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Performance Enhancement of a Dynamic System for Different Controller Using Soft Computing Methods

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***Abstract*— In this Paper we provide a novel approach to enhance the performance of a dynamic system using Genetic algorithms and Mat lab on different controller such as Conventional PID controller, FMRLC and a novel approach using combination of Proportional-integral-derivative and Genetic Algorithm which prove the best result as from the other controller. We used Bravo Fighter Aircraft as a dynamic system for this project. Z-N Tuning rule provide the values for overshoot as 25 (Percentage) and settling time values in-between 20 to 25 seconds. In this Paper we used different performance index factors like Integral Absolute Error (IAE), Integral Squared Error (ISE), Integral Time-weighted Absolute Error (ITAE), Integral Time Square Error (ITSE), Rise time (Sec), Settling Time (Sec) and Overshoot. It has been monitored that PID+GA provide the best result in all aspect. In first part of this Paper we designed an genetic algorithm for Conventional PID controller which provide the different values for index factors are IAE=1.4200, ISE=1.2414, ITAE=1.4937, ITSE=1.1864, Rise time=3.7196, Settling Time =14.1389, Overshoot = 19.9955. But using this algorithm when we implemented Ziegler-Nichols stability margin tuning it gives 1.6 as the Peak value. In second phase of this part we implement genetic algorithm on FMRLC and the result obtained for different index factor are given as IAE =1.8000, ISE =0.0056, IATE =11.9973, ITSE =1.6672, Rise time =7.4921, Settling Time = 8.9422, Overshoot =13.4809 which gives the better from conventional PID controller. But our prime objective is to further enhance the performance index factor of a dynamic system, so we combined conventional PID controller and Genetic Algorithm and after a lots of experiment and analysis we found the result for different performance index factor which is quite better improved from other two controller and also it reduce the peak value of Z-N Tuning rule from 1.6 to 1.3 and the values of performance index factor values as IAE =1.09, ISE =1.2, IATE =1.02, ITSE =1.16, Rise time =03, Settling Time = 13.27, Overshoot =05.**

Keywords- FMRLC,ITAE ; ITSE; ISE; IAE; PID Controller; Z-N tuning rule.

I. INTRODUCTION

The response of aerospace vehicles to perturbations in their flight environments and to control inputs [1-3] deals mainly with dynamics characteristics of flight. To characterize the aerodynamic and propulsive forces and moments acting on the vehicle, and the dependence of these forces and moments on the flight variables, including airspeed and vehicle orientation is the main objective of aircraft dynamics. The rapid advancement of aircraft design from the very limited capabilities of the Wright brothers first successfully airplane to today's high performance military, commercial and general aviation aircraft require the development of many technologies, these are aerodynamics, structures, materials, propulsion and flight control. In longitudinal control, the elevator controls pitch or the longitudinal motion of aircraft system [4]. Pitch is controlled by the rear part of the tail plane's horizontal stabilizer being hinged to create an elevator. By moving the elevator control backwards the pilot moves the elevator up a position of negative camber and the downwards force on the horizontal tail is increased. The angle of attack on the wings increased so the nose is pitched up and lift is generally increased. In gliders the pitch action is reversed and the pitch control system is much simpler, so when the pilot moves [5] the elevator control backwards it produces a nose-down pitch and the angle of attack on the wing is reduced. The pitch angle of an aircraft is controlled by adjusting the angle and therefore the lift force of the rear elevator. Lot of works has been done in the past to control the pitch of an aircraft for the purpose of flight stability and yet this research still remains an open issue in the present and future works [6 -7].

II. MATHEMATICAL MODEL OF DYNAMIC SYSTEM

The notation [8] for describing the aerodynamic forces and moments acting upon, flight vehicle is indicated in figure 1. The variables x, y, z represent coordinates, with origin at the centre of mass of the vehicle. The x- axis [9] points toward the nose of the vehicle. The z-axis is perpendicular to the x-axis, and pointing approximately down. The y axis completes a right-handed orthogonal system, pointing approximately out the right wing [10].

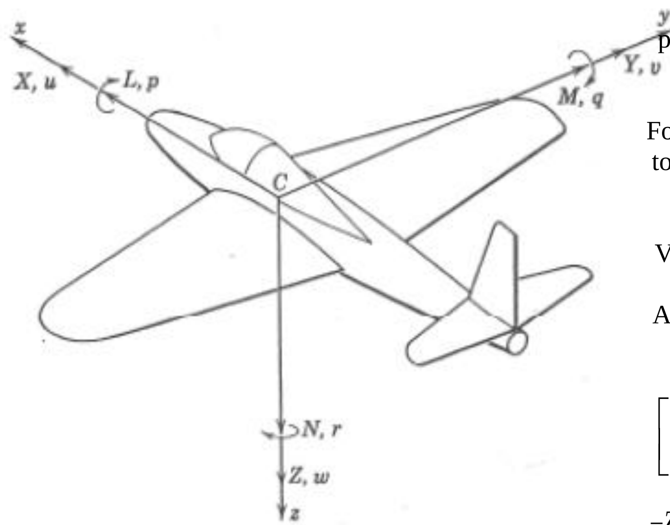

Figure: 1 Force, moments, and velocity components in a body fixed coordinate

Angles θ, φ and δ_e represent the orientation of aircraft pitch angle and elevator deflection angle. The forces, moments and velocity components in the body fixed coordinate are showed in Figure-1. The aerodynamics moment components for roll, pitch and yaw axis are represent as L, M and N. The term p, q, r represent the angular rates about roll, pitch and yaw axis while term u, v, w represent the velocity components of roll, pitch and yaw axis. The angles α and β represents the angle of attack and sideslip respectively [11 -13]. The atmosphere in which the plane flies is assumed undisturbed, thus forces and moment due to atmospheric disturbance are considered zero. Hence, considering Fig. 1, the following dynamic equations describe the longitudinal dynamics of a typical aircraft;

Force equations:

$$X - mgS_\theta = m(\dot{u} + qv - rv) \quad (1)$$

$$Z + mgC_\theta C\phi = m(\dot{w} + pv - qu) \quad (2)$$

Momentum equation:

$$M = I_y\dot{q} + rq(I_x - I_z) + I_{xy}(P^2 - r^2) \quad (3)$$

Equation 1, 2 and 3 should be linearized using small disturbance theory. The equations are replaced by a reference value plus a perturbation or disturbance, as given in equation 4. All the variables in the equation of motion are replaced by a reference value plus a perturbation or disturbance. The perturbations in aerodynamic forces and moments are functions of both, the perturbations in state variables and control inputs.

$$\begin{gathered} u = u_0 + \Delta u,\ v = v_0 + \Delta v,\ w = w_0 + \Delta w \\ p = p_0 + \Delta p,\ q = q_0 + \Delta q,\ r = r_0 + \Delta r \\ X = X_0 + \Delta X,\ M = M_0 + \Delta M,\ Z = Z_0 + \Delta Z \\ \delta = \delta_0 + \Delta\delta \end{gathered} \quad (4)$$

For convenience, the reference flight condition is assumed to be symmetric and the propulsive forces are assumed to remain constant [14]. This implies that

$$V_0 = p_0 = q_0 = r_0 = \varphi_0 = \psi_0 = w_0 = 0 \quad (5)$$

After linearization the following equations were obtained for the longitudinal dynamics, of the aircraft.

$$\left[\frac{d}{dt} - X_u\right] + ug_0\cos\theta_0 - X_w w = X_{\delta e}\delta_e + X_{\delta T}\delta_T \quad (6)$$

$$-Z_u u + \left[(1 - Z_{\dot{w}})\frac{d}{dt} - Z_w\right]w - [u_0 + Z_q]q + g_0\sin\theta_0 = Z_{\delta e}\delta_e + Z_{\delta T}\delta_T \quad (7)$$

$$-M_u u - \left[(M_{\dot{w}})\frac{d}{dt} - M_w\right]w + \left[\frac{d}{dt} - M_q\right]q = M_{\delta e}\delta_e + M_{\delta T}\delta_T \quad (8)$$

The equation 9 gives the transfer function for the change in the pitch rate to the change in elevator deflection angle.

$$\frac{\Delta q(s)}{\Delta\delta_e(s)} = \frac{(M_{\delta e} + M_{\dot{\alpha}}Z_{\delta e}/u_0)s + (M_\alpha Z_{\delta e}/u_0 - M_{\delta e}Z_\alpha/u_0)}{s^2 - (M_q + M_{\dot{\alpha}} + Z_\alpha/u_0)s + (Z_\alpha M_q/u_0 - M_\alpha)} \quad (9)$$

The transfer function of the change in pitch angle to the change in elevator angle can be obtained from the change in pitch rates to the change in elevator angle as given in equation 10, 11 and 12.

$$\Delta q = \Delta\dot{\theta} \quad (10)$$

$$\Delta q(s) = s\Delta\theta(s) \quad (11)$$

$$\frac{\Delta\theta(s)}{\Delta\delta_e(s)} = \frac{1\Delta q(s)}{s\Delta\theta(s)} \quad (12)$$

Hence, the transfer function for the pitch system dynamics of an aircraft can be described by,

$$\frac{\Delta q(s)}{\Delta\delta_e(s)} = \frac{1}{s}\frac{-(M_{\delta e} + \frac{M_{\dot{\alpha}}Z_{\delta e} +}{u_0})s - (\frac{M_\alpha Z_{\delta e} + Z_\alpha M_{\delta e}}{u_0})}{s^2 - (M_q + M_{\dot{\alpha}} + \frac{Z_\alpha}{u_0})s + (\frac{Z_\alpha M_q}{u_0} - M_\alpha)} \quad (13)$$

For simplicity, a first order model of an actuator is employed with the transfer function as given in equation 14, and time constant τ = 0.0167sec is employed

$$H(s) = \frac{1}{\tau s + 1} \quad (14)$$

Modern computer-based flight dynamics simulation is usually done in dimensional form, but the basic aerodynamic inputs are best defined in terms of the classical non-dimensional aerodynamic forms. These are defined using the dynamic pressure,

$$Q = \frac{1}{2}\rho V^2 = \frac{1}{2}\rho SLV_{eq}^{\ 2} \qquad (15)$$

Where ρ is the ambient density at the flight altitude and Veq is the equivalent airspeed, which is defined by the above equation in which ρSL, is the standard sea-level value of the density. In addition, the vehicle reference area S, usually the wing platform area, wing mean aerodynamic chord, $\overline{c}$ and wing span b are used to nondimensionalize forces and moments.

III. PID AND IMPROVED GENETIC ALGORITHM COMBINATION

A. Methodology Description

Positioning control system generally consists of three mains blocks: the PCsoftware, the controller board and the positio ning system. In Figure 3 the general scheme of the proposed methodology is shown in the PC-software block,
In the following paragraphs the complete description of the proposed methodology is presented.

The PCsoftware block contains the system model identifi cation, which is not the scope of this paper, but it is worth mentioning that the Least Squares Method (LSM) as pre sented in [14] is used to carry out the identification stack.

B. Genetic Algorithm Scheme

The Genetic Algorithm, GA, according to Rao in is a power ful optimization searching technique based on the principles of natural genetics and natural selection. A flow chart of the general scheme of the implementation of the GA is shown In figure-2

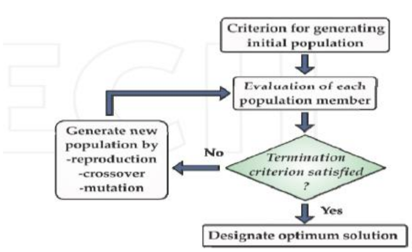

Figure 2: Genetic Algorithm Presenting Generation Cycle

In the GA, normally the design variables, corresponding to the genomes in the natural genetic, are represented as binary strings and they are concatenated to form an indi vidual, corresponding in turn to a chromosome in natura l genetics[15-17].

Other representations can be used. However, a binary repres entation is more adequate if an implementation in a digital s ystem has to be carried out.The main elements of natural genetics, according to Renerin [18], used for the searching procedure are:

- Reproduction
- Crossover
- Mutation

The reproduction operation consists of selecting individuals from the present population without changes to form part of the newpopulation, in order to provide the possibility of sur vival for already developed fit solutions. Meanwhile, the crossover operation consists of creating n ew individuals (offspring) from the present individuals (pare nts), according to a crossover probability, Cp, by selecting one or more crossover points within the chromosome of eac h parent at the same place. Then, the parts delimited by thes e points are interchanged between the parents. On the other hand, the mutation operation makes modifications to a select ed individual according to a mutation probability, Mp, by m odifying one or more values in the binary representation. It i s worth noting that if Mp is too large the GA is a purely stoc hastic search, but if Mp is too small it willbe difficult to crea te population diversity in the IGA.

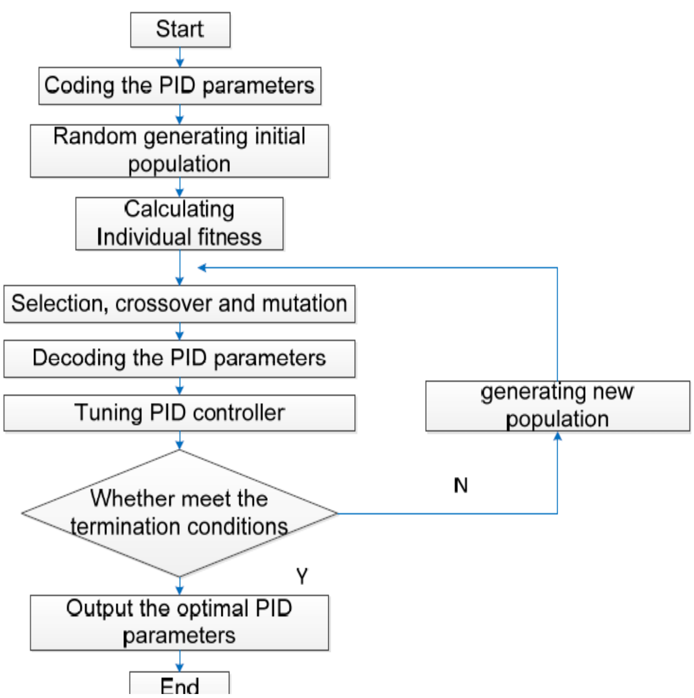

Figure 3: The flow chart of optimization of PID based on IGA

C. Result and discussion of PID and IGA

This part defines the numerical value of the different performance index factor by using the above said methodology.

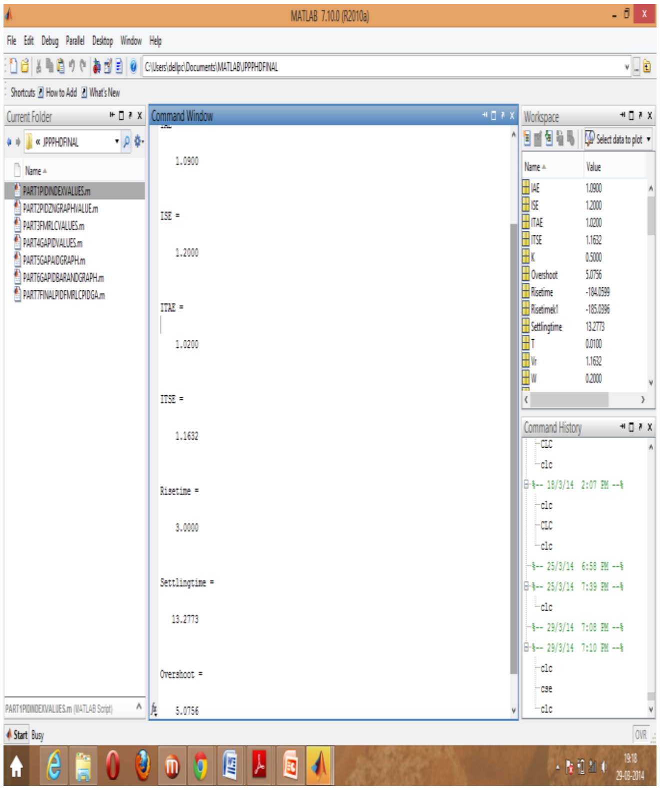

Figure 4: Performance index factor for PID and IGA

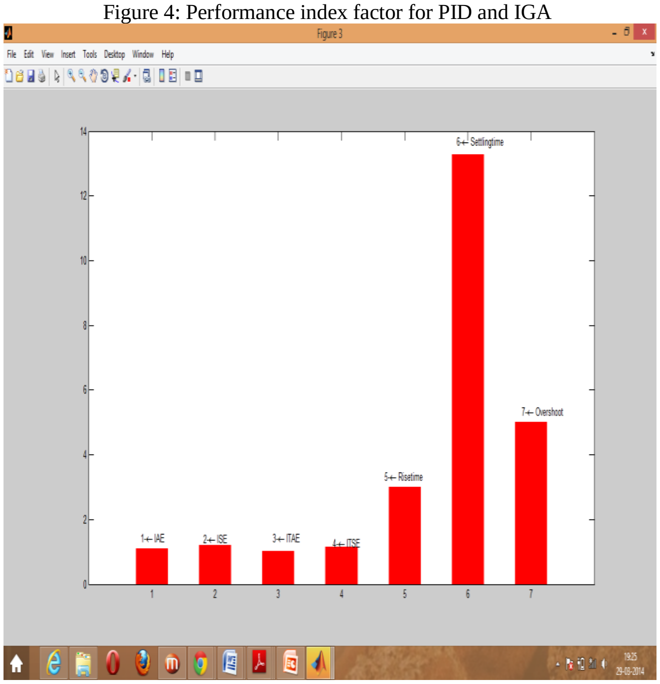

Figure 5: Bar chart for PID and IGA

IV. Fuzzy Model Reference Learning Controller(FMRLC)

The functional block diagram for the FMRLC is shown in Figure-.6[19]. It has four main parts i.e. the plant, the fuzzy controller to be tuned, the reference model, and the learning mechanism (an adaptation mechanism). The FMRLC uses the learning mechanism to observe numerical data from a fuzzy control system (i.e., θ ref(Kt) and θ(kT) where T is the sampling period). Using this numerical data, it characterizes the fuzzy control system's current performance and automatically synthesizes or adjusts the fuzzy controller [20] so that some given performance objectives are met. These performance objectives (closed-loop specifications) are characterized via the reference model shown in Figure 6. The learning mechanism seeks to adjust the fuzzy controller so that the closed loop system (the map from θref(kT) to θ(kT) acts like the given reference model (the map from θref (kT)to θm (kT).The fuzzy control system loop which is the lower part of Figure-1 operates to make θ(kT)to track θref (kT)by manipulating δ(kT).The upper-level adaptation control loop which is the upper part of Figure 6 seeks to make the output of the plant θ(kT) to track the output of the reference model θref(kT)by manipulating the fuzzy controller parameters.

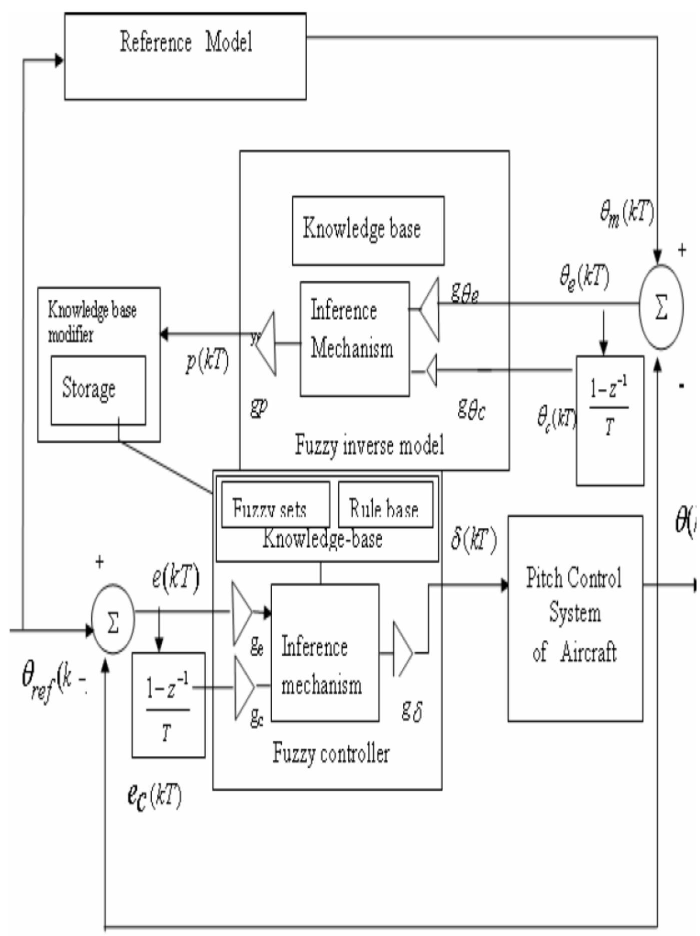

Figure 6: FMRLC for Aircraft Pitch Control

Mathematical formulation for FMRLC

Here plant is taken as the pitch control system of the Bravo fighter aircraft. The input to the plant is the elevator deflection (δ) and the output is the pitch angle (θ) .The longitudinal dynamics[8] of a aircraft can be represented with following set of equations.

$$\dot{u} = X_u u + X_w w - g\cos\gamma_0\theta \qquad (16)$$

$$\dot{w} = Z_u u + Z_w w + U_{0q} - g\sin\gamma_0\theta + Z_{\delta E}\delta_E \qquad (17)$$

$$\dot{q} = M_u u + M_w w + M_{\dot{w}}\dot{w} + M_q q + M_{\dot{\delta} E}\dot{\delta}_E \qquad (18)$$

$$\dot{\theta} = q \qquad (19)$$

Substituting the values of stability derivatives (Z_w, $M_{\dot w}$, M_q, $M_{\dot w}$, U_o, $Z_{\delta E}$, $M_{\dot\delta E}$) of aircraft[8] for flight condition-3 and 4 given the following transfer functios are obtained as follows

Flight Condition-3

$$\frac{\delta(s)}{\theta(s)} = \frac{-0.4500(1+1.6094s)}{[1+(0.0319+0.1844i)s][1+(0.0319-0.1844i)s]} \qquad (20)$$

Flight Condition-4

$$\frac{\delta(s)}{\theta(s)} = \frac{-0.1350(1+2.6045s)}{[1+(0.0170+0.1469)s][1+(0.0170-0.1469)s]} \qquad (21)$$

A. Result and discussion of FMRLC

This part describe the numerical value which are obtained after apply this mathematical formulation value on modified FMRLC algorithm and also it display the bar chart after the numerical value for different performance index factor.

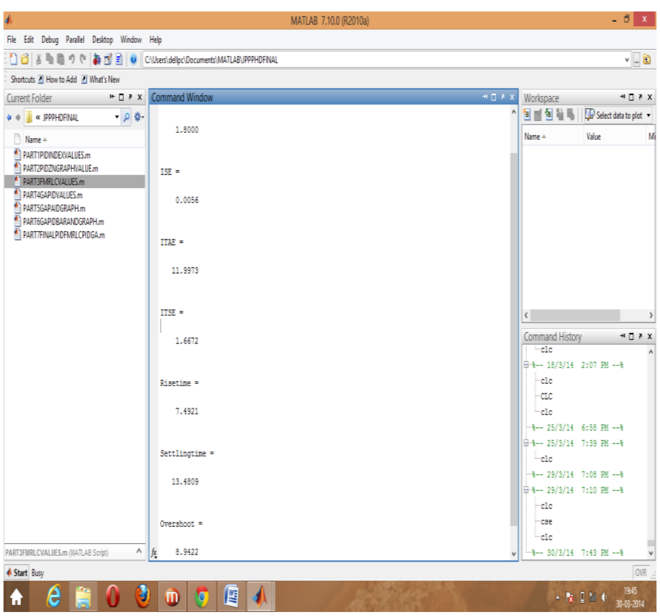

Figure 7: Performance index value of FMRLC

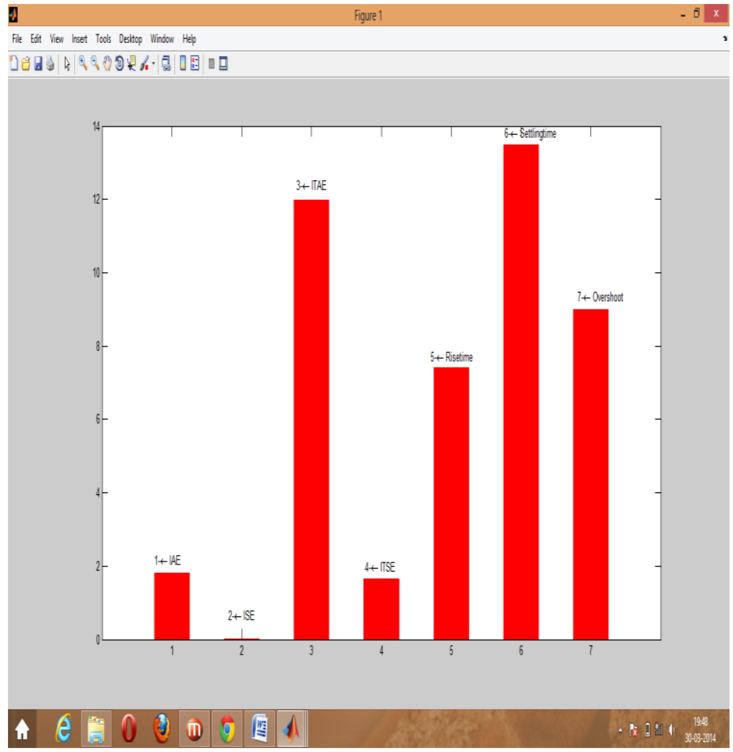

Figure 8: Bar chart for FMRLC index values

V. COMPARISON BETWEEN PID FMRLC AND PID+IGA

The comparison between different performance index factor are calculated by using the different algorithm implemented for the above specified Controller. Here we used matlab to find out the numerical values of IAE, ISE,ITAE,ITSE, Rise Time, Settling Time and Overshoot. These values are calculated for all the controller and it is displayed by using Bar chart and Graphical curve representation.

Controllers	*IAE*	*ISE*	*ITAE*	*ITSE*	*Rise Time(Sec)*	*Settling Time(sec)*	*Overshoot (%)*
Conventional PID	1.42	1.24	1.49	1.18	3.71	14.13	20
FMRLC	1.8	0.0056	11.99	1.66	7.4	13.48	09
PID+GA	1.09	1.2	1.02	1.16	03	13.27	05

Table 1: Performance Index, Rise Time, Settling Time and Overshoot

VI. RESULT AND DISCUSSION

In conventional PID controller we obtained the values 1.42, 1.24, 1.49, 1.18, 3.71, 14.13, and 20 for IAE, ISE, ITAE, ITSE, Rise Time, Settling Time, Overshoot respectively. Here we apply genetic algorithm on PID controller and reduce the Overshoot value from (25 -30) % which was defined by Ziegler–Nichols tuning method.

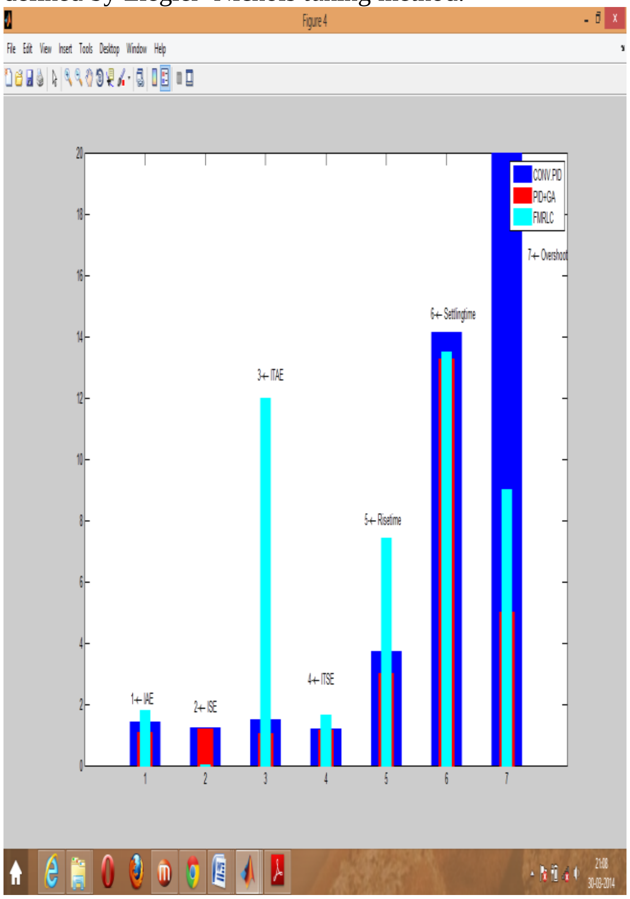

Figure 9: Final comparison chart PID, FMRLC and PID plus Genetic Algorithm.

In the Second part of this project we applied the Genetic Algorithm on FMRLC and it reduce the Settling Time (13.48) and Over Shoot (09%) value. But it increases the Rise Time from 3.71 sec to 7.4. Then in the final step we design a new algorithm by the combination of PID and Improved Genetic Algorithm Method and it provide the best result of the Experiment.

VII. SCOPE OF FUTURE STUDY

User can find out and apply any new Artificial Intelligence techniques in the above said problems to find out the better result and also user can apply the technique in other part of the Aircraft system or in any dynamic system to enhance the performance.

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