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Achieving Aircraft Pitch Control Through Artificial Intelligence

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تحقيق التحكم في درجة الميل والانحراف في الطائرات باستخدام الذكاء الاصطناعي

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Abstract

One of the biggest challenges in the aircraft field is the pitch control. enhancing the safety of the flight is an important factor. today many aircraft control systems employing classical controllers such as PID controllers that will enhance the system characteristics performance. in the past, the PID was tuned with classical methods such as trial and error and Zeigler Nichols. artificial intelligence now used optimization techniques to representing the possible solutions for a problem. using artificial intelligence for tuning the PID parameters will enhance the system's stability. The genetic algorithm optimization technique is used for tuning the PID parameters. The result will be compared with trial and error and Zeigler Nichols tunning methods. The results show that artificial intelligence enhanced the performance and stability of the system better than the other tunning methods.

Keywords: Genetic Algorithm, Artificial Intelligence, Optimal Control, PID, Pitch Control.

الملخص

أحد أكبر التحديات في مجال الطائرات هو التحكم في درجة الميل والانحراف. العامل الرئيسي هو تحقيق سلامة الرحلات. اليوم العديد من أنظمة التحكم في الطائرات تستخدم وحدات تحكم كلاسيكية مثل وحدات التحكم PID التي من شأنها تحسين أداء خصائص النظام. في الماضي، تم ضبط PIDبالطرق الكلاسيكية مثل طريقة التجربة والخطأ وطريقة وزيجلر نيكولاس. يستخدم الذكاء الاصطناعي الآن تقنيات التحسين لتمثيل الحلول الممكنة للمشكلة. سيؤدي استخدام الذكاء الاصطناعي لضبط معاملات المتحكم PID إلى تعزيز استقرار النظام. يتم استخدام تقنية تحسين الخوارزمية الجينية لضبط معاملات المتحكم PID. سيتم مقارنة النتيجة مع الطرق الكلاسيكية الأخرى والتي هي طريقة التجربة والخطأ وطريقة ضبط زيجلر نيكولاس. أظهرت النتائج أن الذكاء الاصطناعي عزز أداء واستقرار النظام مقارنة بطرق الضبط الأخرى.

الكلمات المفتاحية: الخوارزمية الجينية، الذكاء الاصطناعي، التحكم المثالي، المتحكم التفاضلي التكاملي،

Introduction

Air travel has a rich history, dating back to the early 20th century when the Wright brothers achieved the first powered flight. Since then, aviation has evolved tremendously, with continuous advancements in aircraft design, engine technology, navigation systems, and safety measures. Today, commercial flights are operated by a vast network of airlines, catering to millions of passengers worldwide. Furthermore, flight have played a crucial role in shaping the global Economy. They have fostered trade relations between nations, enabling the transportation of goods and facilitating economic growth. Air cargo services have become vital for transporting perishable items, high-value goods, and time-sensitive materials across continents, supporting industries such as pharmaceuticals, automotive, electronics, and e-commerce. Enhancing safety in aircraft is of paramount importance to the aviation industry. Continuous advancements in technology, rigorous regulations, comprehensive training programs, and proactive maintenance procedures are some of the key factors contributing to the ongoing efforts to improve aircraft safety. Enhancing stability in aircraft is essential for the safety of the flight. The Stability is the aircraft's ability to maintain its desired flight path and resist disturbances caused by external factors [4].

PID controllers are used widely in industrial processes. most of the control loops in process industries are PID type. Tuning is the parameters kp,ki and kd of the PID parameter values for getting the best performance from the system or process. This is the important part in the feedback closed loop control systems. There are a several of tuning methods have been introduced for giving acceptable and optimal performance. PID control is a feedback control algorithm that uses the proportional, integral, and derivative terms to continuously adjust the control variable based on the error between the desired setpoint and the system's output. By dynamically responding to changes and disturbances, PID control helps achieve accurate and efficient control in diverse systems, contributing to improved performance, stability, and productivity [4].

This paper presents development of an optimal PID controller for a composition control system using GA technique. This paper also compares the transient performance of the system using GA technique with Zeigler Nichols technique and trial and error technique.

The genetic algorithms generate and maintain a population of individuals they call chromosomes. Chromosomes are a string almost equivalent to the chromosomes that appear in DNA. These chromosomes are encoded solutions to a problem. It describes the process of evolution as per the rules of selection, reproduction, and mutation. Each chromosome gets a measure of its fitness in the environment. Then the Reproduction selects individuals with the best fitness values in the population. crossover and mutation of such individuals will produce, a new population in which individuals are an acceptable fit for their environment. The crossover process includes two chromosomes have the amount of data and depend on the reproduction process. Mutation introduces slight changes in a little extant of the population, that called evolutionary [2].

Mathematical model of the system

This section explains a description on the modeling of pitch control longitudinal equation of aircraft, according to a simulation environment for performance and development evaluation of the selected controller techniques. The system of longitudinal dynamics is explained in this paper mathematically and implemented as a transfer function. The pitch control system has been considered in this paper as shown in Figure 1 below where X_b,Y_b and Z_b describes aerodynamic force components. , Φ and δ_e represent the orientation of aircraft or angle pitch in the earth-axis system and elevator deflection angle [3].

The equations that describe the motion of an aircraft are a complicated group of six nonlinear coupled differential equations. Although, under certain conditions, they can be simplified and linearized into longitudinal and lateral equations. the longitudinal dynamics governed the Aircraft pitch. In this paper autopilot will be designed to control the aircraft pitch. The coordinate axes and forces acting on an aircraft are shown in the figure 1 [3].

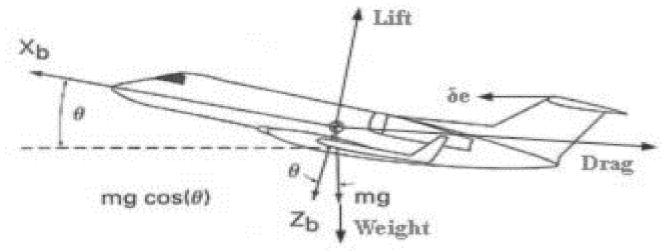

Figure 1 Pitch Control System.

Figure 2 describe the moments, forces and velocity components in the body fixed coordinate of aircraft system. The aerodynamics moment components for yaw, roll and pitch axis are describes as M, L 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. α and β are represents as the angle of attack and sideslip [3].

A few probabilities need to be considered before starting the modeling process. First, the aircraft is steady state cruise at constant altitude and velocity, thus the thrust and drag are cancelled out and the lift and weight balance out each other Second, the change in pitch angle will not change the speed of an aircraft under any condition [3].

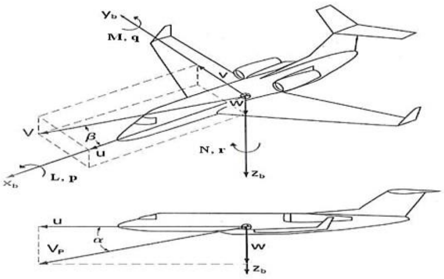

Figure. 2 Definition of force, moments and velocity in body fixed coordinate.

From Figure 1 and Figure 2, the dynamic equations in table 1 including force and moment equations are determined as shown in equations (1), (2) and (3). The longitudinal stability derivatives parameter used are described in Table 1 [1].

Table 1: Longitudinal Derivative Stability Parameters**.**

Longitudinal Derivatives	Components		
	Dynamics Pressure and Dimensional Derivative Q = 36.8lb/ft2, QS = 6771lb, QS C = 38596ft.lb, (C / 2u0) = 0.016s		
	X-Force, (S^{-1})	Z-Force, (F^{-1})	Pitching Moment, (FT^{-1})
Rolling velocities	Xu = -0.045	Zu = -0.369	Mu = 0
Yawing velocities	Xw = 0.036 $X_{\dot{W}}$ = 0	Zw = -2.02 $Z_{\dot{W}}$ = 0	Mw = -0.05 $M_{\dot{W}}$ = -0.051
Angle of attack	Xα = 0 $X_{\dot{\alpha}}$ = 0	Zα = -355.42 $Z_{\dot{\alpha}}$ = 0	Mα = -8.8 $M_{\dot{\alpha}}$ = -0.976
Pitching rate	Xq = 0	Zq = 0	Mq = -2.05
Elevator deflection	Xδe = 0	Zδe = -28.15	Mδe = -11.874

$$X - mgS_\theta = m(\dot{u} + qv - rv) \qquad (1)$$
$$Z - mgC_\theta\, C_\emptyset = m(\dot{w} + pv - qu) \qquad (2)$$
$$M = I_y\dot{q} + rq(I_x + I_z) + I_{xz}(p^2 - r^2) \qquad (3)$$

considering the following assumption:

1. Rolling rate $\rho = \emptyset - \psi S_\theta$
2. Yawing rate $q \doteq \theta C_\phi + \psi C_\theta S_\phi$
3. Pitching rate $r = \psi C_\theta C_\phi - \dot{\theta} S_\phi$
4. Pitch angle $\dot{\theta} = qC_\phi - rS_\phi$
5. Roll angle $\dot{\phi} = p + qS_\phi T_\theta + rC_\phi T_\theta$
6. Yaw angle $\psi = (qS_\phi + r_\phi)\sec\theta$

Equation (1), (2) and (3) have to linearized by a small disturbance theory. The equations are replaced by a reference value plus a disturbance.

$$u = u_0 + \Delta u \ , \quad v = v_0 + \Delta v \ , \quad w = w_0 + \Delta w \ , \quad p = p_0 + \Delta p \ , \quad q = q_0 + \Delta q \ , \quad r = r_0 + \Delta r \ ,$$
$$x = x_0 + \Delta x \ , \quad M = M_0 + MY \ , \quad Z = Z_0 + \Delta Z \ , \quad \delta = \delta_0 + \Delta\delta$$

For simplicity, the reference flight condition is assumed to be symmetric and the propulsive forces are assumed as a constant. This will produce that:

$$v_0 = p_0 = q_0 = r_0 = \varphi_0 = w_0 = 0$$

After the linearization of (4), (5) and (6):

$$\left(\frac{d}{dt} - X\right)\Delta u - X_w \Delta w + (g\cos\theta_0)\Delta\theta = X\delta_e \Delta\delta_e \qquad (4)$$
$$-Z_u\Delta u + \left[(1 - Z_u)\frac{d}{dt} - Z_w\right]\Delta w - \left[(u_0 - Z_0)\frac{d}{dt} - \sin\theta_0\right]\Delta\theta = Z_{\delta e}\Delta\delta_e \qquad (5)$$
$$-M_u\Delta u - \left[\left(M_w\frac{d}{dt} + M_w\right)\Delta w\right] - \left[\left(\frac{d^2}{d^2t} - M_q\frac{d}{dt}\right)\Delta\theta\right] = M_{\delta e}\Delta\delta_e \qquad (6)$$

By rewritng the (4), (5), (6) and substituting the parameters values of the longitudinal stability derivatives, the transfer function for the change in the pitch change in the pitch rate to the change in elevator deflection angle is shown as (7) obtained:

$$\frac{\Delta q(s)}{\Delta\delta_\theta(s)} = \frac{-\left(M_{\delta e} + \frac{M_{\dot{\alpha}} Z_{\delta e}}{u_0}\right)s - \left(\frac{M_\alpha Z_{\alpha e}}{u_0} - \frac{M_{\delta e} Z_\alpha}{u_0}\right)}{S^2 - \left(M_q + M_{\dot{\alpha}} + \frac{Z_\alpha}{u_0}\right)S + \left(\frac{Z_\alpha M_q}{u_0 - M_\alpha}\right)} \qquad (7)$$

The transfer function of the change in pitch angle to the change in elevator angle can be obtained with respect to the change in pitch rates to the change in elevator angle in the following:

$$\Delta q = \Delta\dot{\theta} \qquad (8)$$

$$\Delta q(s) = s\Delta\theta(s) \qquad (9)$$

$$\frac{\Delta\theta(s)}{\Delta\delta_e(s)} = \frac{1}{s}.\frac{\Delta q(s)}{\Delta\theta(s)} \qquad (10)$$

so, the transfer function of the pitch control system will be:

$$\frac{\Delta q(s)}{\Delta\delta_0(s)} = \frac{1}{s}\frac{\left(M_{\delta e} + \frac{M_{\dot{\alpha}} Z_{\delta e}}{u_0}\right)s - \left(\frac{M_\alpha Z_{\delta e}}{u_0} - \frac{M_\alpha Z_\alpha}{u_0}\right)}{s^2 - \left(M_q + M_{\dot{\alpha}} + \frac{Z_\alpha}{u_0}\right)s + \left(\frac{Z_\alpha M_\alpha}{u_0 - M_\alpha}\right)} \qquad (11)$$

By taking the Laplace transform of the above modeling equations, zero initial conditions should be assumed. The Laplace transform of the above equations are [1]:

$$\frac{\Delta\theta(s)}{\Delta\delta_e(s)} = \frac{1.151s + 0.1774}{s^3 + 0.739s^2 + 0.921s} \qquad (12)$$

These values are taken from the data from one of Boeing's commercial aircraft.

PID Controller

PID (Proportional-Integral-Derivative) control is a widely used feedback control algorithm in various industries and applications. It is a fundamental control technique that helps regulate and stabilize systems by continuously adjusting a control variable based on the error between the desired setpoint and the system's actual output. This introduction will provide an overview of PID control, its components, and its role in achieving precise and efficient control in diverse systems.

Proportional (P) Control: The proportional term directly adjusts the control variable in proportion to the error. It provides a response that is proportional to the magnitude of the error and helps reduce steady-state errors. The P term acts as the primary correction factor and can increase the control effort as the error increases. Integral (I) Control: The integral term continuously accumulates the error over time and applies a correction based on the integral of the error. It helps address steady-state errors that persist even with proportional control. The I term is responsible for eliminating any long-term bias or offset by gradually reducing the accumulated error. Derivative (D) Control: The derivative term predicts the future trend of the error by calculating the rate of change of the error. It provides a damping effect and helps improve the system's response to sudden changes or disturbances. The D term reduces overshoot and oscillations by anticipating the error's future behavior and adjusting the control variable accordingly.

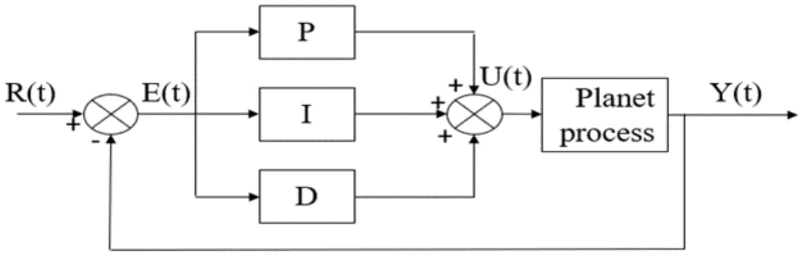

Figure 3: diagram of a PID controller.

The formula of the PID controller is:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)d\tau + k_d \frac{d}{dt} e(t)$$

Genetic Algorithm GA

The genetic algorithm operates on a population of potential solutions, representing candidate solutions to the problem at hand. Each candidate solution is encoded as a string of values, known as a chromosome or genotype. The genetic algorithm evolves this population over successive generations, applying genetic operators to simulate the processes of selection, crossover, and mutation, which are analogous to natural selection and genetic recombination. [6].

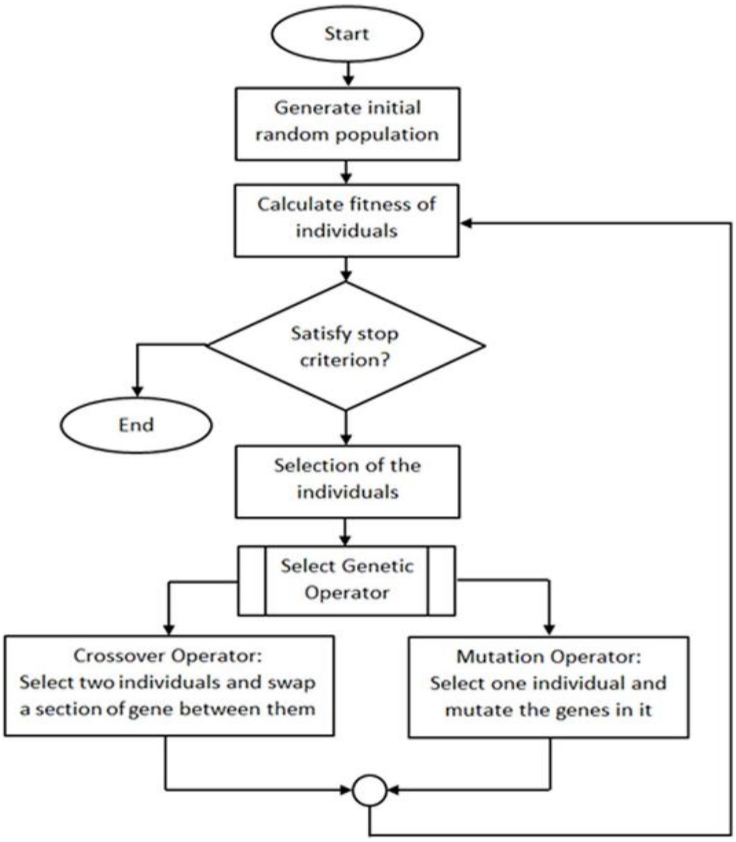

Figure 4: Genetic Algorithm Flowchart.

System Without Controller

The response of the pitch of the aircraft without controller as shown in the figure 5 shows that the system is unstable, thus, it must design a controller that gives a good stability for the system with high performance.

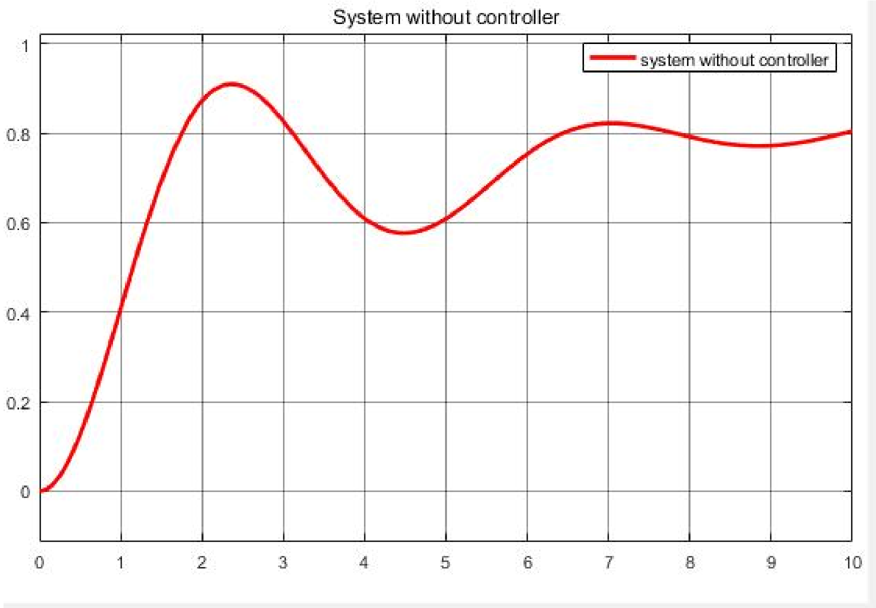

Figure 5: system without controller.

Pitch Control of Aircraft Based on PID Controller Tuned by The Classical Methods

1. Trial and Error Method

The first method to tunning the PID parameters is trial and error. The response of the overall system after 5 trails (kp=10, ki=3, kd=5) given bellow in figure 6, the trial and error method gives a settling time 2.44sec, peak time 0.737sec, rise time 0.302sec, peak amplitude 1.21, overshoot 21.4% and steady state 0 .

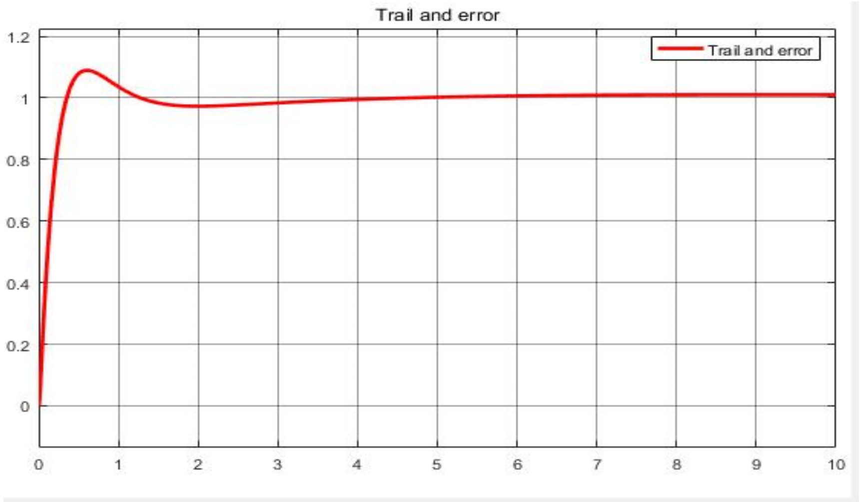

Figure 6: Final System Response with the PID parameters tuned by trial and error method.

2. Zigler Nichols Method

The second method to tunning the PID parameters is Zigler Nichols method, The response of the overall system (kp=7, ki=3, kd=4.5) given bellow in figure 7. the Zigler Nichols method gives a settling time 2.82 sec, peak time 0.854sec, rise time 0.351 sec, peak amplitude 1.17, overshoot 16.6% and steady state 0 .

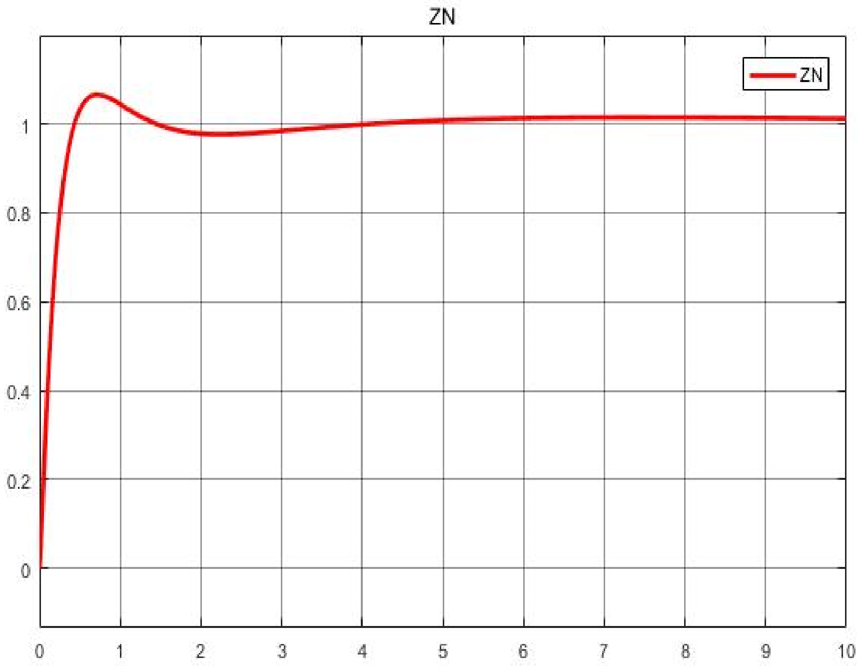

Figure 7: Final System Response with the PID parameters tuned by ZN method.

Pitch Control of Aircraft Based on Pid Controller Tuned by The Artificial Intelligence Method

Using the genetic algorithm technique to tunning the PID parameters. The response of the overall system (kp=10, ki=7.812, kd=10.844) given bellow in figure 8. the genetic algorithm method gives a settling time 1.25 sec, peak time 0.619 sec, rise time 0.204 sec, peak amplitude 1.06, overshoot 5.79% and steady state 0.

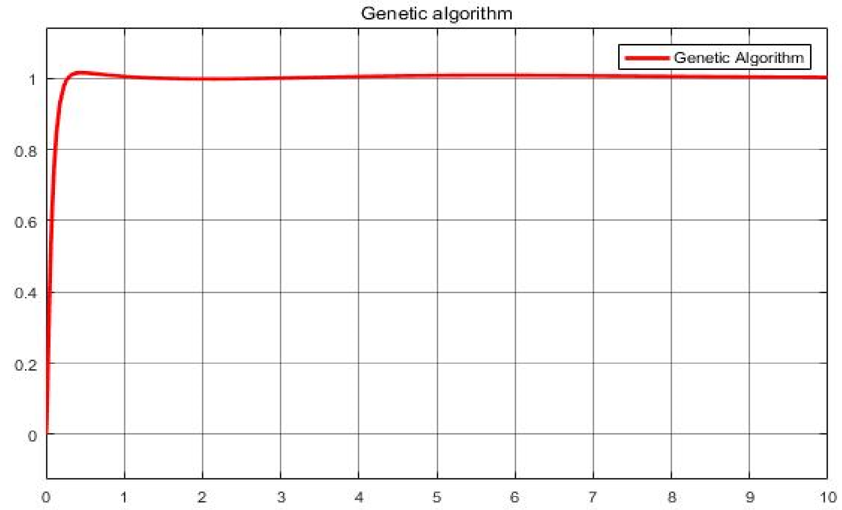

Figure 8: overall step response of the system with PID controller tunned by GA method.

System Response for Set-Point Tracking

The setpoint tracking response of PID controller tuned by the GA algorithm method, ZN and Trial and Error method obtained with the help of MATLAB/Simulink. The block diagram in MATLAB/Simulink and setpoint tracking response are shown in figures 9,10,11.

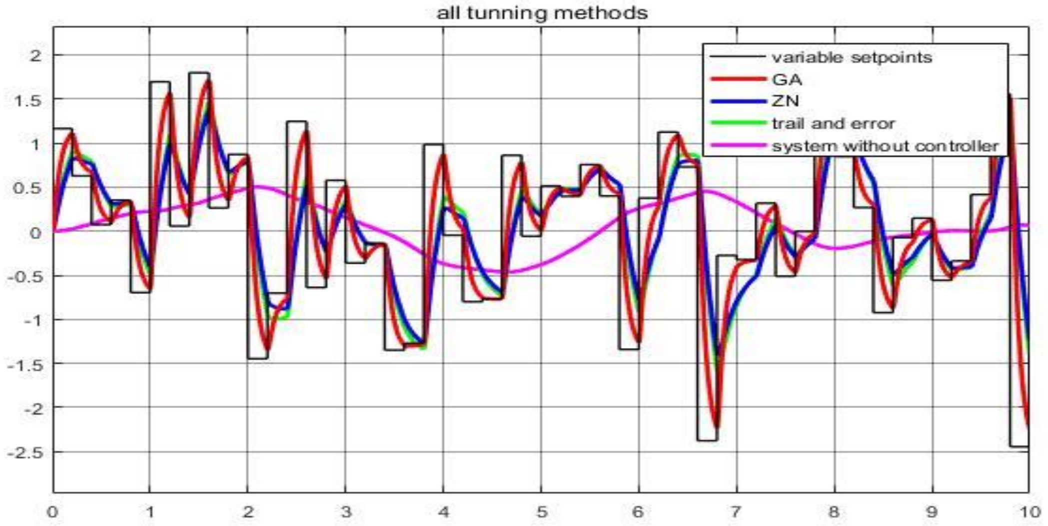

Figure 9: overall methods with step-tracking input signal (A).

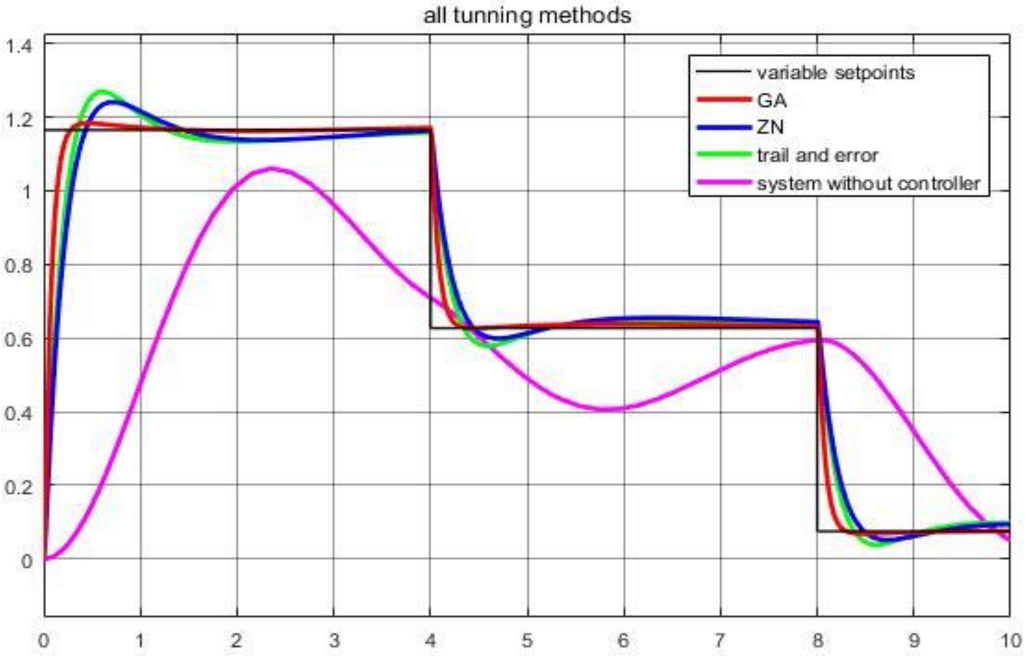

Figure 10: overall methods with step-tracking input signal (B).

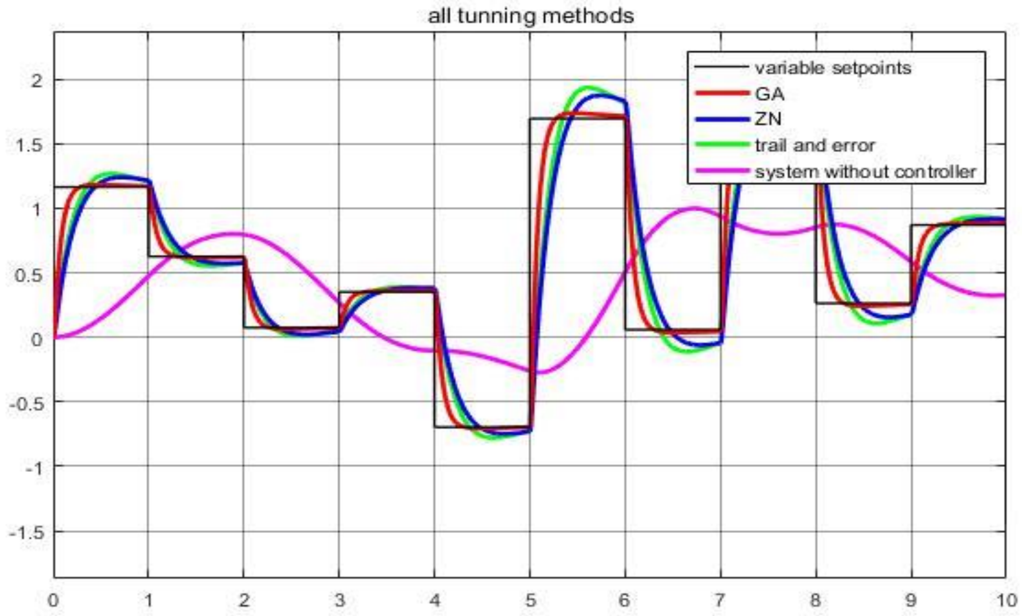

Figure 11: overall methods with step-tracking input signal (C).

Results and Discussion

The output responses of different tuning methods designed and simulated in m-file of MATLAB and Simulink for tuning the parameters of the PID controller are compared. figure 10 and table 2 shows the comparison between genetic algorithm optimization, ZN and Trial and Error methods in response's characteristics. GA method give promising results better than the Trial-and-Error method and ZN method; genetic algorithm gives settling time approximately 1.25 second whereas ZN method gives 2.82 second and trial and error method gives 2.44 second. For the overshoot, the genetic algorithm about 5.79% and ZN 16.6%. All methods give the same steady state error value that means the final value is the same as the setpoint. Generally, the three methods give a stable system. the GA methods better than trail-and-error method and ZN method. Hance, the GA method performance is the best between the three methods.

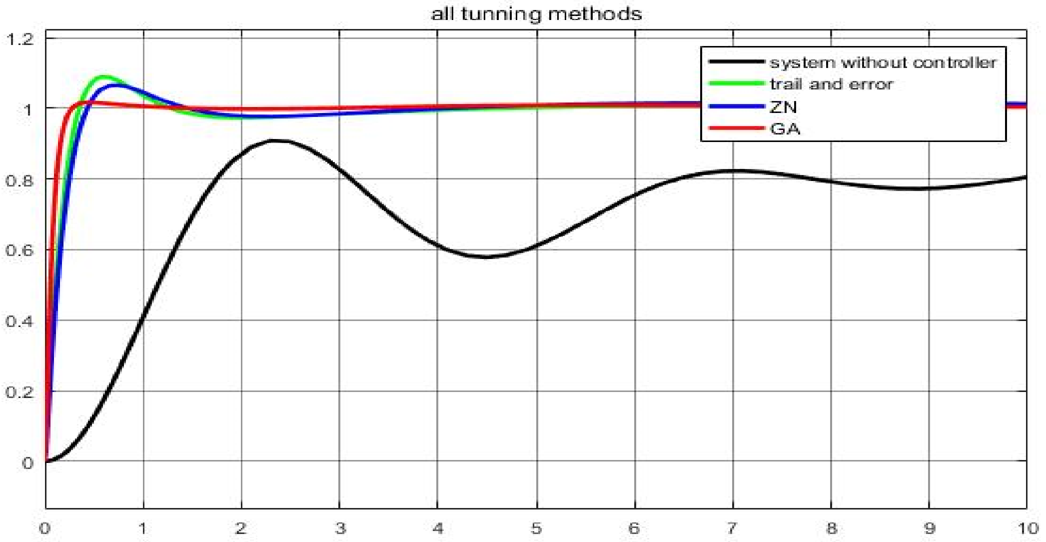

Figure 10: Final Comparison Between Different Tunning Methods.

Table 2: Final Comparison Between Different Tunning Methods.

Specification/method	Trial and Error	ZN	GA
Tr	0.302 sec	0.351 sec	0.204 sec
Tp	0.737 sec	0.854 sec	0.619 sec
Ts	2.44 sec	2.82 sec	1.25 sec
OS	21.4%	16.6%	5.79%
SS	0	0	0
Peak amplitude	1.21	1.17	1.06

Conclusion

In this research, the mathematical model for a pitch control for aircraft has been presented. The artificial intelligent is used to optimize the PID parameters in which to perform high and accurate response. This optimization is enhancing the pitch degree of the aircraft. System performance that used the GA artificial intelligent for tunning parameters have been compared with the classical method which are ZN and trail and error. In the final results, the GA artificial intelligent method gives a response a much better than the ZN and trial-and-error methods. In the characteristic response, the GA artificial intelligent has achieved a peak time batter than GA while the overshoot is approximately the same. However, the GA produced a settling time far better than the other methods. Generally, GA more complicated in programing than the others. But this algorithm will produce an optimal control system and more robustness. Thus, the final conclusion is that the GA artificial intelligent is considered to be the best optimization technique compared to the classical methods.

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