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PID Controller Design and Simulation for Aircraft Roll Control Based on Evolutionary Technique Using MATLAB

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Abstract*—Artificial Bee Colony algorithm (ABC) is considered as very common algorithms which use artificial intelligence technique of swarm bees. The ABC algorithm mimics foraging and dance behaviors of real bee colonies. It has high performance and success for numerical optimization problems. In this paper presents ABC technique to design PID controller that controls the roll angle of an aircraft system to compared to other programs such as particle swarm optimization (PSO) and Genetic Algorithm(GA).In the proposed methods we derive an optimal control law to minimize a generalized performance index to achieve better performance. Simulation results of roll controllers are presented in time domain and the results obtained with ABC control are compared with the results of PSO and GA. According to simulation results, it was observed that ABC-PID controller has a better performance than PSO-PID and GA-PID controllers.

Index: **Aircraft Roll Control; Autopilot; PID Controller; ABC; PSO; GA.**

I. INTRODUCTION

An aircraft is controlled by three main surfaces. They are elevator, rudder and ailerons. Pitch control may be reached by varying the lift on the forward or aft control surface. If a flap is used, the flapped portion of the tail surface is called an elevator. Yaw control is achieved by deflecting a flap on the vertical tail called the rudder and roll control .It can be achieved by deflecting small flaps located outboard toward the wing tips in a differential manner. These flaps are called ailerons. Elevator, rudder and ailerons are depicted in Fig. 1.

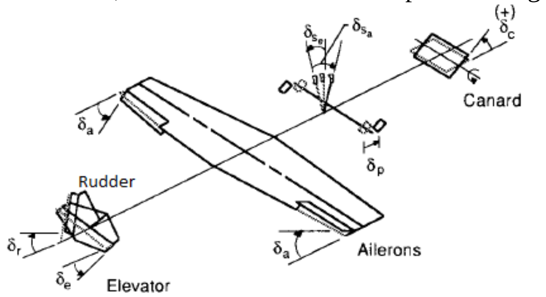

Fig 1. Aerodynamic controls of an aircraft.

The rolling motion of an aircraft is controlled by adjusting the roll angle. Artificial Bee Colony (ABC) is one of the most recently defined algorithms by Dervis Karaboga in 2005, motivated by the intelligent behavior of honey bees.

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It is as simple as Particle Swarm Optimization (PSO) and Differential Evolution (DE) algorithms, and uses only common control parameters such as colony size and maximum cycle number. In this study, for this situation an autopilot is designed to control the roll angle of an aircraft [1]. An Artificial Bee Colony (ABC), particle swarm optimization (PSO) and Genetic Algorithm controller (GA) was developed for the roll control of an aircraft system. Performances of three controllers are analyzed with respect to the desired roll angle. Comparison of these control theory is presented and it has been pointed out which controller is more suitable for the roll control of an aircraft.

II. MODELING OF A ROLL CONTROL SYSTEM

Roll control is a lateral problem and this work it has been developed to control the roll angle of an aircraft for roll control in order to stabilize the system when an aircraft performs the rolling motion. The roll control system is shown in Fig. 2.

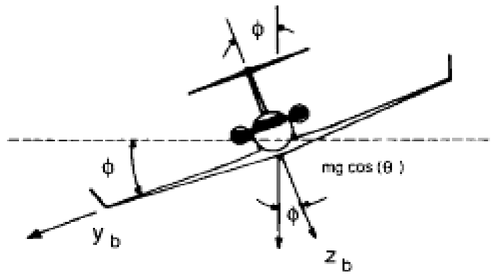

Fig 2. Roll control system description.

In figure (2,)Yb and Zb represent the aerodynamics force components, φ and δa represent the orientation of aircraft (roll angle) in the earth-axis system and aileron deflection angle respectively. The transfer function from aileron deflection angle to roll angle is given the following equation [2].

$$\frac{\Delta\phi(s)}{\Delta\delta a(s)} = \frac{-28.92s^2 - 29.81s - 140.8}{s^4 + 9.409s^3 + 14.02s^2 + 48.5s + 0.3979} \quad \text{......(1)}$$

III. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) Algorithm is used to finding the global optimum of PID parameters. Kennedy and Eberhart developed a PSO algorithm based on the behavior

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of individuals (i.e. particles or agents) of a swarm [3] .It has been perceived that members within a group seem to share information among them, a fact that causes to increased efficiency of the group. An individual in a swarm approaches to the optimum by its present velocity, previous experience, and the experience of its neighbors .In a physical n-dimensional search space, parameters of PSO technique are defined as follows: [4]

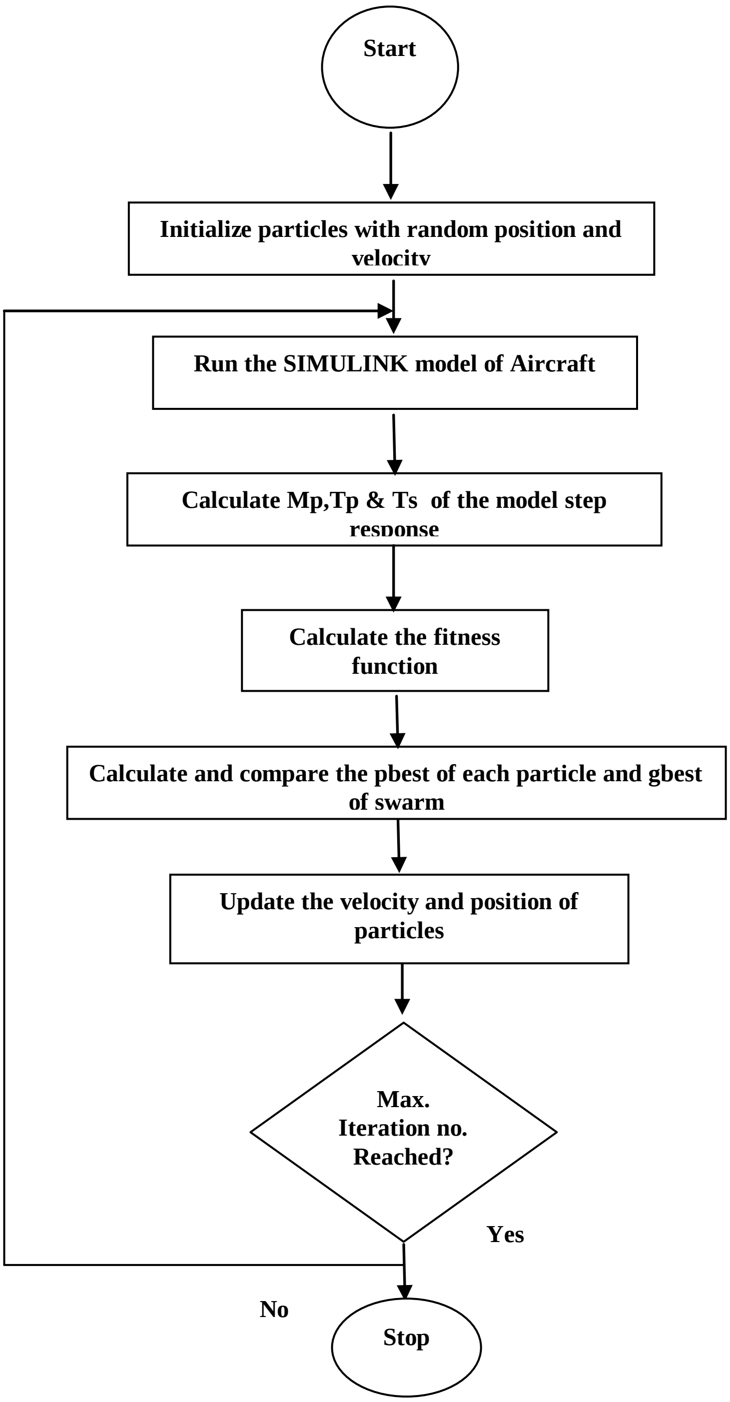

Fig 3. Flow chart of basic PSO algorithm.

V_i (t+1)=W. Vi(t)+C_1 * rand. (pbest (t) – xi(t)) + c_2 *rand. (g best(t) – xi (t)) ………(2)

Xi(t+1) = Xi(t) + Vi (t+1) ………….(3)

Where,

v_i(t+1) is the velocity of the i^{th} particle at (t+1) iteration.

x_i(t+1) is the position of the i^{th} particle at (t+1) iteration.

w is the inertial weight factor (weighting function).

c_1 and c_2 are acceleration constants called cognitive learning rate and social learning rate respectively. rand is Random number between 0 and 1.

pbest is the individual best position of the particle. gbest is the global best position of the swarm of the particles.

The weighting function, w is responsible for dynamically adjusting the velocity of the particles, hence it is responsible for balancing between local and global search. Applying a large inertia weight at the start of the algorithm and decaying to a small value through the PSO execution makes the algorithm search globally at the beginning and locally at the end of the execution. The weighting function w is calculated as:

$$w = w_{max} - \frac{(w_{max} - w_{min}).iter}{iter_{max}} \quad -- 4$$

Here, wmax and wmin are the initial and final weights, iter is the current iteration time and itermax is the maximum number of iterations. The proposed Fitness function for the optimization of parameters of PID controller is defined as:

F= w_{max}* (1-exp (-1))*(Mp+Ess)+w_{min}*exp(-1)*(ts-tr).

Where Mp: Maximum Overshoot, tr: Rise Time, and ts, Settling time

The flow chart depicting the implementation of PSO algorithm for optimizing the parameters of PSO-PID controller for the aircraft is shown in figure (3).

IV.PSO-PID CONTROLLER

The PSO algorithm was mainly utilized to determine three optimal controller parameters K_p, K_i, and K_d, such that the controlled system could obtain a good output response. In this paper, the PSO algorithm is applied for searching the PID controller parameters. The “individual” is used to replace the “particle” and the “population” is used to define the “group”. The three controller parameters K_p,K_i and K_d composed an individual K by $K \equiv [K_p, K_i, K_d]$; hence there are three members in an individual. These members are assigned as real values.

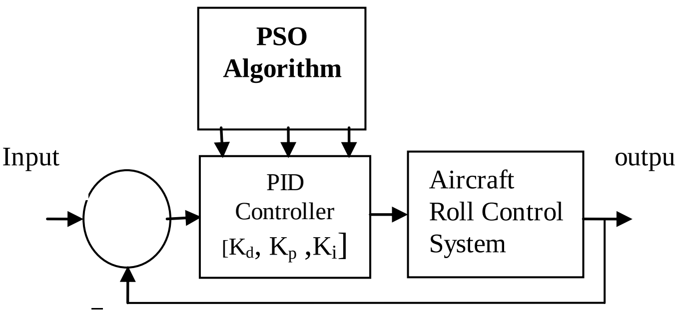

Fig 4. PSO-PID controller

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If there are *n* individuals in a population, then the dimension of a population is *n* x 3. A set of good control parameters K_p, K_i, and K_d, can achieve a good output response for the system and result in minimization of performance criteria in the time domain including the settling time (Ts) , rise time (Tr), maximum overshoot (%OS) and steady state error (e_{ss}). The PSO-PID controller for Longitudinal Aircraft Dynamics is shown in figure 4.[5]

V.GENETIC ALGORITHM

The Genetic Algorithm (GA) is an optimization and stochastic global search technique based on the principles of genetics and natural selection and developed by John Holland (1975).The basic structure of the GA consists of: coding, selection, crossover (mating), and mutation .GA has been widely employed in the tuning of PID controllers, subjected to the minimization of a certain cost function. Initially a random population of genes is chosen from the search space. They undergo reproduction, crossover and mutation to yield individuals with better fitness. The individuals with higher fitness values have more probability of creating their copies in the next generation. This is termed as reproduction. Two parent individuals can do information interchange in a probabilistic fashion to create a child in the next generation. This process is known as crossover. In mutation a small part of the parent gene is randomly changed to yield a child. The Graphical Illustration of the Genetic Algorithm loop is shown in Figure 5.[6]

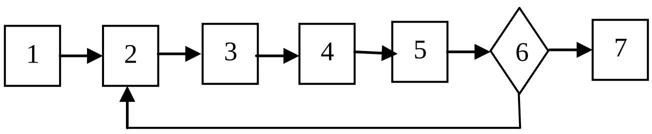

Fig 5.Genetic algorithm loop

1-Intial population.
2. Select individuals for mating.
3. Mate individuals to generate offspring.
4. Mutate offspring.
5. Insert new individuals into population.
6. Are criteria satisfied?
7. End of searching.

An objective function could be created to find a parameter of GA-PID controller as shown in figure 7 that gives the smallest overshoot, fastest rise time or quickest settling time but in order to combine all of these objectives it was decided to design an objective function that will minimize the error of the controlled system. Each chromosome in the population is passed into the objective function one at a time. The chromosome is formed by three values that correspond to the three gains of the K_d ,K_p and K_i to be adjusted in order to achieve a satisfactory behavior is illustrated in Fig.6. [6]

K_d	K_p	K_i

Fig.6 . Chromosome definition

The objective function is Integral Square Error has the following form:

$$ISE = \int_0^T e^2(t)dt = \int_0^T (r_i - y_i)^2\, dt \qquad --- \quad 5$$

Where r_i is reference variable, yi is controlled output, ei is control error and. The ISE squares the error to remove negative error components. ISE discriminates between over-damped and under damped systems, i.e. a compromise minimizes the ISE

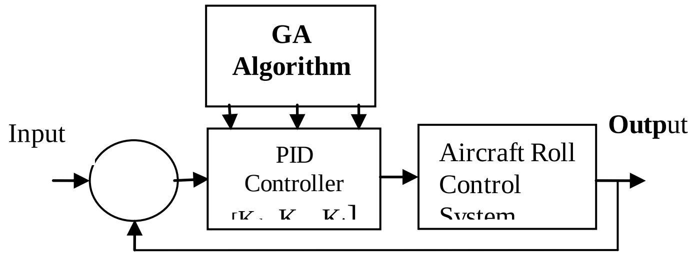

Fig 7. GA-PID controller

The genetic algorithm parameters chosen for the tuning purpose are shown in Table 1

Table 1. Parameters of GA

GA property	Value/Method
Population Size	20
Max No. of Generations	100
Performance Index/Fitness Function	Integral Square Error
Selection Method	Normalized Geometric Selection
Probability Of Selection	0.05
Crossover Method	scattering
Crossover probability	0.2
Mutation Method	Uniform Mutation
Mutation Probability	0.01

VI.ARTIFICIAL BEE COLONY ALGORITHM (ABC)

Artificial Bee Colony Algorithm (ABC)is one of the popular algorithms of using the intelligence of swarm bees. The ABC algorithm mimics foraging and dance behaviors of real bee colonies. It has high performance and success for numerical optimization problems. In Bees Algorithm, the colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. First half of the colony consists of the employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose the food source has been abandoned

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by the bees becomes a scout. The position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. The number of the employed bees or the onlooker bees is equal to the number of solutions in the population.[7]

VII.ABC ALGORITHM

Steps (pseudo-coding) to initialize the artificial BA:

1. Initialize the population of solutions xi,j, i = 1. . .SN,(SN is the number of food source) j = 1. ….D.(is the dimension of problem for optimization of PID(namely K_p ,K_i and K_d) ,there is D=3.)
2. Evaluate the population.
3. Cycle=1
4. Repeat
5. Produce new solutions xi,j for the employed bees by using (4) and evaluate them.
6. Apply the greedy selection process.
7. Calculate the probability values Pi,j for the solutions xi,j by (4 & 3).
8. Produce the new solutions xi,j for the on looking from the solutions xi,j selected depending on Pi,j and evaluate them.
9. Apply the greedy selection process.
10. Determine the abandoned solution for the scout, if exists, and replace it with a new randomly Produced solution xi,j by (4& 5).
11. Memorize the best solution achieved so far.
12. Cycle = Cycle+1.
13. Until Cycle = MCN (Maximum Cycle Number).

VIII.ABC-PID Controller

The ABC algorithm was mainly utilized to determine three optimal controller parameters K_p, K_i, and K_d, such that the controlled system could obtain a good output response. In this work, the ABC algorithm is applied for searching the PID controller parameters. A set of good control parameters K_p, K_i, and K_d, can achieve a good output response for the system and result in minimization of performance criteria in the time domain including the settling time (Ts) , rise time (Tr), maximum overshoot (MP %) and steady state error (e_{ss}). The ABC-PID controller for Longitudinal Aircraft Dynamics is shown in figure 8. The proposed Fitness function for the optimization of parameters of PID controller is defined as:

$J= w_{max}*(1-\exp(-1))*(Mp+Ess)+w_{min}*\exp(-1)*(ts-tr)$.

Where

Mp: Maximum Overshoot ,tr:Rise Time,and ts, Settling time. and Ess, steady state error.

The response of the roll angle with ABC-PID, PSO-PID and GA-PID controllers are shown in Figure. 9 ,10 ,11 and 12 respectively. Comparing between the results for these controllers is shown in Table 2. The parameter values taken for running the PSO algorithm in MATLAB environment is give table 3.

Table 2: Parameters of PID controller with ABC, PSO and GA.

Controller	t_r	t_s	M_p %	K_p	K_i	K_d
ABC-PID	0.0063	0.0124	0.0517 %	-65.2446	-22.3531	-12.3873
PSO-PID	0.0072	0.0138	0.0311 %	-67.9742	-27.9767	-10.8438
GA-PID	0.0226	0.0374	0.78238 %	-31.9599	-8.82542	-11.4093

Table 3: PSO parameter values

Parameter	Values
Particle size	20
Maximum no. of Iterations	100
Cognitive Component C1	2
Social Component C2	2
Maximum Speed	10
Maximum Inertia Weight	0.9
Minimum Inertia Weight	0.4

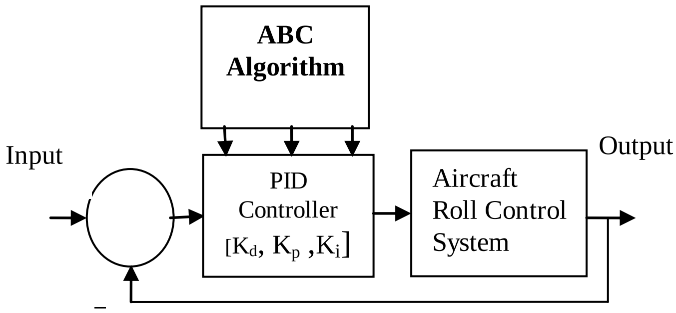

Fig.8 Roll angle response with ABC-PID controller

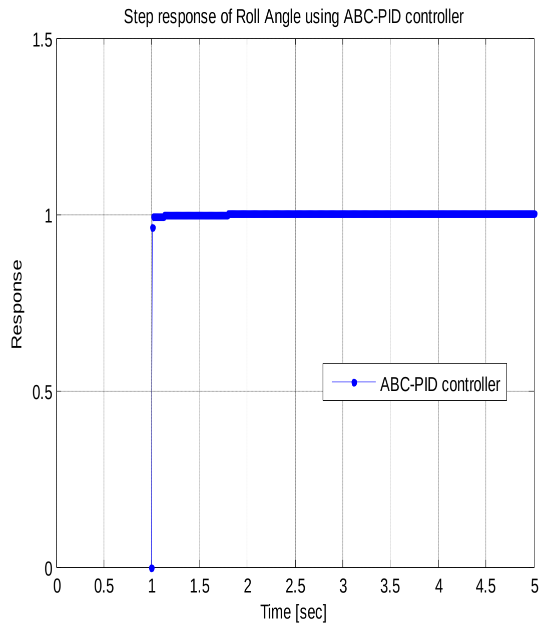

Fig.9 Roll angle response with ABC-PID controller.

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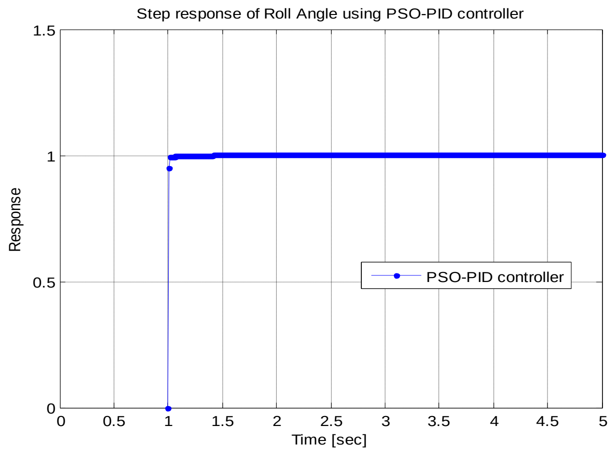

Fig.10 Roll angle response with PSO-PID controller.

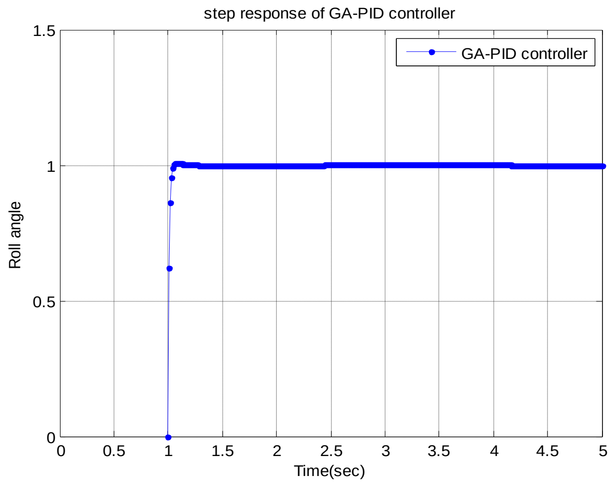

Fig.11 Roll angle response with GA-PID controller.

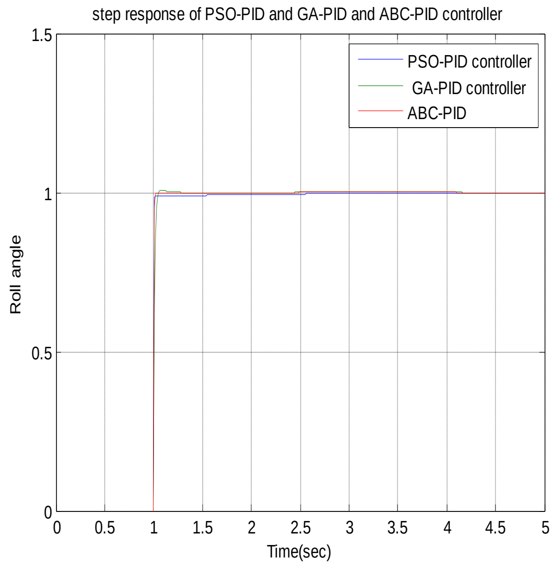

Fig.12 Roll angle response with ABC-PID, PSO-PID and GA-PID controllers.

The convergence curve for each gain is called as particle for K_p, K_i and K_d is plotted to give an idea how the ABC, PSO and GA converged to its final value has been illustrated in Figures 13, 14 .

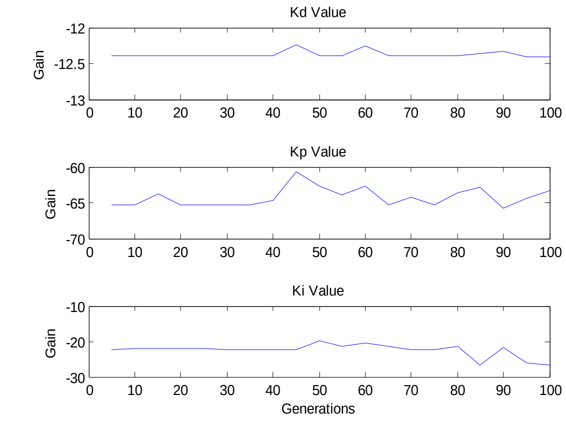

Fig 13.Number of generation of K_p ,K_i and K_d value of ABC-PID controller.

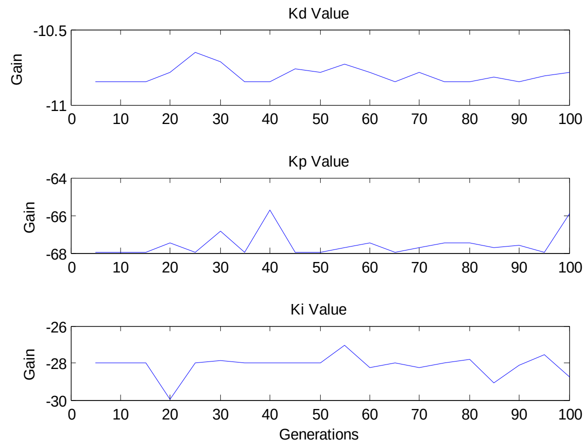

Fig 14.Number of generation of K_p ,K_i and K_d of value GA-PID controller.

IX. CONCLUSION

In this paper, ABC, PSO and GA are successfully designed an aircraft roll control system. The results from ABC are compared with those obtained using PSO and GA controllers. It was observed that both ABC, PSO and GA have different settling time, steady-state error and overshoot. ABC has good and acceptable performances according to the results from simulation and analysis.

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