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Modeling and Dynamic Analysis of Pitch Motion Control of an Aircraft System

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النمذجة والتحليل الديناميكي للتحكم في حركة ميل أنظمة الطيران

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Abstract:
Safe and efficient flight operations require accurate and steady aircraft pitch angle control. Conventional control approaches struggle to achieve ideal transient response characteristics like minimum overshoot and fast settling time. This thesis compares aircraft pitch angle control techniques. Due to its instability, the open-loop aircraft pitch system requires powerful feedback control. This paper simulates the longitudinal dynamics of an aircraft pitch control system and builds PID controllers utilizing Trial-and-Error, Ziegler-Nichols, and GA-based optimization. A Model Predictive Control (MPC) technique is also tested. While Trial-and-Error and Ziegler-Nichols conventional PID tuning approaches stabilize the system, simulation studies show that they have higher overshoot and longer settling periods in transient response. The GA-optimized PID controller has a faster reaction (0.204 s, peak time 0.619 s, settling time 1.25 s) and a 5.79% reduction in overshoot. With comparable performance measures (settling time of 1.33 s, overshoot of 6.11%), the MPC technique works well in complex control contexts. A thorough comparison shows that the GA-tuned PID controller beats classical PID approaches and MPC in important transient response characteristics. This shows that artificial intelligence can optimize aircraft pitch control systems better. The results show that GA-based tuning can provide accurate and robust control, providing insights for aerospace control system design.

Keywords: GA, MPC, Pitch Control, PID, Pitch Angle, Genetic Algorithm, Flight Control

الملخص
تتطلب عمليات الطيران الآمنة والفعالة تحكمًا دقيقًا وثابتًا في زاوية ميل الطائرة. وتواجه أساليب التحكم التقليدية صعوبة في تحقيق خصائص الاستجابة العابرة المثالية مثل الحد الأدنى من التجاوز ووقت الاستقرار السريع. تقارن هذه الأطروحة تقنيات التحكم في زاوية ميل الطائرة. نظراً لعدم استقرارها، يتطلب نظام ميل الطائرة ذو الحلقة المفتوحة تحكماً قوياً في التغذية الراجعة. تحاكي هذه الأطروحة الديناميكيات الطولية لنظام التحكم في ميل الطائرة وتقوم ببناء وحدات تحكم *PID* باستخدام تقنيات التجربة والخطأ، وزيغلر-نيكولز، والتحسين القائم على *GA*. يتم أيضًا اختبار تقنية التحكم التنبؤي بالنموذج*(MPC)* في حين أن نهجي ضبط *PID* التقليديين *Trial-and-Error* و*Ziegler-Nichols* يعملان على استقرار النظام، تُظهر دراسات المحاكاة أن لهما تجاوزًا أعلى وفترات استقرار أطول في الاستجابة العابرة. تتمتع وحدة التحكم *PID* المحسّنة من خلال *GA* برد فعل أسرع (0.204 ثانية، ووقت الذروة 0.619 ثانية، ووقت الاستقرار 1.25 ثانية) وانخفاض بنسبة 5.79% في التجاوز الزائد. مع مقاييس أداء مماثلة (زمن الاستقرار 1.33 ثانية، وتجاوز التجاوز بنسبة 6.11%)، تعمل تقنية *MPC* بشكل جيد في سياقات التحكم المعقدة. تُظهر المقارنة الشاملة أن وحدة تحكم *PID*المضبوطة بالذكاء الاصطناعي المضبوطة بالذكاء الاصطناعي تتفوق على نهج *PID* الكلاسيكي وتقنية *MPC* في خصائص الاستجابة العابرة المهمة. وهذا يوضح أن الذكاء الاصطناعي يمكنه تحسين أنظمة التحكم في درجة ميل الطائرة بشكل أفضل. تُظهر النتائج أن الضبط القائم على *GA* يمكن أن يوفر تحكمًا دقيقًا وقويًا، مما يوفر رؤى لتصميم نظام التحكم في الطيران.

الكلمات المفتاحية: الخوارزمية الجينية، التحكم التنبؤي، التحكم بدرجة الميل، المتحكم التفاضلي التكاملي، زاوية الميل.

Introduction

Pitch control in aircraft has an interesting history that combines the advancements of engineering, technology, and aerodynamics. Understanding the basic laws of flight, the background of aviation, and the technical developments that have influenced contemporary aircraft design are all necessary to completely comprehend the importance of pitch control.[2]

Fundamentally, pitch control describes an aircraft's capacity to regulate its nose attitude with respect to the horizon, which is essential for manoeuvre execution and stable flying. One of an aircraft's three main axes, along with roll and yaw, is the pitch. The angle of attack (AOA) of the aircraft, or the angle between the chord line of the wing and the incoming airflow, is what controls the pitch axis, which extends from wingtip to wingtip.

The elevators, usually found on the horizontal stabilizer near the aircraft's tail, are the main control surfaces that affect pitch. The elevators deflect up or down as the pilot pushes the control yoke or stick forward or backward, which causes the nose of the aircraft to tilt up or down. By changing the AOA, this operation influences lift and drag, which in turn affects the aircraft's ability to ascend, descend, and fly level.

Pitch control in modern aviation has developed further in tandem with technological breakthroughs. In order to provide pilots more control over pitch, roll, and yaw, modern aircraft use complex flight control systems that combine a number of sensors, computers, and actuators. By automatically adjusting control surfaces in reaction to shifting flying circumstances, these systems can increase safety and stability.

The adoption of fly-by-wire technology, which enables more accuracy and flexibility in aircraft control, is one of the most important advancements in pitch control. Artificial intelligence and machine learning algorithms can be integrated into fly-by-wire systems to improve safety and maximize flying performance. For instance, the fly-by-wire technology of the Airbus A320 line of aircraft, which incorporates envelope protection, keeps pilots from going beyond certain flying parameters.

Modelling and methods principle

In order to assess the effectiveness and advancement of the chosen controller algorithms, this section describes how to model the pitch control longitudinal equation of an Aeroplan using a simulation environment. This work provides a mathematical explanation and implementation of the longitudinal dynamics system as a transfer function. Figure 1 below illustrates the pitch control system that has been examined in this research. Aerodynamic force components are described by Xb, Yb, and Zb, while aircraft orientation or angle pitch in the earth-axis system and elevator deflection angle are represented by Φ and δe.[1]

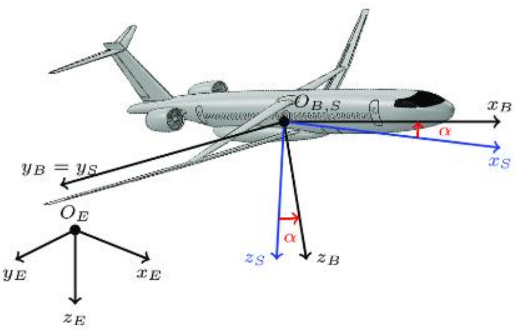

Figure 1: Pitch control system.

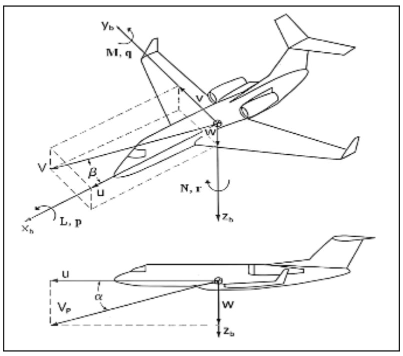

Figure 2: Definition of force, moments and velocity in body fixed coordinate.

The moments, forces, and velocity components in the aircraft system's body fixed coordinate are shown in Figure 2. M, L, and N are the descriptions of the aerodynamics moment components for the yaw, roll, and pitch axes. While terms u, v, and w describe the velocity components of the roll, pitch, and yaw axes, terms p, q, and r represent the angular rates about these axes. The angles of attack and sideslip are denoted by α and β, before beginning the modelling procedure, a few probabilities must be taken into account. First, because the aeroplane is in a steady state cruise at a constant altitude and speed, lift and weight balance each other out, and thrust and drag are eliminated. Secondly, Equations (1), (2), and (3) illustrate how the dynamic equations in Table 1—which include force and moment equations—are derived from Figures 1 and 2.

Table 1 describes the longitudinal stability derivatives parameter that was employed.

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

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

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):

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

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:

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

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:

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

$$\Delta q(s) = s\Delta\theta(s) \tag{9}$$

$$\frac{\Delta\theta(s)}{\Delta\delta_e(s)} = \frac{1}{s}\cdot\frac{\Delta q(s)}{\Delta\theta(s)} \tag{10}$$

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

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

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]:

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

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

Genetic algorithms work on the fundamental tenet that they create and preserve a population of people represented by chromosomes. A character string that is almost identical to the chromosomes found in DNA is called a chromosome. Usually, these chromosomes include encoded solutions to issues. It evolves according to the laws of mutation, reproduction, and selection. Every individual in the ecosystem, represented by a chromosome, receives a fitness score. Reproduction selects members of the population with high fitness values. Through this individuals' crossover and mutation, they identify a new population whose members may be even more suited to their surroundings. Crossover is similar to reproduction in that it involves two chromosomes exchanging data segments. Mutation is an evolutionary phase that brings small changes into a small portion of the population

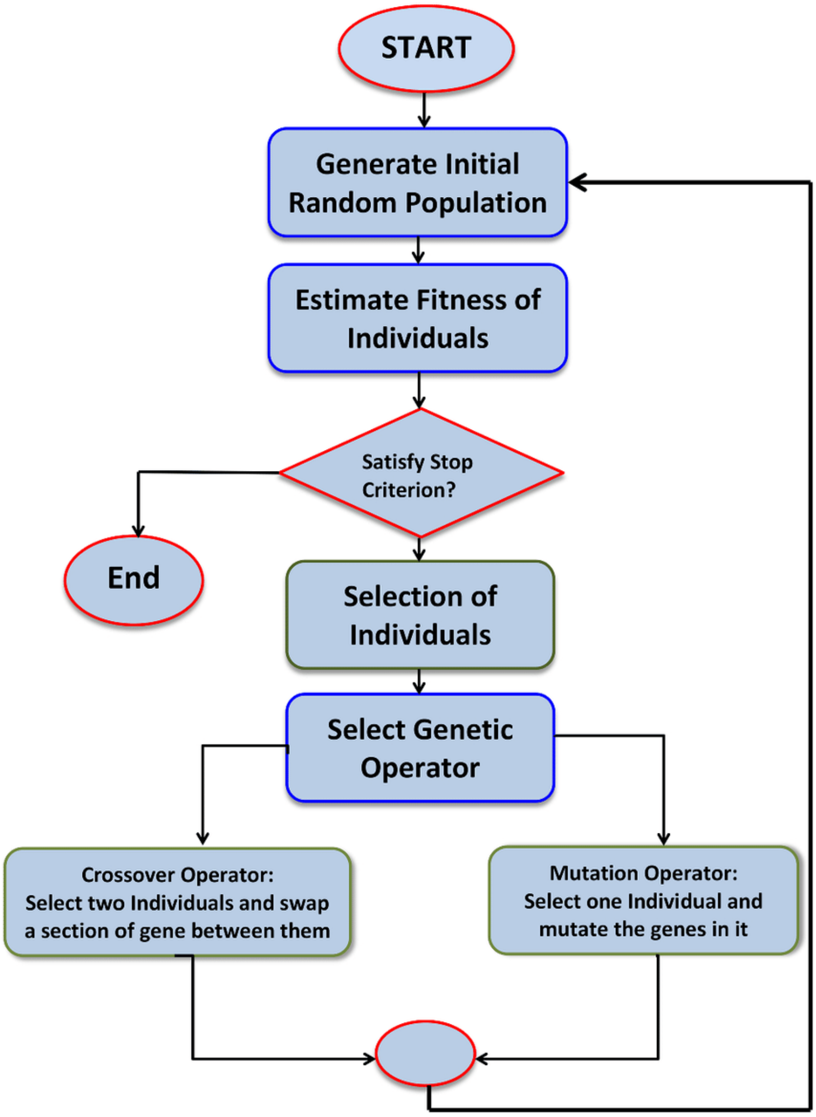

Figure 3: Genetic Algorithm Flowchart.

Model Predictive Control (MPC) is an advanced control technique that has garnered significant attention in numerous industrial applications due to its capability to effectively manage multivariable control problems, constraints, and dynamic systems. Processes characterized by significant temporal delays, complexity, or nonlinearity are particularly conducive to Model Predictive Control (MPC). Thoroughly analysing MPC's fundamental concepts, historical development, mathematical representation, advantages, disadvantages, and applications across various sectors is essential for comprehensive understanding.

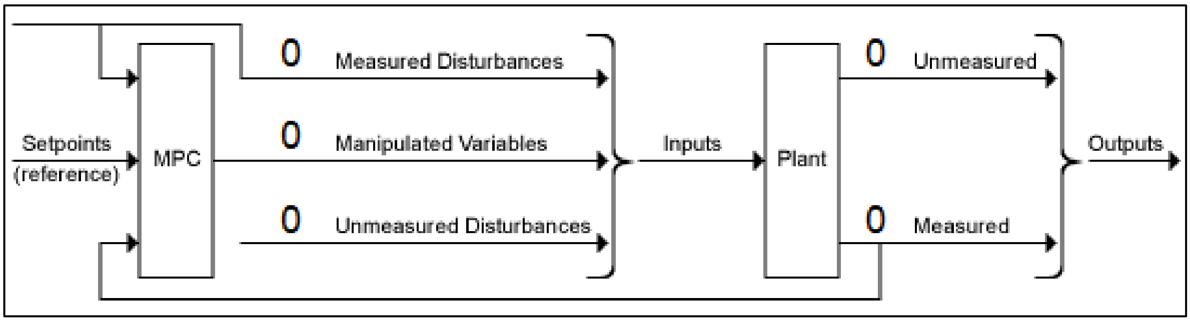

Figure 4: MPC structure.

Results and discussion

Firstly, the system without a controller has been tested. After that the PID controller will be implemented by computing the PID parameters (kp – ki – kd) for each method (trial and error, Ziegler Nichols, Genetic algorithm) then implement the Model predictive control on the system. They then collect the system specifications of each method of the previous methods. The results of each technique will be compared to find the most acceptable method.

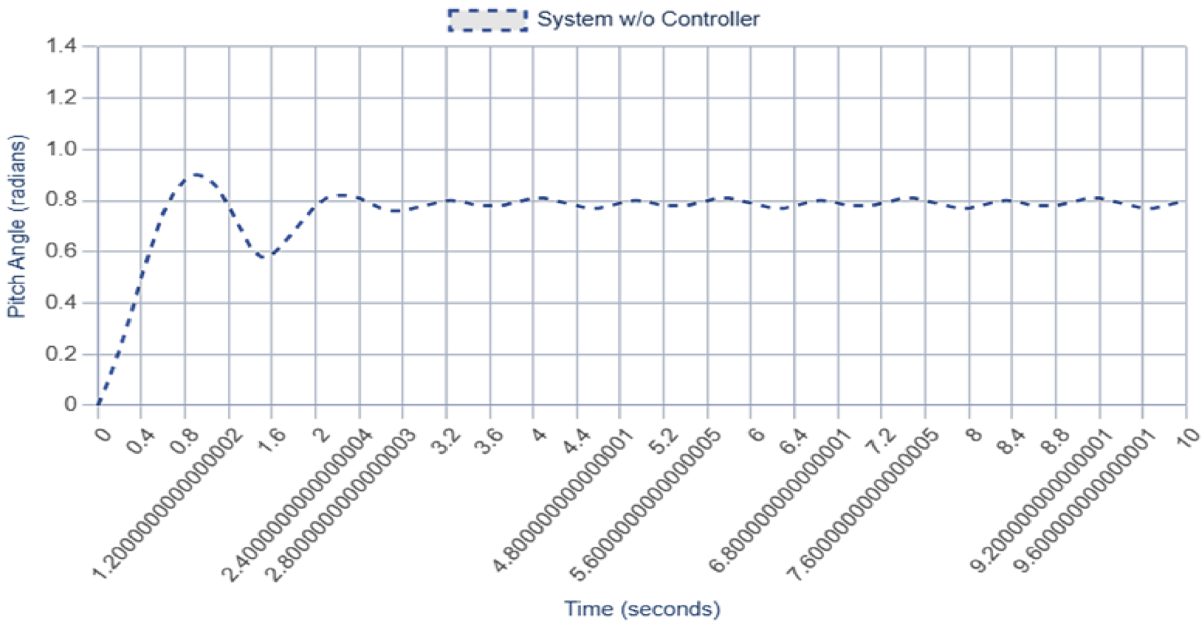

Figure 5: Pitch control system specifications without controller.

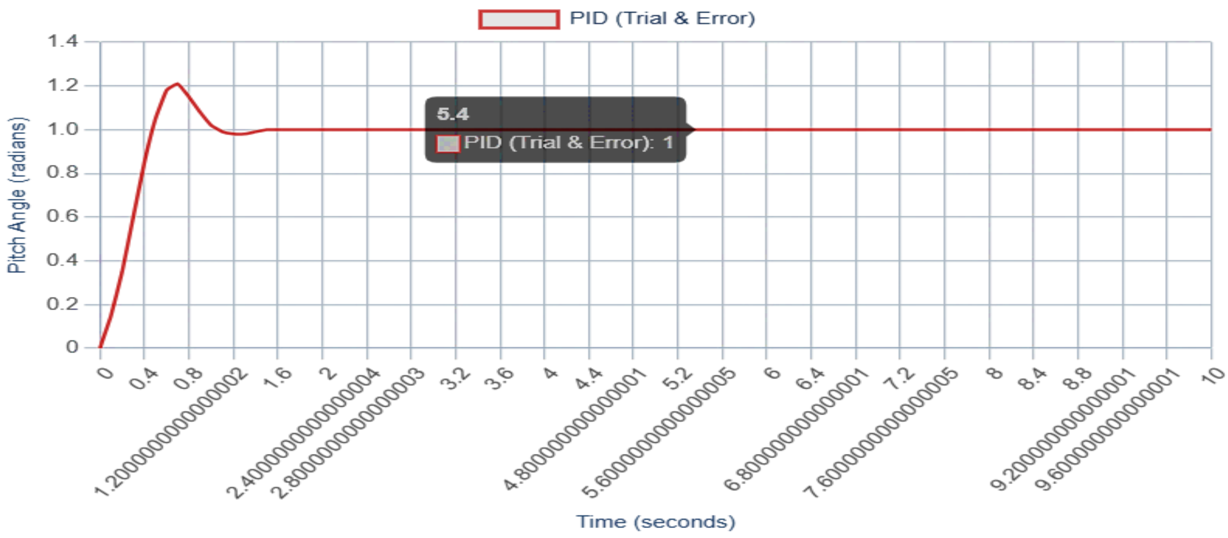

Figure 6: Pitch control system specifications with PID controller based on trial-and-error tunning method technique.

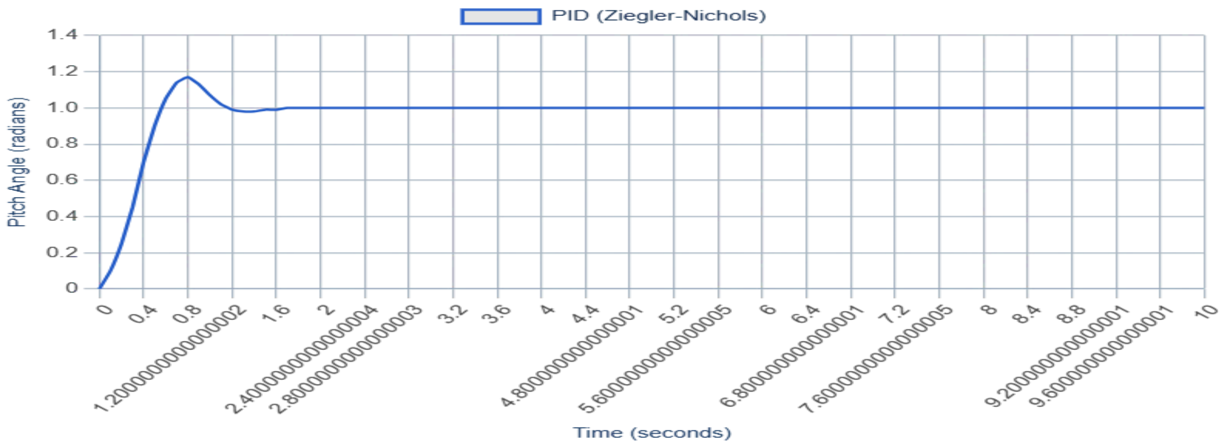

Figure 7: Pitch control system specifications with PID controller based on Ziegler Nicholas tunning method technique.

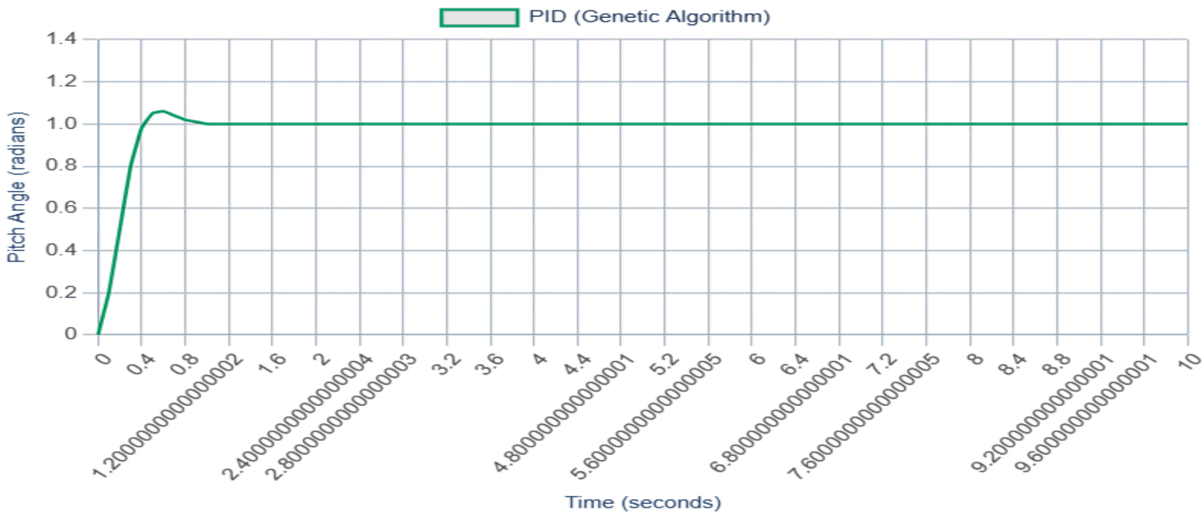

Figure 8: Pitch control system specifications with PID controller based on genetic algorithm tunning method technique.

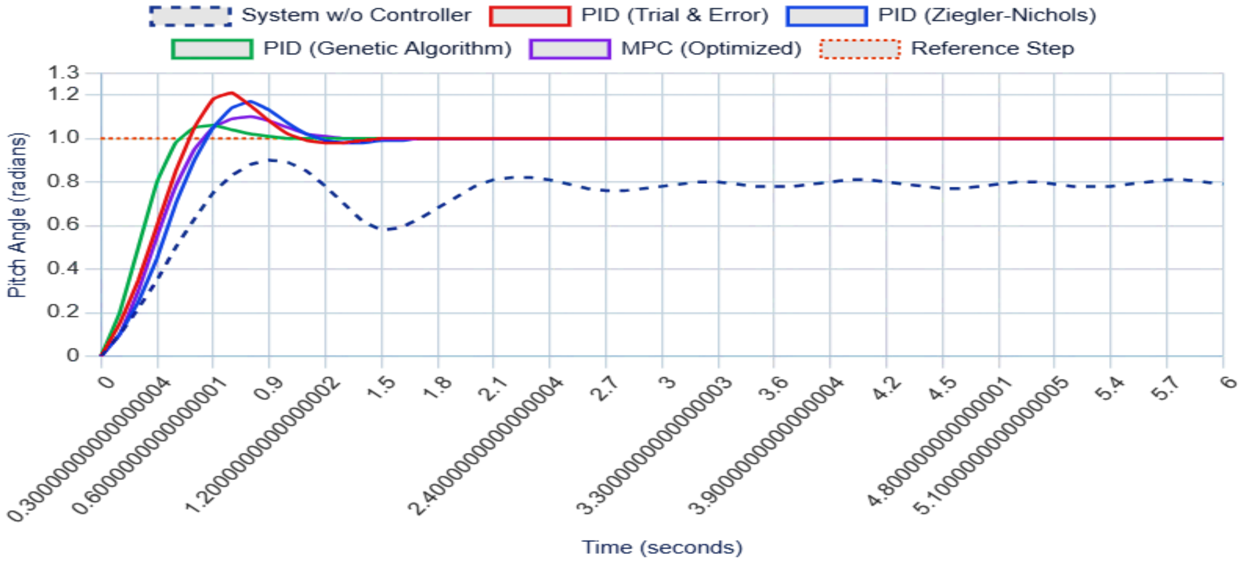

Figure 9: The comparison between methods (a).

Table 1 show the comparison between genetic algorithm optimization, ZN, Trial and Error, and MPC methods in response characteristics. The GA method gives promising results better than the Trial-and-Error method ZN method, and MPC method; the genetic algorithm gives a settling time of approximately 1.25 seconds and MPC 1.33 whereas the ZN method gives 2.82 seconds, and the trial-and-error method gives 2.44 seconds. For the overshoot, the genetic algorithm was about 5.79% and MPC 6% ZN 16.6%. All methods give the same steady state error value, which means the final value is the same as the setpoint. Generally, the three methods give a stable system. The GA method is a little better than MPC, and both better than trial-and-error methods and the ZN method. Hence, the GA method performance is the best of the four methods.

Table 2: Final Comparison Between Different Tunning Methods.

Method	Rise Time (Tr) (s)	Peak Time (Tp) (s)	Settling Time (Ts) (s)	Overshoot (OS) (%)	Steady State Error	Peak Amplitude
PID (Trial & Error)	0.302	0.737	2.44	21.40	0	1.21
PID (Ziegler-Nichols)	0.351	0.854	2.82	16.60	0	1.17
PID (Genetic Algorithm)	0.204	0.619	1.25	5.79	0	1.06
MPC (Optimized)	0.310	0.950	1.33	6.11	0	1.10

The results clearly indicate that the PID controller tuned with the Genetic Algorithm (GA) provided the most favorable combination of fast response (low Tr, Tp, Ts) and minimal overshoot (OS). MPC also performed exceptionally well, showing its strength as an advanced control technique. Traditional PID tuning methods (Trial & Error, Ziegler-Nichols) stabilized the system but with slower responses and higher overshoots.

This research successfully demonstrated the application and comparison of various control strategies for aircraft pitch control. The key findings are:

• The aircraft pitch system without a controller is inherently unstable.
• PID controllers, when tuned effectively, can stabilize the system and achieve desired performance.

• The Genetic Algorithm (GA) proved to be a highly effective method for optimizing PID controller parameters, resulting in superior performance (fastest settling time of 1.25s and lowest overshoot of 5.79%) compared to traditional tuning methods (Trial & Error, Ziegler-Nichols).
• Model Predictive Control (MPC) also delivered excellent results (settling time 1.33s, overshoot 6.11%), showcasing its capability in handling complex control problems.

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 MPC and classical method which are ZN and trial and error. MPC are designed to control the pitch angle and enhanced the robust and aggressive of closed loop performance and enhancing the performance estimation in the MPC designer for optimal performance. the fitness function has been implemented to produce the three generation of PID parameters. Also manually, the PID parameters have been tunned in the Trial-and-error method with 5 trials. in the final results, the GA artificial intelligent method gives a response a much better than the MPC, ZN and trial-and-error methods. In the characteristic response, the GA artificial intelligent has achieved a peak time batter than other methods and the overshoot is the best. However, the GA produced a settling time better than the other methods. Generally, GA more complicated in programing than the others. And MPC is less complicated than GA while ZN and Trail and error are easier to design. But this algorithm will produce an optimal control system and more robustness than the others. Thus, the final conclusion is that the GA artificial intelligent is considered to be the best optimization technique compared to the classical methods.

References

[1] Laith Abualigah ,Davut Izci, Serdar Ekinci, Raed Abu Zitar, Optimizing Aircraft Pitch Control Systems: A Novel Approach Integrating Artificial Rabbits Optimizer with PID-F Controller, International Journal of Robotics and Control Systems,Vol. 4, No. 1, 2024, pp. 354-364.
[2] A.B. Kisabo, F. A. Agboola, C.A. Osheku, M. A. L. Adetoro1 and A.A. Funmilayo, Pitch Control of an Aircraft Using Artificial Intelligence, Journal of Scientific Research & Reports, 1(1): 1-16, 2012; Article no. JSRR.2012.001.
[3] Yihao Du, Advances in flight control systems for modern commercial aircraft, 2nd International Conference on Machine Learning and Automation.
[4] Gustavo Ceballos, Manuel. Duarte-Mermoud and Marcos E. Orchard, Enhancing the Pitch-Rate Control Performance of an F-16 Aircraft Using Fractional-Order Direct-MRAC Adaptive Control, Fractal and Fractional.
[5] Sudha, G., and S. N. Deepa. "Optimization for pid control parameters on pitch control of aircraft dynamics based on tuning methods." Applied Mathematics & Information Sciences 10.1 (2016): 343.
[6] Wahid, Nurbaiti, and Nurhaffizah Hassan. "Self-tuning fuzzy PID controller design for aircraft pitch control." 2012 Third International Conference on Intelligent Systems Modelling and Simulation. IEEE, 2012.
[7] Izci, Davut, et al. "HHO algorithm based PID controller design for aircraft pitch angle control system." 2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA). IEEE, 2020.
[8] Singh, Ajai Kumar, and Rahul Dahiya. "Design and modeling of controllers for aircraft pitch contol movement." International Journal of Engineering and Computer Science, ISSN (2016): 2319-7242.
[9] Ohri, Jyoti. "GA tuned LQR and PID controller for aircraft pitch control." 2014 IEEE 6th India International Conference on Power Electronics (IICPE). IEEE, 2014.
[10] Lee, Sangchul, Kwangjin Kim, and Youdan Kim. "A sliding mode control with optimized sliding surface for aircraft pitch axis control system." Transactions of the Japan Society for Aeronautical and Space Sciences 55.2 (2012): 94-98.
[11] Ting, Eric, and Mohammad A. Ayoubi. "Optimized fuzzy-proportional/integral/derivative controller for aircraft pitch control." Journal of Aerospace Information Systems 10.8 (2013): 414-429.
[12] Aldeeb, Ahseen Naser, et al. "Optimization of PID Parameters Based on Genetic Algorithm Optimization for Ball and Beam System." African Journal of Advanced Pure and Applied Sciences (AJAPAS) (2023): 191-199.
[13] Kamalasadan, Sukumar, and Adel A. Ghandakly. "A neural network parallel adaptive controller for fighter aircraft pitch-rate tracking." IEEE Transactions on Instrumentation and Measurement 60.1 (2010): 258-267.
[14] Rehman, Asad Ur, et al. "Aircraft Pitch Control based on Genetic Algorithm Tuning with PID and LQR Controller." 2021 6th International Multi-Topic ICT Conference (IMTIC). IEEE, 2021.