over speed. PID controller is a well known controller which is used in feedback control in industrial application. But in some industrial application the speed control with PID controller is not able to achieve the perfect control due to non linear element present in the system.

Therefore in this research the Particle Swarm Optimization based PID controller and Hybrid Fuzzy Logic Controller are use to overcome this problem. Fuzzy logic control offers an improvement in the quality of the speed response concentrated by emulating the expert and implemented in language based on operator's experience. Particle Swarm Optimization algorithm on the PID controller is an advanced approach for getting a stable and linear response of any system. PSO is a population based stochastic optimization technique is initialized with a population of random solutions and searches for optima by updating generations. A comparative analysis of performance analysis both the controllers have been done.

Keywords: Speed Control, DC Servomotor, PID, PSO, Fuzzy, Hybrid Fuzzy.

I. Introduction:

DC Servomotors are widely used in industrial applications, robotics industries and home appliances as they shows higher reliability, flexibility and allows precise control of position, velocity and acceleration [VI]. In modern usage the term servomechanism or servo is restricted to feedback control systems in which the controlled variable is mechanical position or time derivatives of position as velocity or acceleration [VII].

The DC Servomotor considered in this research presented is armature controlled with fixed field current type motor [V]. DC Servomotor interacts with two magnetic fields and produce mechanical energy. Magnet of poles assembly produces one magnetic field, and electrical current flow through motor windings creates another. The resulting magnetic field produces a torque which tends to rotate the rotor. DC Servomotor outperforms to AC motor because it provides better speed control on high torque loads and is used in wide industrial application [VI].

In practice, the design of DC Servomotor involves a complex such as model, devise of control scheme and simulation. Tuning of controller parameter for servomotor involves a sophisticated process and requires an experienced engineer [III]. In many research presented different control mechanism such as PID controller with Cohen-Coon tuning method and MPC has been proposed. PID or MPC controller can be suitable for linear motor. In DC Servomotor non-linear element are present which could not solved by PID or MPC controller [IV].

Fuzzy control is a very powerful method of reasoning when mathematical models are not available and input data are imprecise. Some studies have also shown that the fuzzy logic controller performs better than conventional PID controller [VII]. In a research shows a fuzzy logic controller has been proposed for DC Servomotor [VI].

Most of the industries uses conventional PID controller but it sensitive to parameter variation. Due to this PID does not give satisfactory result. To overcome the problems faced by conventional tuning rules several evolutionary computation methods are suggested. As Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Cuckoo search, Ant Colony Optimization (ACO), Differential Evolution (DE) etc. Among all these methods Particle Swarm Optimization (PSO) is the simplest technique to apply [VIII].

The view of the above research the present study was carried out with following objective:

1) Comparative study of hybrid fuzzy controller and PSO based PID controller.
2) Analysis the result and evaluate the performances.

II. DC Servomotor:

Speed control stands for intentional speed variation carried out manually or automatically. DC Servomotors are most suitable for wide range speed control and therefore is used in many adjustable speed drives.

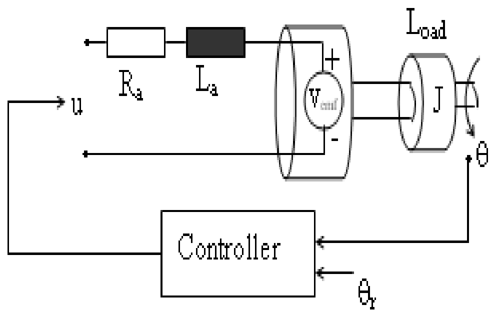

Figure: 1 Control configuration of the DC Servomotor

In this project we deal with the armature controlled dc motor where the field is constant. The Figure: 1 is the control configuration of DC Servomotor system.
Where,

R_a = 1 (armature-winding resistance) Ω.

L_a= 0.5(armature-winding inductance) H.

I_a = 0.1 (armature current) A.

E_a = 220 (applied armature voltage) V.

E_b = back emf (volts).

θ = angular displacement of the motor shaft, (rad).

T_M = torque delivered by the motor, (N-m).

J = 0.01(equivalent moment of inertia and load referred to the motor shaft) kg-m2.

F = 0.1(viscous-friction coefficient of the motor and load referred to the motor shaft) N-m /rad⁄s.

K_b = 0.01(Back emf constant) rad/sec.

K_T = 0.01(Motor torque constant) N-m/A.

Hence the effective transfer function becomes:

$$\mathbf{G_m(s)} = \frac{2}{s^2 + 12s + 20.02} \quad (1)$$

III. Fuzzy Logic Control:

Fuzzy logic provides a linguistic control based strategy which is derived from expert knowledge into an automatic control strategy. Fuzzy logic is performing better as compared to conventional control mechanisms like PID. Wherever logic in the spirit of human thinking can be introduced, fuzzy logic finds extreme application there. Most applications of fuzzy logic exploits its tolerance for imprecision. Because precision is costly, is costly, it makes sense to minimize the precision needed to perform a task. Thus the applicability of fuzzy logic is indeed promising.

FLC consist of three stages: Fuzzification, Fuzzy Inference Mechanism and Defuzzification.

(A) Fuzzification

Fuzzification is related to the vagueness and imprecision in a natural language. The crisp sets are based on two valued logic as either members or not members. For example, crisps set define as High in terms of temperature where μ= membership value and T = Temperature.

$$\mu_{HIGH} = \begin{cases} 0 \textit{ if } \text{T is Low} \\ 1 \textit{ if } \text{T is High} \end{cases}$$

The crisp set convert to fuzzy set which may be define as

$$\mu_{HIGH} = \begin{cases} 0 & \textit{if } \text{T is Low to small medium} \\ 0.5 & \textit{if } \text{T is small medium to large medium} \\ 1 & \textit{if } \text{T is large medium to high} \end{cases}$$

Where, the temperature may have many fuzzy sets associated with it (for example Low, small medium, large medium and high) and the domains of all the fuzzy sets constitute which is known as the Universe of Discourse.

This transformation is represented as membership function. In this research triangular membership function is chosen which is most popular among scientist. Triangular membership function shown in Figure 2.

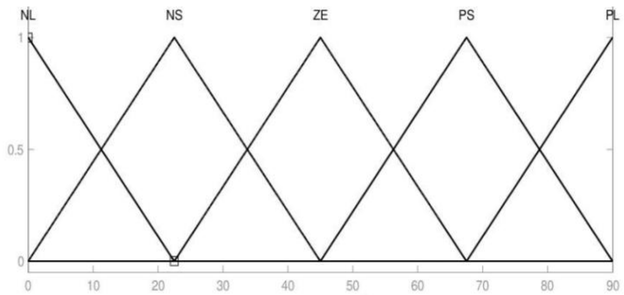

Figure: 2 Triangular shaped membership function

(B) Rule Base

The rule base is to represent in a structured way to control policy of an experienced process operator and control engineer in the form of a set of production rules such as *if* < Process output > *then* < Control Output >.

In this project 25 (5*5) rules are processed by the interface engine shown in Table 1.

e/de	**NL**	**NS**	**ZE**	**PS**	**PL**
PL	ZE	PS	PL	PL	PL
PS	NS	ZE	PS	PL	PL
ZE	NL	NS	ZE	PS	PL
NS	NL	NL	NS	ZE	PS
NL	NL	NL	NL	NS	ZE

Table: 1 Rule Base designed for speed control of DC Servomotor

(C) Defuzzification

In this stage set of modified control output values are converted into single point-wise values. There many procedure outlined in the literature for defuzzification which are center of gravity, center of mass, first of maxima etc. Among them center of gravity is most efficient.

IV. Particle Swarm Optimization:

Particle Swarm Optimization, developed by James Kennedy and Russell Eberhart in 1995 is one of the nature inspired optimization algorithm. It was developed based on the idea of how a swarm of bird moves in search for their food.

PSO is very simple to implement and efficacious. It has very few parameters to tweak, which makes it simpler and also with the absence of greediness in the algorithmic design it makes it faster. PSO progresses towards the solution by mutual sharing of knowledge of every particle collectively.

The Particle Swarm Optimization method is mainly works on updating the velocity and position of the individual particles. It continues updating until it reaches the global best value. The fitness functions which update the position and velocity takes place are given by:

$$V_{i,j}^{k+1} = w \times V_{i,j}^{k} + c_1 \times r_1 \times (Pbest_{i,j}^{k} - X_{i,j}^{k}) + c_2 \times r_2 \times (Gbest_{j}^{k} - X_{i,j}^{k}) \quad (2)$$

$$X_{i,j}^{k+1} = X_{i,j}^{k} + V_{i,j}^{k+1} \quad (3)$$

Where, X= Initial position of the swarm = $[X_1, X_2 \dots\dots X_N]^T$

V= Initial velocity of the swarm =$[V_1, V_2 \dots\dots V_N]^T$,

i = (1, 2, 3 …N),

j = (1, 2, 3 …D),

N = Population size,

D = Dimension,

T = Transpose operator

c_1, c_2 = Acceleration constant

W = Inertia weight factor

r_1, r_2 = Random numbers between 0 and 1

k = Number of iteration

The flow chart is given which describe the optimization steps for DC Servomotor

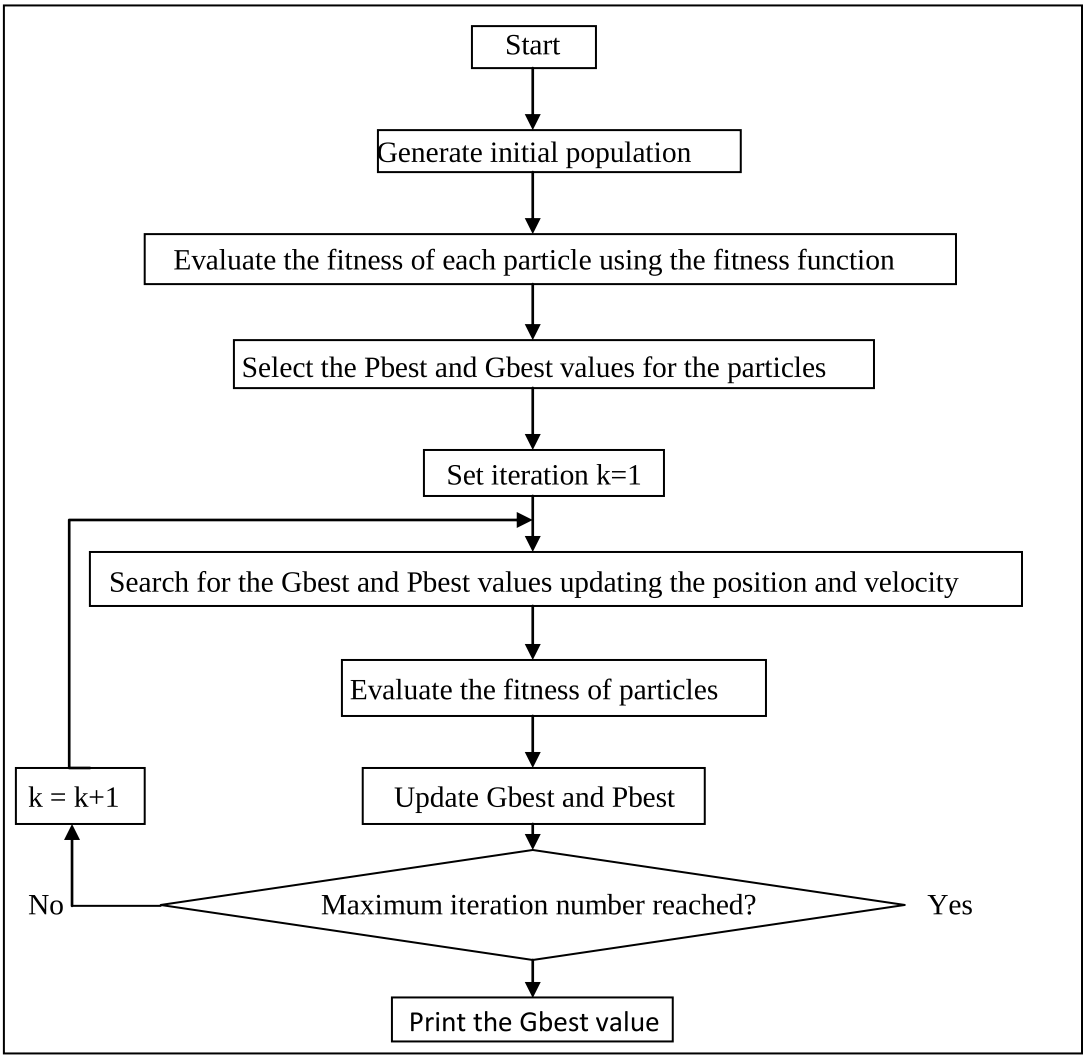

Figure: 3 Flow chart of the PSO algorithm for speed control of DC Servomotor

V. Simulation:

Dynamic simulations are performed in order to analyze the performance of controllers.

- **Hybrid Fuzzy Logic Controller**

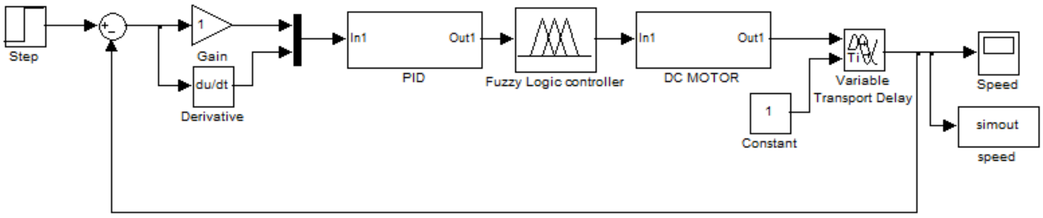

Figure: 4 Simulink model with Hybrid Fuzzy Logic Controller for DC Servomotor

According to Ziegler-Nichols tuning rule controller parameters found to be,

Controller	K_P	K_I	K_D
P	11.3875	0	0
PI	10.24875	2.733	0
PD	18.22	0	10.248
PID	13.665	6.0734	7.6865

Table: 2 Controller Parameters According to Ziegler-Nichols Rule

The corresponding speed vs. time response for Fuzzy-P, Fuzzy-PI, Fuzzy-PD, and Fuzzy-PID shown in figure 5, figure 6, figure 7, and figure 8 according to control parameters calculated in above table 2.

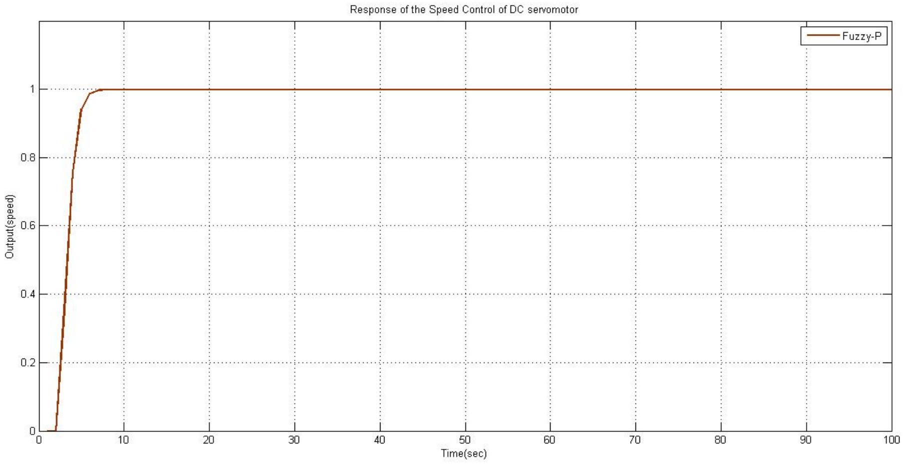

Figure: 5 Speed Simulation curve using Fuzzy-P Controller

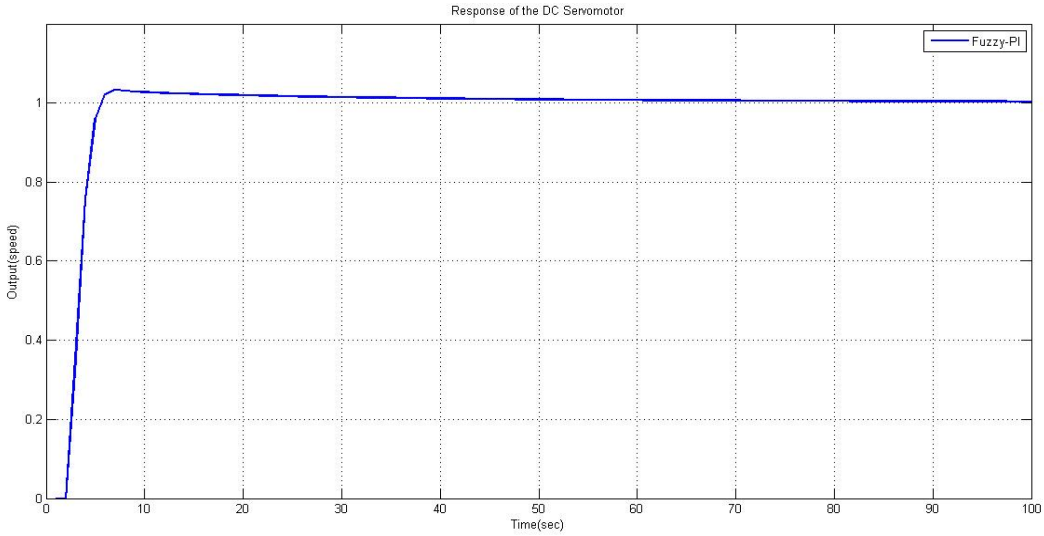

Figure: 6 Speed Simulation curve using Fuzzy-PI Controller

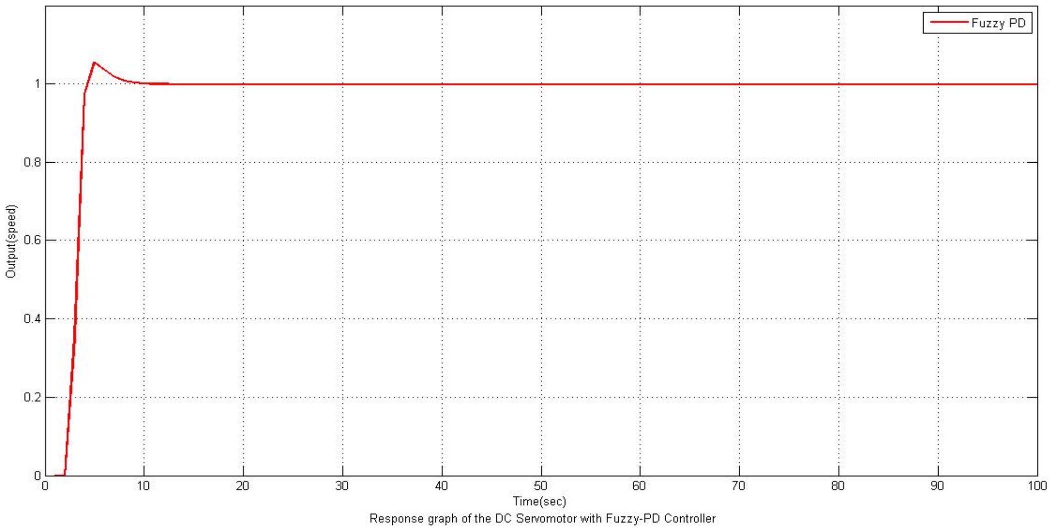

Figure: 7 Speed Simulation curve using Fuzzy-PD Controller

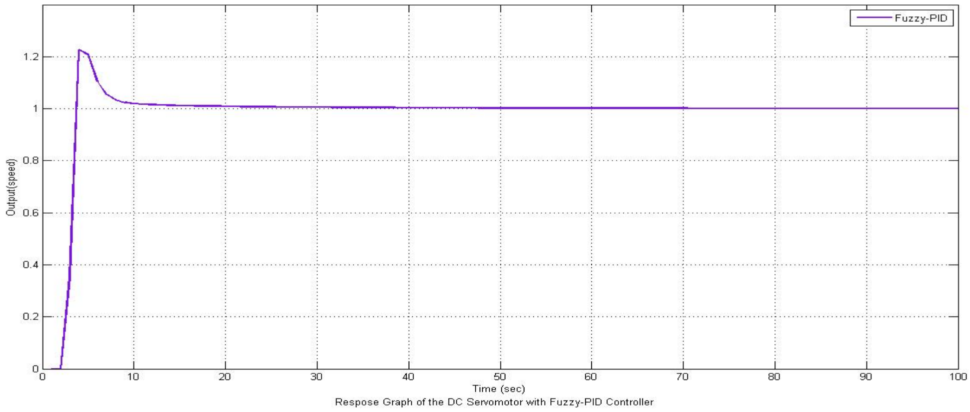

Figure: 8 Speed Simulation curve using Fuzzy-PID Controller

All the four responses obtained from Fuzzy-P, Fuzzy-PI, Fuzzy-PD, Fuzzy-PID is altogether shown in figure9 for comparison of their performances.

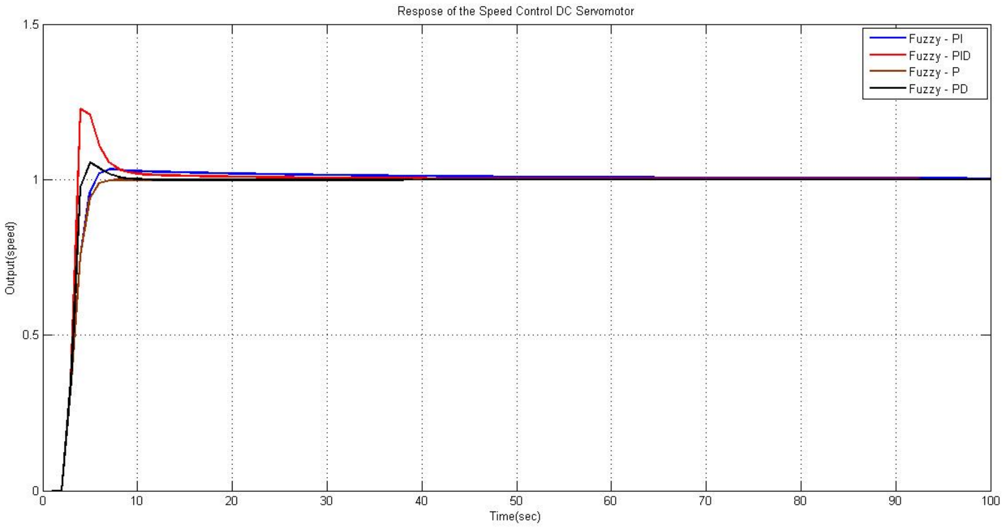

Figure: 9 Speed Simulation curve for comparison of performance among Fuzzy-P, Fuzzy-PI, Fuzzy-PD, Fuzzy-PID Controller

- **Particle Swarm Optimization:**

According to execution, following PSO parameters are used to determine the gain of the PID controller use to improve the performance of DC Servomotor.

- Population size = 100.
- Acceleration constant c_1 and c_2 = 1.5.
- K_P = 14.7580.
- K_I = 80.5167.

- K_D = 35.7414.

The corresponding speed vs. time simulation for Particle Swarm Optimization shown in figure 9 according to calculated control parameter above.

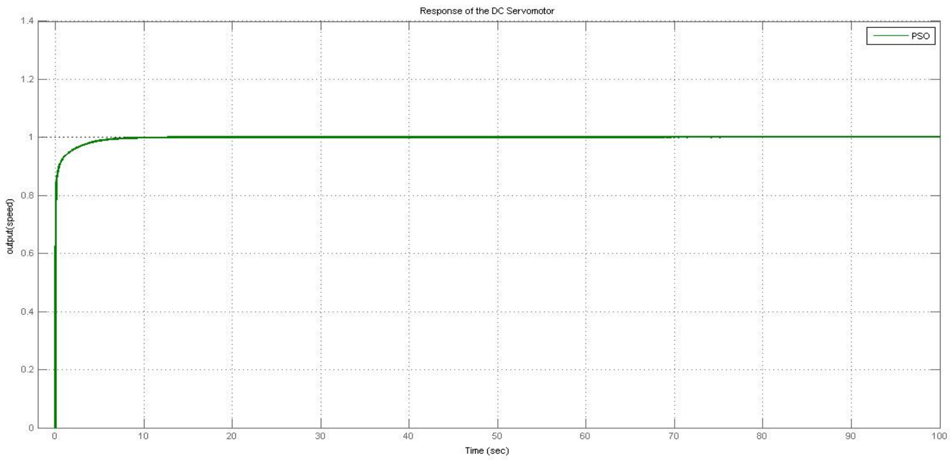

Figure: 10 Speed Simulation Curve Using PSO based PID Controller

All the five responses obtain from Fuzzy-P, Fuzzy-PI, Fuzzy-PD, Fuzzy-PID, and PSO based PID controller are altogether shown in figure11 for comparison of their performance.

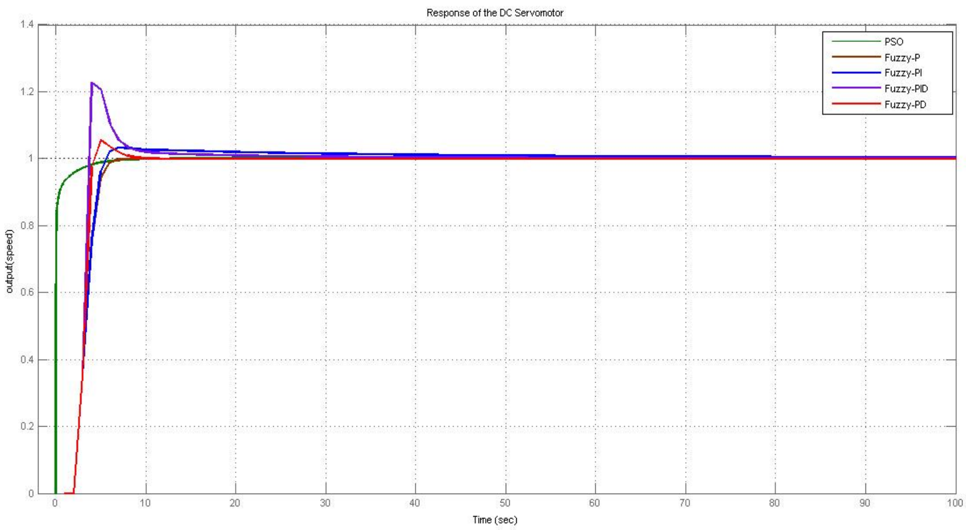

Figure: 11 Speed Simulation curve for comparison of performance among Fuzzy-P, Fuzzy-PI, Fuzzy-PD, Fuzzy-PID, and PSO based PID Controller

VI. Result and Discussion:

In this research paper, the performance of the speed control mechanism is analyzed for DC Servomotor with different controller. Table 2 shows the different performance parameters such as Rise Time (T_r), Settling Time (T_s), Percentage of Overshoot (M_P %) for analysis the stability and reliability of the system.

System	Controller	Rise Time (T_r) (Sec)	Settling Time (T_s) (Sec)	Percentage of Overshoot (M_P) (%)
DC Servomotor	**Fuzzy – P**	4.5	8	0
DC Servomotor	**Fuzzy – PI**	4.5	20	3.3
DC Servomotor	**Fuzzy –PD**	3.5	10	5.5
DC Servomotor	**Fuzzy – PID**	4	10	22.7
DC Servomotor	**PSO – PID**	0.432	3.74	0

Table: 3 Performance analysis of DC Servomotor

In Fuzzy - P controller and PSO – PID controller, there is zero overshoot while in case of PSO-PID Rise Time is very less but for Fuzzy – P, it is very high. Again, the settling time for Fuzzy – PI is very large but for PSO – PID, it is very less. Except for certain application where oscillation cannot be tolerated, it is desirable that the transient response should be significantly fast and sufficiently damped for the desired output.

VII. Conclusion:

This paper presented a better speed control mechanism for DC Servomotor using hybrid fuzzy logic controller and PSO based PID controller.

Here Hybrid fuzzy controllers with four different modes have been implemented and studied for each mode and evaluated the performance of speed mechanism. Fuzzy-P controller, Fuzzy-PI controller, Fuzzy-PD controller, and Fuzzy-PID controller have been implemented and their performances have also been analyzed which shows Fuzzy-PD controller has less rise time and small overshoot with less settling time. It is also seen that Fuzz-P controller has no overshoot and less settling time but shows highest rise time. In case of Fuzzy-PI controller, it has low overshoot but highest rise time and highest settling time among them. Again in case of Fuzzy-PID controller it shows low rise time with less settling time and highest overshoot among them. After a careful investigation, it is concluded that Fuzzy-PD controller shows a better performance and can easily achieve a good control over speed of DC Servomotor.

The PSO based PID controller implemented and analyzed for speed control mechanism which shows no overshoot, lowest rise time and fast settling time. Hence it can be concluded that PSO-PID shows the best speed control among the entire controller studied. Our study has also showed that PSO-PID controller gives better response over Hybrid Fuzzy Controller.

Thus Particle Swarm Optimization technique is showing the best output for speed control mechanism but it is only possible if we run the algorithm designed for speed control many times, notably four or five times and thus it achieves the best controller gain for PID controller. But in case of Fuzzy Logic Controller, it is giving better output for speed control mechanism with a simple procedure to design the controller.

In this paper we analyzed and studied both of the controllers and hence conclude that PSO gives best output but with latency, so PSO would be very suitable for research industries like robotics, satellite centre where works based on best accuracy no tolerance and latency can be accepted. In case of food beverage industry, thermal power plant or steel plants where small tolerance can accept but latency cannot be accepted. So for these types of industries, Fuzzy-PD controller is suitable according to control and performance analysis.

Future Scope

This project will be extended further with fuzzy based PSO algorithm and Artificial intelligence to observe the improvement of the performance in speed control mechanism.

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