Genetic Algorithm tuned PID Controller for Aircraft Pitch Control

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Abstract **The changes in the attitude of the aircraft will influence the transient response, by varying the gain in the loop. The controller should have the capability to adopt the changes, both internally and externally to enhance the better performance of the vehicle. In this work, a self-adaptive controller has been implemented through genetic algorithm, to adjust the control parameters by measurement and evaluation of the environmental factors. This self-adaptive controller for the pitch control system has been designed by tuning the PID controller based on genetic algorithm. To investigate the effectiveness, comparison has been made for the Genetic algorithm based PID controller with Fuzzy logic based PID controller and conventional PID controller through time response analysis. The results show that the proposed controller having better performance than the traditional controllers and most suitable for the effective operation of the vehicle.**

Keywords —PID controller, Fuzzy logic, Genetic algorithm, Step response, Self-adaptive control, Fitness funtion

I. Introduction

Fly-by-wire system is a typical flight control system, which controls the attitude of the vehicle through the electrical signals generated from the pilot stick. For the implementation of the Fly-by-wire system, a controller should be used to generate the control signals to the system based on input and output signals. This controller should be tuned based on time, stability and frequency responses of the system. When the attitude of the vehicle changes, the transient response will also change and thus indicates the change in the characteristic equation of the stated flight condition. To avoid this problem the gain of the controller should be schedules as a function of the vehicle attitude. Establishing the relationship between the control parameters and vehicle attitude is expensive and time consuming one and thus requires an extensive system analysis.

Proportional integral derivative (PID) controller is still used in many of the industries due to its advanced control schemes [1]. But the drawback of PID controller is that beyond the tuned operating range, it will not provide satisfactory control [2]. Hence soft computing based PID controllers are the optimized solution for this problem, proposed by many researchers [3]-[4].Air Research and Development Command suggested, that the self-adaptive controllers will be better solution for this problem which establishes the control parameters based on the internal process of changing environment. Among all soft computing techniques, the genetic algorithm is widely used due to its accuracy and ease of design. The accuracy and robustness of the uncertainty parameter based non-linear systems can increased by designing predictive adaptive controllers [5]. The multivariable, time-variant systems are controlled effectively when using simple and feasible controllers based on self-adaptive algorithms [6]. These self-adaptive algorithms can be extended effectively for MIMO systems [7]. E. G. Shopova introduced a genetic algorithm to suit for most of the engineering optimization problems [8]. Genetic algorithms used in the PID controllers will avoid the premature convergence and optimization problem [9]. Even though many methods are proposed to control dynamics of the aircraft; it is still being a thrust area to improve [10]. In this present work, Genetic algorithm based PID controller was designed for pitch control of the aircraft. The proposed control strategy was simulated in the MATLAB and its performance has been compared with conventional PID & Fuzzy logic based PID controllers.

II. Mathematical Modelling of Pitch Control System

A. *Review Stage*

In the mathematical modelling of the aircraft pitch control system, it is assumed that the aircraft is rigid body

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and the equation of motion can be separated as lateral and longitudinal equations [11].The variables u, v, w and X, Y, Z (see Figure 1) represent the linear velocities and aerodynamic forces in the x, y, z directions respectively. Similarly, the angular velocities and the aerodynamic moments about the x, y, z axes are represented by p, q, r and L, M, N be respectively. The velocity components v and w can be translated as sideslip angle β and angle of attack α respectively.

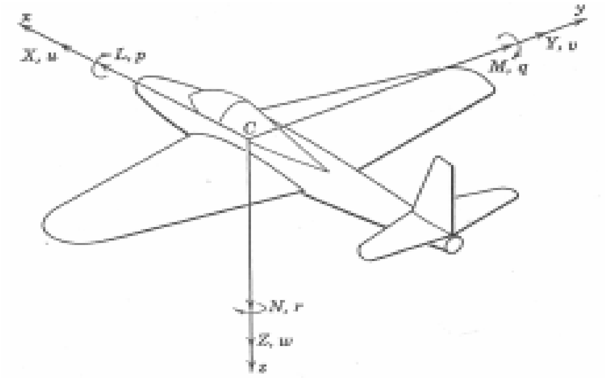

Figure 1. Force, Moment and Velocity components in body frame

Hence, the longitudinal equations of motion are given by,

$$X - W\sin\theta = \frac{W}{g}(\dot{u} + qw - rv) \quad (1)$$

$$Z - W\cos\theta\cos\varphi = \frac{W}{g}(\dot{w} + pv - qu) \quad (2)$$

$$M = I_y\dot{q} + (I_x - I_z)pr \quad (3)$$

Where θ, φ, ψ are the pitch, roll, yaw angles respectively and I_x, I_y, I_z represents the inertial properties of the vehicle. By including the small disturbances, the longitudinal state variables X, Y, Z can be written as,

$$\Delta X = mX_u u + mX_w w + mX_{\delta_e}\delta_e + mX_{\delta_T}\delta_T \quad (4)$$

$$\Delta Z = mZ_u u + mZ_w w + mZ_{\dot{w}}\dot{w} + mZ_q q + mZ_{\delta_e}\delta_e + mZ_{\delta_T}\delta_T \quad (5)$$

$$\Delta M = mM_u u + mM_w w + mM_{\dot{w}}\dot{w} + mM_q q + mM_{\delta_e}\delta_e + mM_{\delta_T}\delta_T \quad (6)$$

Where δ_e and δ_T represents the perturbations from the elevator trim and throttle settings respectively. Hence the small disturbance equation for longitudinal motion is given as,

$$\left[\frac{d}{dt} - X_u\right]\Delta u + g\cos\theta_0\Delta\theta - X_w\Delta w = X_{\delta_e}\Delta\delta_e + X_{\delta_T}\Delta\delta_T \quad (7)$$

$$-Z_u\Delta u + \left[(1 - Z_{\dot{w}})\frac{d}{dt} - Z_w\right]\Delta w - [u_0 + Z_q]\Delta q + g\sin\theta_0\Delta\theta = Z_{\delta_e}\Delta\delta_e + Z_{\delta_T}\Delta\delta_T \quad (8)$$

$$-M_u\Delta u - \left[M_{\dot{w}}\frac{d}{dt} - M_w\right]\Delta w - \left[\frac{d}{dt} - M_q\right]\Delta q = M_{\delta_e}\Delta\delta_e + M_{\delta_T}\Delta\delta_T \quad (9)$$

By solving the equation 1, the transfer function for variation of pitch rate Δq to the variation of elevator angle $\Delta\delta_e$ can be obtained as,

$$\frac{\Delta q(s)}{\Delta\delta_e(s)} = \frac{-\left(M_{\delta_e} + \frac{M_\alpha Z_{\delta_e}}{u_0}\right)s - \left(\frac{M_\alpha Z_{\delta_e}}{u_0} - \frac{M_{\delta_e}Z_\alpha}{u_0}\right)}{s^2 - \left(M_q + M_{\dot{\alpha}} + \frac{Z_\alpha}{u_0}\right) - \left(\frac{Z_\alpha M_q}{u_0} - M_\alpha\right)} \quad (10)$$

Hence, the transfer function for variation of pitch angle $\Delta\theta$ to the variation of elevator angle $\Delta\delta_e$ is derived as,

$$\frac{\Delta\theta(s)}{\Delta\delta_e(s)} = \frac{1}{s} * \frac{-\left(M_{\delta_e} + \frac{M_\alpha Z_{\delta_e}}{u_0}\right)s - \left(\frac{M_\alpha Z_{\delta_e}}{u_0} - \frac{M_{\delta_e}Z_\alpha}{u_0}\right)}{s^2 - \left(M_q + M_{\dot{\alpha}} + \frac{Z_\alpha}{u_0}\right) - \left(\frac{Z_\alpha M_q}{u_0} - M_\alpha\right)} \quad (11)$$

III. DESIGN OF CONTROLLERS

A. Conventional PID Controller

PID controllers are named by its three constituent terms (proportional, Derivative and Integral) whose sum will give the output of the controller. The general form of the PID controller in time domain is given as,

$$u(t) = K_p e(t) + K_p \int_0^t e(t)\,dt + K_d \frac{d}{dt}e(t) \quad (12)$$

Where K_p, K_d, K_i are the proportional, derivative, integral gains respectively and e(t) is the measured error signal.

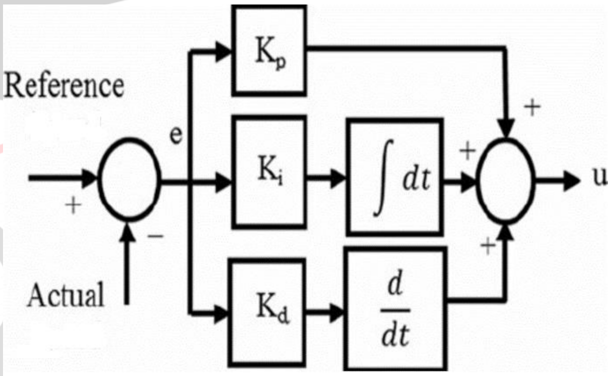

Figure 2. Structure of PID Controller

Even though the PID controller is one of the effective controllers in the control system design, it is not suitable for the optimal control. Because, the non-existence of process in the model.

B. Fuzzy logic tuned PID controller

Fuzzy logic is mathematical model that deals with the analog variables whose can vary continuously from 0 to1 and most suitable for the variables those cannot be expressed as 0 or 1. The primary advantage of fuzzy logic is, the solution of the problem can be modeled in terms that humans understand. So that the experience of human operators can be effectively used in the design of the controller.

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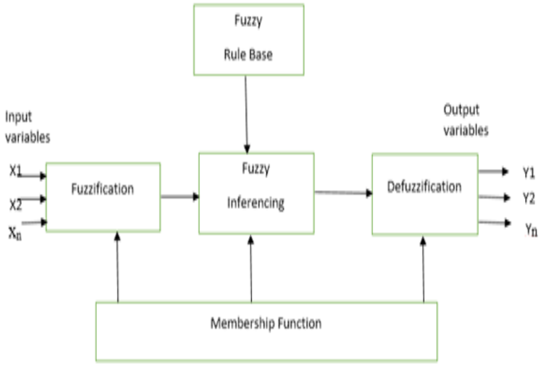

Figure 3. Structure of Fuzzy Process

The fuzzy process consists of three steps namely fuzzification, fuzzy interferencing and defuzzification. The input variables mapped by a sets of membership function to convert as a fuzzy value and this process is called fuzzification. By combining the fuzzified inputs with the fuzzy rule base, the rule strength is established. Based on the rule strength and membership function the consequences are formed to determine the output distribution. The process of determining the output distribution from the fuzzy input values is called fuzzy interferencing. Further, the output is defuzzified based on the membership function to produce the output variables which required. -3 to 3 is chosen as basic domain and -6 to 6 is chosen as fuzzy domain for the fuzzification of e(k). The rules base is composed of 3 sub-rules that are independent of each other. At the same time, each sub-rule is formed by 49 multiple-input and single-output (MISO) rules.

C. Genetic algorithm tuned PID controller

Genetic algorithm is evolutionary algorithm which can be applied for any function optimization problems. This generates all feasible solutions for the problem in the search space called population. Based on the fitness value, weaker solutions are terminated to rise the overall fitness of the population and the criteria is given by,

$$Ef \geq G \tag{13}$$

Where G is the random value selected in between the range of 0 to $|EF|$ and EF is described as the sum of expected fitness value of all solutions in the population. Further the expected fitness value is given as,

$$Ef_i = \frac{f_i}{Af} \tag{14}$$

Where Ef_i is the expected fitness value i^{th} solution, f_i is the fitness value i^{th} solution and Af is the average fitness value in the population.

The selected solutions are subjected to mutation (action applied to one solution and results in one new solution) and recombination (action applied on two or more of the selected solutions to generate one or more new solutions), for generation of new solutions which are completely different from the older one. Thus, increases the overall fitness of population and repeated until highest possible fitness is achieved. The crosses over probability p_c and mutation probability p_m are the key parameters for the performance of Genetic algorithm. When the p_c is high, there is a possibility of genetic mode damage and when p_c is small, the search process will become slow. Similarly, the high value p_m will make the genetic algorithm as a random algorithm and smaller p_m is not prone to the generation of newer structure. So, great concern is required in the selection of p_m and p_c values to ensure the diversity of population and convergence of algorithm. The values p_m and p_c is chosen such as,

$$p_c = \begin{cases} p_{c_1} - \frac{(p_{c_1}-p_{c_2})(f'-f_{avg})}{f_{max}-f_{avg}}, f' \geq f_{avg} \\ p_{c_1}, f' < f_{avg} \end{cases} \tag{15}$$

$$p_m = \begin{cases} p_{m_1} - \frac{(p_{m_1}-p_{m_2})(f'-f_{avg})}{f_{max}-f_{avg}}, f' \geq f_{avg} \\ p_{m_1}, f' < f_{avg} \end{cases} \tag{16}$$

Where f_{max} is the maximum individual fitness, f_{avg} is the average individual fitness and f 'for the larger individual fitness between two individuals. Through iterative steps the values of p_{c_1},p_{c_2}, p_{m_1} and p_{m_2} are selected as 0.9, 0.6, 0.1 and 0.01 respectively.

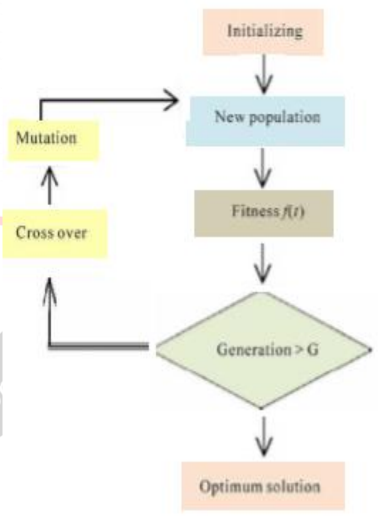

Figure 4.Process of Genetic algorithm tuned PID controller

IV. RESULTS AND DISCUSSIONS

Matlab is used to tune the PID controller with fuzzy logic and genetic algorithms by solving the differential equations. The problem was characterized into suitable genetic algorithm chromosomes and those are used to derive the population. Each chromosome consist proportional, integral and derivative gain parameters of the PID controllers. The designed controller is excited by the unit step input and the performance analyzed by the time domain specifications. The response of the proposed system with different controllers for the step response is shown in Figure. 6, Figure. 7 and Figure. 8.

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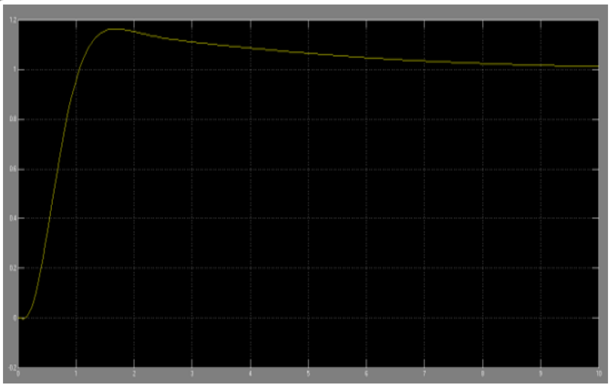

Figure 5. Response of Conventional PID controller

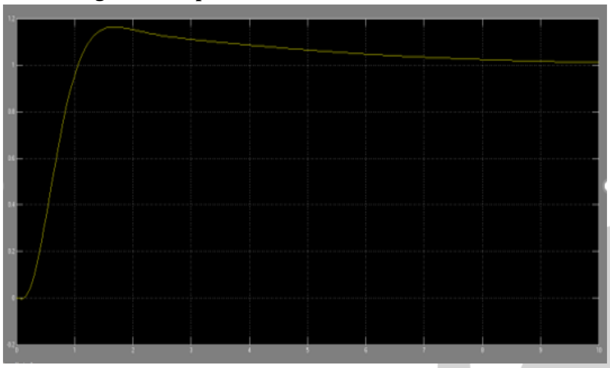

Figure 6. Response of fuzzy logic tuned PID controller

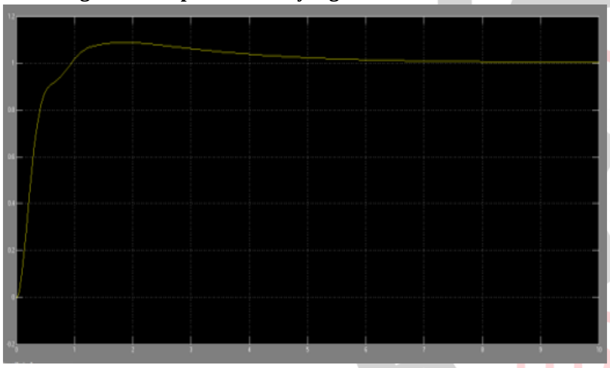

Figure 7. Response of genetic algorithm tuned PID controller

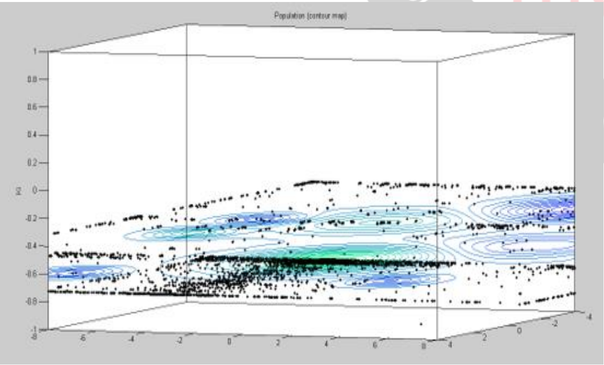

Figure 8. Population generated through Genetic algorithm

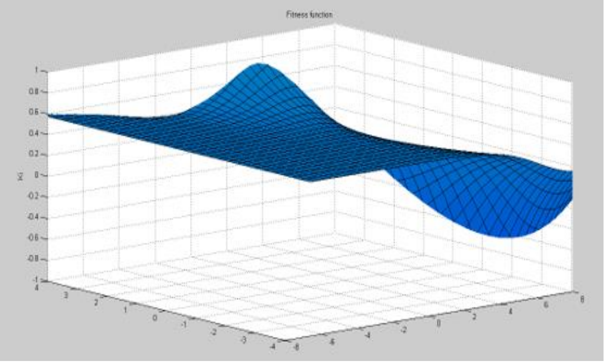

Figure 9. Fitness function plot of population

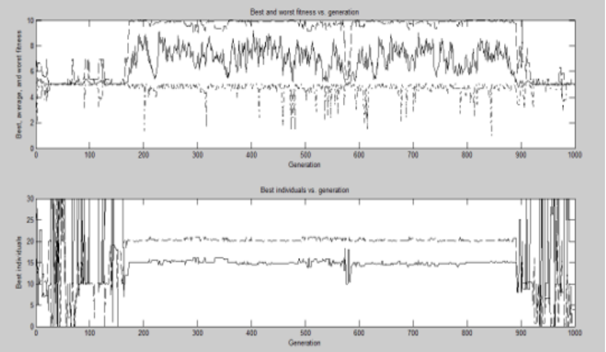

Figure 10. Individuals in generation

It is evident that from the step response of the system with PID and fuzzy logic tuned PID controllers are oscillatory when compare to the system with the genetic algorithm tuned PID controller [12]. The time domain specifications of the pitch control system with various controllers are listed in table1. From Table 1, it is observed that the genetic algorithm tuned PID controller reduced the settling time of the system by 29% when compare to the fuzzy logic tuned PID and by 47% compare to the conventional PID controller. When compare to genetic algorithm tuned PID controller, the conventional PID increased the peak overshoot by 29% and the fuzzy logic tuned PID controller increased the peak overshoot by 14%.

S. No	Parameter	Conventional PID Controller	Fuzzy logic tuned PID Controller	Genetic algorithm tuned PID Controller
1	K_p	4.78	3.678	2.4291
2	K_i	2.45	0.015	1.1478
3	K_d	-0.25	1.785	0.0566
4	Settling time	8 sec	5.7sec	4.2 sec
5	Peak overshoot	17%	14%	12%
6	Rise time	0.133 sec	0.14 sec	0.135 sec
7	Steady state error	4%	3.67%	2.96%

Table 1. Performance comparison of controllers

V. CONCLUSION

The self-adaptive controller for the pitch control system of the aircraft was designed and analyzed. Thus, the proposed approach was compared with the conventional and fuzzy logic tuned PID controllers. The performance of the proposed controller was estimated by exciting the system with unit step input analyzing the time domain parameters. The time domain parameters like steady state error, settling time, peak overshoot and rise time are studied as optimal in the case of Genetic algorithm tuned PID controller when compare to conventional and fuzzy logic tuned PID controllers. From the results, it is evident the proposed approach is best suitable method for

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eliminating the oscillatory responses and for providing the optimal pitch control of the aircraft.

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