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Optimizing Aircraft Pitch Control Systems: A Novel Approach Integrating Artificial Rabbits Optimizer with PID-F Controller

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ABSTRACT

The precise control of aircraft pitch angles is critical in aviation for maintaining specific attitudes during flight, including straight and level flight, ascents, and descents. Traditional control strategies face challenges due to the non-linear and uncertain dynamics of flight. To address these issues, this study introduces a novel approach employing the artificial rabbits optimizer (ARO) for tuning a PID controller with a filtering mechanism (PID-F) in aircraft pitch control systems. This combination aims to enhance the stability and performance of the aircraft pitch control system by effectively mitigating the kick effect through the incorporation of a filter coefficient in the derivative gain. The study employs a time-domain-based objective function to guide the optimization process. Simulation results validate the stability and consistency of the proposed ARO/PID-F approach. Comparative analysis with various optimization algorithm-based controllers from the literature demonstrates the effectiveness of the proposed technique. Specifically, the ARO/PID-F controller exhibits a rapid response, zero overshoot, minimal settling time, and precise control during critical phases. The obtained results position the proposed methodology as a promising and innovative solution for optimizing aircraft pitch control systems, offering improved performance and reliability.

1. Introduction

Controlling the pitch angle of an aircraft holds paramount importance in the aviation industry, where pilots are tasked with maintaining specific attitudes for straight and level flight, as well as controlled ascents and descents relative to the horizon [1]. Given the demanding nature of these tasks, many advanced aircraft are equipped with autopilot systems to alleviate pilot workload and enhance navigation accuracy. These systems aim to operate the airplane without direct control over longitudinal surfaces like the elevator or tail.

The design of effective flight control systems encounters challenges due to the inherent non-linearity and unpredictable dynamics of flight [2]. Traditional controllers, such as the proportional-integral-derivative (PID) [3], have been widely used for plane trajectories [4]. However, the non-linear and uncertain flight dynamics may limit the efficacy of such controllers in achieving desired stability and performance. Various adaptive and complex control strategies have been explored to address these challenges [5]-[12], including intelligent controllers like fuzzy, intelligent fuzzy, adaptive, fractional-order PID controllers, and sliding mode controllers [13]-[16].

Precise control of the pitch angle is crucial, especially during critical phases like takeoff and landing. Metaheuristic algorithms, including genetic algorithm [17], Harris hawks optimization [18], Henry gas solubility optimizations [19], bat algorithm [10] and bacterial foraging optimization [20], have been employed to regulate aircraft pitch angles. This paper contributes to the existing literature by introducing a novel optimization technique called artificial rabbits optimizer [21], inspired by survival strategies observed in rabbits. Despite its proven applicability in diverse engineering problems, such as leaf disease classification [22], infinite impulse response system identification [23], energy management system for photovoltaic, battery and supercapacitor based isolated microgrid system [24], automatic voltage regulator control [25], and design of optimal hybrid microgrid system [26], its potential for aircraft pitch control systems remains unexplored.

In addition to proposing the artificial rabbits optimizer, this paper introduces a PID controller with a filter mechanism (PID-F) [27] for aircraft pitch control systems. The study adopts a time-domain-based objective function known as Zwee-Lee Gaing [28] for the optimization problem. This approach significantly improves aircraft pitch control system performance by addressing the kick effect through a filter coefficient in the derivative gain. The controller parameters are tuned using artificial rabbits optimization, and the stated objective function is utilized for minimization.

Simulation results affirm the stability and consistency of the proposed approach for aircraft pitch control systems. Comparative analysis with various optimization algorithm-based approaches from the literature, including battle royale optimization [29], sine cosine algorithm [19], grasshopper optimization algorithm [19], Henry gas solubility optimization [19], Harris hawks optimization [18], atom search optimization [18], and salp swarm algorithm [18], reveals the effectiveness of the PID-F controller tuned by the proposed artificial rabbits optimizer. This approach exhibits a rise time of 0.0094 seconds, zero overshoot, settling time of 0.0155 seconds, zero steady-state error, and an objective function value of 0.0023. These results position the proposed technique as a promising method for achieving rapid response, minimal overshoot, and precise control in aircraft pitch systems.

2. Modeling of Aircraft Pitch Control System

The investigation of the aircraft pitch control system involves creating a mathematical model that considers various forces like thrust, drag, weight, and lift, as depicted in Fig. 1. The model assumes a steady cruise condition with a consistent velocity and altitude. For simplicity, we assume that alterations in the pitch angle do not impact the aircraft's speed. The longitudinal equations of motion for the aircraft under these assumptions are expressed as:

$$P(s) = \frac{\Theta(s)}{\Delta(s)} = \frac{1.151s + 0.1774}{s^3 + 0.739s^2 + 0.9215s} \quad (1)$$

where $\Delta(s)$ signifies the elevator deflection angle, and $\Theta(s)$ denotes the pitch angle. The Laplace domain transfer function is then formulated in state-space form as given in (2) and (3) [18].

The block diagram illustrating the closed-loop-controlled aircraft pitch control system is presented in Fig. 2, and its step response is depicted in Fig. 3. Examination of the closed-loop step

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response indicates the necessity for an efficient and suitable controller to eliminate oscillations, as well as to reduce rise and settling times.

$$\begin{bmatrix} \dot{\alpha} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} -0.313 & 56.7 & 0 \\ -0.0139 & -0.426 & 0 \\ 0 & 56.7 & 0 \end{bmatrix} \begin{bmatrix} \alpha \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} 0.232 \\ 0.0203 \\ 0 \end{bmatrix} \delta \tag{2}$$

$$y = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \alpha \\ q \\ \theta \end{bmatrix} \tag{3}$$

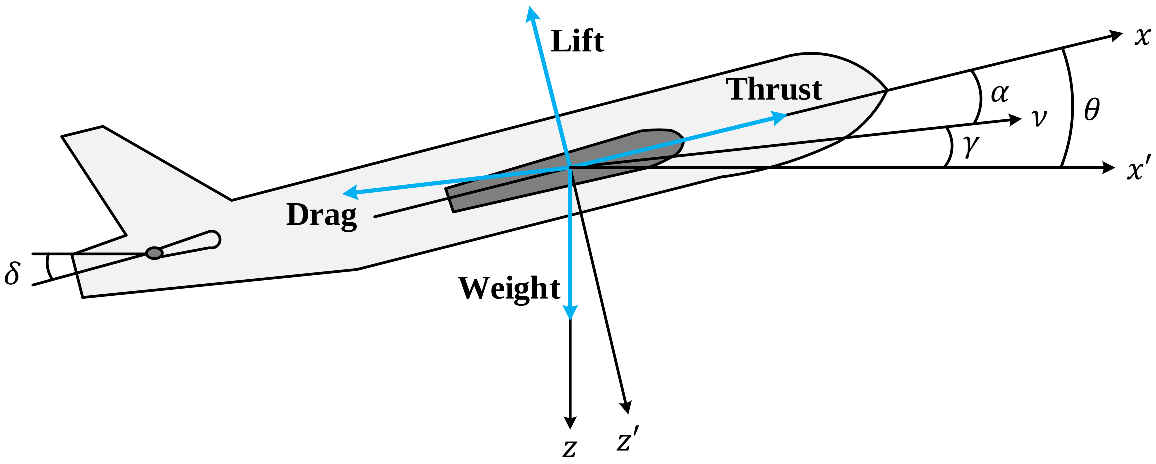

Fig. 1. Coordinate axes and forces acting on the aircraft

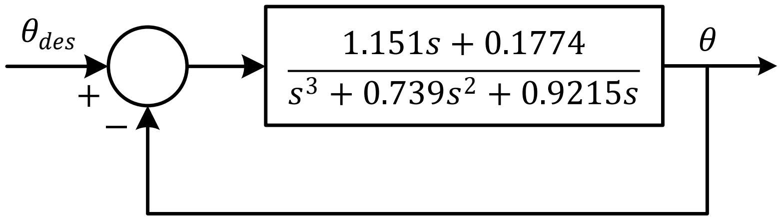

Fig. 2. Closed loop-controlled aircraft pitch control system

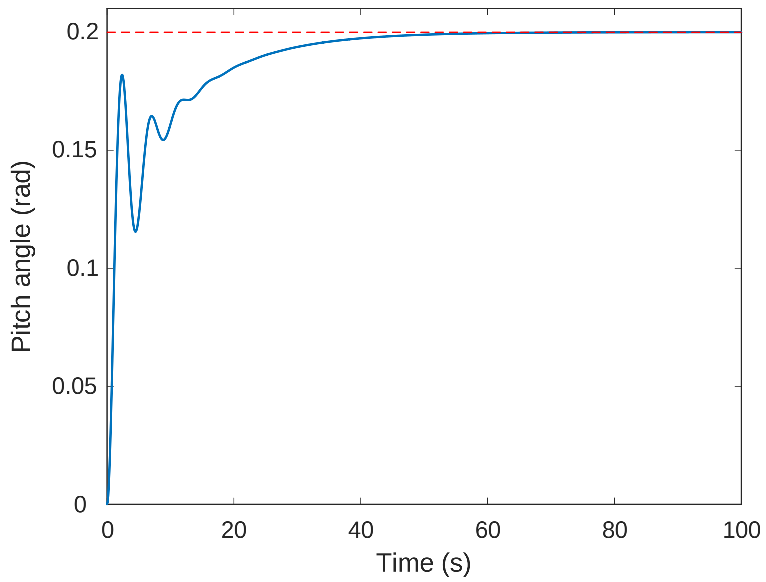

Fig. 3. Closed-loop response of aircraft pitch system without any controller

3. Overview of Artificial Rabbits Optimization

Artificial rabbits optimization (ARO) stands out as a novel and robust metaheuristic algorithm inspired by the survival strategies exhibited by rabbits [21]. This algorithm ingeniously incorporates foraging behaviors such as random hiding and detour foraging, mirroring the way rabbits seek food near other burrows to confuse potential predators and safeguard their own habitats. Unlike traditional foraging patterns, ARO introduces a unique approach where rabbits venture to more distant locations in their quest for sustenance.

In the ARO swarm, the population size is determined by the number of rabbits, each equipped with an eating zone containing plants, grass, and multiple burrows. During the foraging phase, rabbits embark on random explorations of other rabbits' burrows, updating their positions based on chosen companions and introducing perturbations. This foraging action can be mathematically expressed as follows.

$$\overrightarrow{\Delta_l}(t+1) = \overrightarrow{z_j}(t) + \rho \cdot \left(\overrightarrow{z_l}(t) - \overrightarrow{z_j}(t)\right) + round\left(0.5 \cdot (0.05 + g_1)\right) \cdot n_1 \tag{4}$$

here, ρ represents a mathematical operator symbolizing rabbit locomotion [23]. The algorithm incorporates essential parameters such as E, c, g_1, g_2, and g_3, defining aspects like foraging round duration, random hiding strategy, and uniform random numbers [21].

The exploitation phase involves rabbits employing a random hiding strategy to evade predators by creating burrows close to their original positions. The corresponding mathematical expressions for this process are given by:

$$\overrightarrow{BU_{\iota J}}(t) = \overrightarrow{z_l}(t) + H \cdot h \cdot \overrightarrow{z_l}(t) \tag{5}$$

where H is determined by $H = ((1 - t + T)/\mathrm{T}) \cdot g_4$. In the random hiding mode, the rabbit's position is updated using the definition in (6).

$$\overrightarrow{\Delta_l}(t+1) = \overrightarrow{z_l}(t) + \rho \cdot \left(g_4 \cdot BU_{ir}(t) - \overrightarrow{z_l}(t)\right) \tag{6}$$

The ARO algorithm introduces a mechanism to transition from exploratory to exploitative modes, where the energy of rabbits diminishes as the iteration progresses. This transition is governed by (7).

$$\overrightarrow{z_l}(t+1) = \begin{cases} \overrightarrow{z_l}(t) & f(\overrightarrow{z_l}(t)) \le f(\overrightarrow{\Delta_l}(t+1)) \\ \overrightarrow{\Delta_l}(t+1) & f(\overrightarrow{z_l}(t)) > f(\overrightarrow{\Delta_l}(t+1)) \end{cases} \tag{7}$$

here, α is a random number. If $A(t) > 1$, the algorithm prioritizes global exploration, while $A(t) \le 1$ guides the algorithm toward local exploitation. Fig. 4 illustrates the detailed procedure of the ARO algorithm.

4. Proposed Control System for Aircraft Pitch Control

4.1. PID Controller with Filter Mechanism

The PID controller, a widely used feedback control system in engineering and industrial applications, is designed to regulate a specified setpoint by continuously adjusting a control variable based on the difference between the setpoint and the actual process variable. Comprising proportional (K_p), integral (K_i), and derivative (K_d) components, this control mechanism is a standard choice in control systems [30], [31]. In contrast to the conventional PID controller, our study introduces a novel approach for the aircraft pitch control system, integrating a PID controller with a filtering mechanism (PID-F) [27]. This innovative strategy significantly improves the performance of the aircraft pitch control system. The transfer function of the PID-F controller is expressed in (8) [32]:

$$C(s) = K_p + \frac{K_i}{s} + K_d \frac{ns}{s+n} \tag{8}$$

where the low-pass filter gain is denoted as 'n' [32]. The PID-F controller offers a distinct advantage by effectively mitigating the kick effect through the inclusion of a filter coefficient in the derivative gain. Consequently, this modification enhances the immunity of the aircraft pitch control system to noise. The block diagram of the controlled plant is illustrated in Fig. 5.

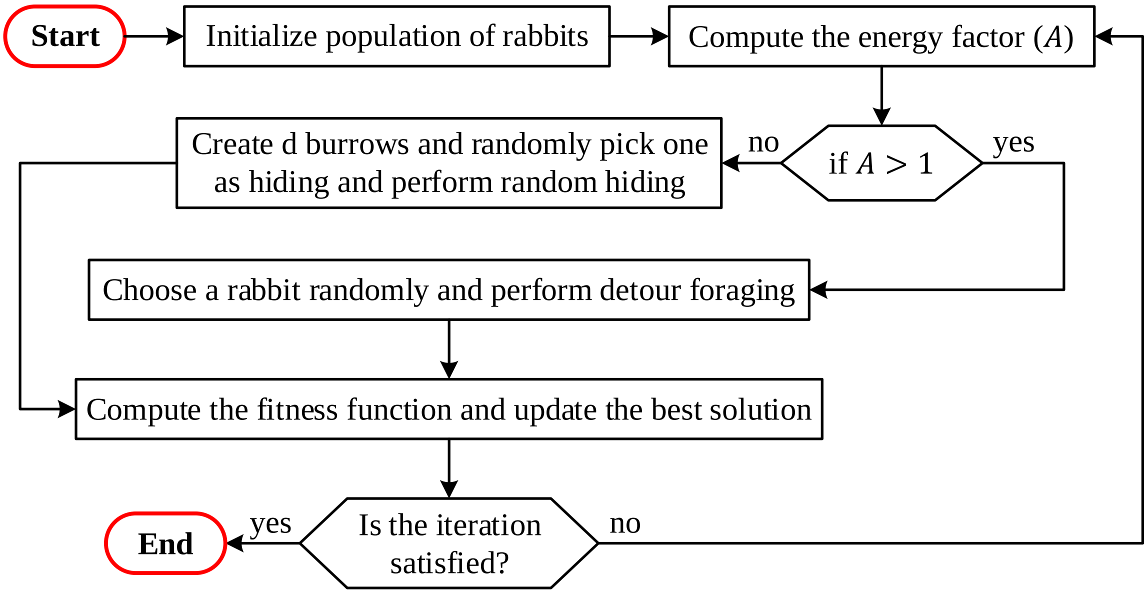

Fig. 4. Procedure of ARO

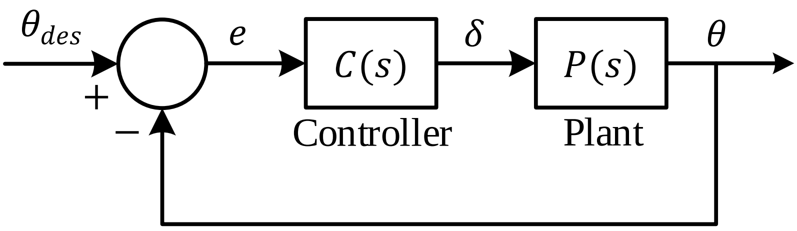

Fig. 5. Block diagram of a controlled system

4.2. Cost Function and Constrained Optimization Problem

To formulate the aircraft pitch control system as a minimization problem suitable for optimization algorithms, we follow a systematic procedure. Representing the parameters of the PID-F controller as $X = [x_1, x_2, x_3, x_4] = [K_p, K_i, K_d, n]$, the optimization process utilizes an objective function called Zwee-Lee gain (ZLG) [33]. The ZLG cost function is expressed as given in (9) [34]-[37]:

$$F_{ZLG} = (1-\varphi)\left(M_p + E_s\right) + \varphi(T_s - T_r) \tag{9}$$

here, $\varphi = 1/e$ represents a balancing factor, E_s denotes the steady-state error, M_p signifies the overshoot, T_s represents the settling time, and T_r corresponds to the rise time. Optimization constraints of $0.1 \le K_p, K_i, K_d \le 150$ and $1 \le n \le 1000$ are considered. The ZLG objective function enables the optimization of PID-F controller parameters to achieve desired system performance.

The application of ARO to the aircraft pitch control system is detailed in Fig. 6. The process involves using the pitch angle value to compute the objective function, serving as a metric to evaluate system performance. ARO dynamically updates the parameters of the PID-F controller with the goal of minimizing the objective function through iterative adjustments. In simpler terms, ARO leverages pitch angle information to assess and continuously improve the aircraft pitch control system's performance, aiming for the lowest possible objective function value over multiple iterations.

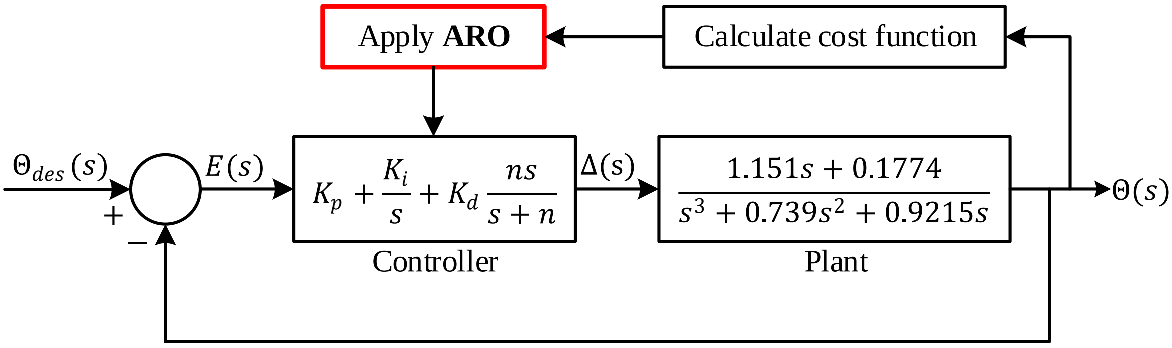

Fig. 6. Suggested novel design method

5. Results of and Comparisons with Recent Approaches

The evaluation of the proposed ARO integrated PID-F controller is presented in this section. The ARO algorithm was executed with a population size of 40 and a total of 50 iterations, conducted over 25 runs.

5.1. ARO Performance Metrics

The statistical results of the cost function obtained via ARO are summarized in Table 1, providing insights into the performance metrics. Notably, the minimum cost function value was recorded at 2.2589E−03, while the maximum was at 2.3610E−03. The median and average values were 2.2903E−03 and 2.2962E−03, respectively. The standard deviation was found to be 2.6836E−05, and the relative deviation from the average was calculated at 4.45%. These results highlight the stability and consistency of the ARO-based optimization process.

Table 1. Statistical results for cost function obtained via ARO

Statistical metric	Value
Minimum	2.2589E−03
Maximum	2.3610E−03
Median	2.2903E−03
Average	2.2962E−03
Standard deviation	2.6836E−05
$(\lvert Maximum - Minimum \rvert)/(Average)$	4.4465%

Additionally, Fig. 7 illustrates the convergence profile of ARO, visually representing the optimization progress over iterations. The convergence profile demonstrates the algorithm's ability to efficiently converge towards optimal solutions.

5.2. Comparative Analysis with Other Optimization Approaches

To facilitate a comprehensive comparison, various optimization algorithms from the literature were considered, including battle royale optimization based PID-F (BRO/PID-F) and PID (BRO/PID) controllers [29], sine cosine algorithm based PID (SCA/PID) controller [19], grasshopper algorithm based PID controller (GOA/PID) [19], Henry gas solubility optimization based PID controller (HGSO/PID) [19], Harris hawks optimization based PID (HHO/PID) controller [18], atom search optimization based PID controller (ASO/PID) [18], and salp swarm based PID (SSA/PID) controller [18]. The controller parameters obtained through these approaches are compiled in Table 2 for clarity and comparative purposes. It showcases the proposed ARO/PID-F controller's parameters alongside those obtained through other methods. The ARO/PID-F parameters, namely K_p, K_i, K_d, and n, are reported as 67.1759, 124.9674, 149.7192, and 578.6752, respectively.

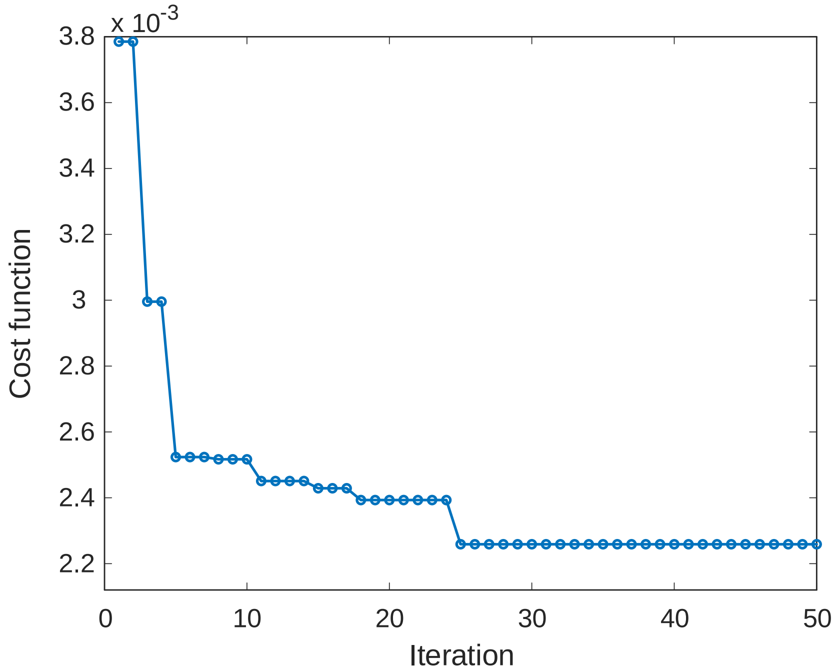

Fig. 7. Convergence profile of ARO

Table 2. The controller parameters obtained via proposed and other approaches reported in the literature

Method	K_p	K_i	K_d	n
ARO/PID-F (proposed)	67.1759	124.9674	149.7192	578.6752
BRO/PID-F	7.0355	59.0294	99.9552	345.8215
BRO/PID	63.6688	11.5507	99.9028	–
SCA/PID	70.8938	64.8932	72.4551	–
GOA/PID	63.8156	21.5434	77.6758	–
HGSO/PID	69.7726	3.6054	95.1465	–
HHO/PID	55.2698	51.4031	90.9434	–
ASO/PID	17.3672	24.2791	84.5323	–
SSA/PID	84.6747	68.0177	76.8185	–

5.3. Response and Performance Metrics

Fig. 8 presents the step response obtained for a pitch angle reference of 0.2, showcasing the system's dynamic behavior. Additionally, Table 3 provides performance metrics such as rise time (T_r), overshoot (M_p), settling time (T_s), steady-state error (E_s), and ZLG objective function values (F_{ZLG}) for each optimization approach.

Table 3. Comparative numerical results obtained for performance metrics

Method	T_r (s)	M_p (%)	T_s (s)	E_s (%)	F_{ZLG}
ARO/PID-F (proposed)	0.0094	0	0.0155	0	0.0023
BRO/PID-F	0.0138	0	0.0223	0	0.0031
BRO/PID	0.0191	0	0.0338	0	0.0054
SCA/PID	0.0260	0.3464	0.0447	0	0.0091
GOA/PID	0.0244	0.1158	0.0426	0	0.0074
HGSO/PID	0.0200	0	0.0352	0	0.0056
HHO/PID	0.0210	0	0.0373	0	0.0060
ASO/PID	0.0229	0	0.0423	0	0.0071
SSA/PID	0.0244	0.4511	0.0417	0	0.0092

The proposed ARO/PID-F controller exhibits a rise time of 0.0094 seconds, zero overshoot, settling time of 0.0155 seconds, zero steady-state error, and a ZLG objective function value of 0.0023. These results position the ARO/PID-F controller as a promising approach in terms of achieving rapid response, minimal overshoot, and accurate control. In another word, the presented results and comparisons demonstrate the effectiveness of the proposed ARO/PID-F controller in optimizing the aircraft pitch control system, offering favorable performance metrics when compared to other state-of-the-art optimization approaches.

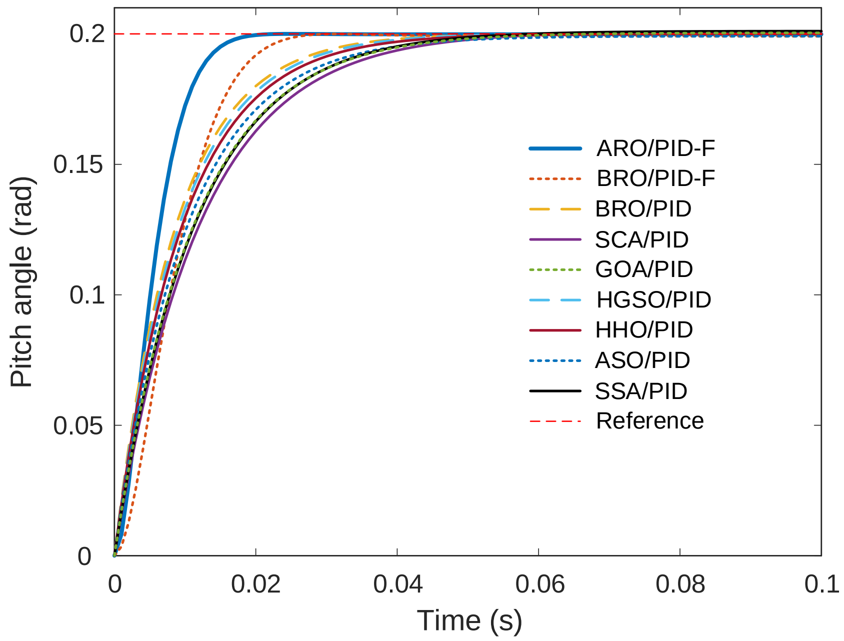

Fig. 8. Step response obtained for pitch angle of 0.2

6. Conclusion

This study addresses the critical challenge of controlling aircraft pitch angles, which is pivotal for maintaining specific attitudes during various flight phases. Traditional control methodologies encounter limitations in handling the non-linear and uncertain dynamics inherent in flight. To overcome these challenges, a novel approach is proposed, integrating the ARO with a PID controller augmented by a filtering mechanism (PID-F). The proposed ARO/PID-F methodology demonstrates its efficacy in enhancing the stability and performance of aircraft pitch control systems. Through meticulous tuning of PID-F controller parameters using the ARO algorithm, the system achieves rapid response, minimal overshoot, and precise control during critical flight operations. The incorporation of a filter coefficient in the derivative gain effectively addresses the kick effect, contributing to improved system robustness. The comparative analyses with various optimization algorithm-based controllers from the literature underscore the superiority of the proposed ARO/PID-F approach. Statistical results and performance metrics affirm the stability and consistency of the methodology, showcasing its potential to outperform traditional and alternative control strategies.

While the present study provides valuable insights and promising results, there are avenues for future research to further advance the understanding and application of the proposed approach. Future investigations may explore the adaptation of the ARO/PID-F methodology to diverse aircraft models, considering different operational conditions and constraints. Additionally, the integration of real-time data and considerations for uncertainties in flight dynamics could enhance the methodology's robustness. Further research could delve into the optimization of additional control parameters and explore the scalability of the proposed approach for broader applications in the field of aviation. Investigating the real-time implementation and testing of the ARO/PID-F approach in practical flight scenarios would contribute to validating its effectiveness in real-world aviation settings.

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References

[1] G. E. Ceballos Benavides, M. A. Duarte-Mermoud, M. E. Orchard, J. C. Travieso-Torres, "Pitch Angle Control of an Airplane Using Fractional Order Direct Model Reference Adaptive Controllers," *Fractal and Fractional*, vol. 7, no. 4, p. 342, 2023, https://doi.org/10.3390/fractalfract7040342.

[2] S. A. Jalo, M. Ahmed, A. B. Abdulqadiri, M. U. Ilyasu, I. M. Inuwa, G. Elhassan, "A Study on Aircraft Pitch Control in Rejecting Disturbances," *International Seminar on Aeronautics and Energy*, pp. 187–196, 2024, https://doi.org/10.1007/978-981-99-6874-9_15.

[3] D. Izci, "Design and application of an optimally tuned PID controller for DC motor speed regulation via a novel hybrid Lévy flight distribution and Nelder–Mead algorithm," *Transactions of the Institute of Measurement and Control*, vol. 43, no. 14, pp. 3195–3211, 2021, https://doi.org/10.1177/0142331221101963.

[4] A. Khalid, K. Zeb and A. Haider, "Conventional PID, Adaptive PID, and Sliding Mode Controllers Design for Aircraft Pitch Control," *2019 International Conference on Engineering and Emerging Technologies (ICEET)*, pp. 1-6, 2019, https://doi.org/10.1109/CEET1.2019.8711871.

[5] M. E. -S. M. Essa, M. Elsisi, M. Saleh Elsayed, M. Fawzy Ahmed, A. M. Elshafeey, "An Improvement of Model Predictive for Aircraft Longitudinal Flight Control Based on Intelligent Technique," *Mathematics*, vol. 10, no. 19, p. 3510, 2022, https://doi.org/10.3390/math10193510.

[6] A. Idir, Y. Bensafia, K. Khettab, L. Canale, "Performance improvement of aircraft pitch angle control using a new reduced order fractionalized PID controller," *Asian Journal of Control*, vol. 25, no. 4, pp. 2588–2603, 2022, https://doi.org/10.1002/asjc.3009.

[7] L. Wang, W. Jiang, Z. Wu, L. Zhao, Z. Jiao, "Modeling the Bio-Inspired Wing-Tail Interaction Mechanism and Applying It in Flapping Wing Aircraft Pitch Control," *IEEE Robotics and Automation Letters*, vol. 8, no. 5, pp. 2914–2921, 2023, https://doi.org/10.1109/LRA.2023.3262178.

[8] M. Subramanian, P. Kokil, "Stabilisation of network-controlled aircraft pitch control system with time delay," *Transactions of the Institute of Measurement and Control*, vol. 44, no. 13, pp. 2475–2484, 2022, https://doi.org/10.1177/01423312221083756.

[9] Vishal and J. Ohri, "GA tuned LQR and PID controller for aircraft pitch control," *2014 IEEE 6th India International Conference on Power Electronics (IICPE)*, pp. 1-6, 2014, https://doi.org/10.1109/IICPE.2014.7115839.

[10] P. Kumar, S. Narayan, "Multi-objective bat algorithm tuned optimal FOPID controller for robust aircraft pitch control," *International Journal of Systems, Control and Communications*, vol. 8, no. 4, pp. 348–362, 2017, https://doi.org/10.1504/IJSCC.2017.087127.

[11] S. A. Al-Hiddabi and N. H. McClamroch, "Tracking and maneuver regulation control for nonlinear nonminimum phase systems: application to flight control," *IEEE Transactions on Control Systems Technology*, vol. 10, no. 6, pp. 780-792, 2002, https://doi.org/10.1109/TCST.2002.804120.

[12] A. Abdulla, "Aircraft Pitch Angle Control Using Pole Placement Approach Based on GA and ABC Optimization Techniques," *Przeglad Elektrotechniczny*, pp. 81–85, 2022, https://doi.org/10.15199/48.2022.03.18.

[13] S. Lee, K. Kim, Y. 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*, vol. 55, no. 22, pp. 94-98, 2012, https://doi.org/10.2322/tjsass.55.94.

[14] E. Ting, M. A. Ayoubi, "Optimized Fuzzy-Proportional/Integral/Derivative Controller for Aircraft Pitch Control," *Journal of Aerospace Information Systems*, vol. 10, no. 8, pp. 414–429, https://doi.org/10.2514/1.I010053.

[15] I. N. Ibrahim and M. A. Al Akkad, "Exploiting an intelligent fuzzy-PID system in nonlinear aircraft pitch control," *2016 International Siberian Conference on Control and Communications (SIBCON)*, pp. 1-7, 2016, https://doi.org/10.1109/SIBCON.2016.7491828.

[16] A. Idir, Y. Bensafia, L. Canale, "Influence of approximation methods on the design of the novel low-order fractionalized PID controller for aircraft system," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 46, no. 98, pp. 1-16, 2024, https://doi.org/10.1007/s40430-023-04627-7.

[17] A. Ur Rehman, M. U. Khan, M. S. Shah, Q. Maqsood, M. F. Ullah and S. Uba, "Aircraft Pitch Control based on Genetic Algorithm Tuning with PID and LQR Controller," *2021 6th International Multi-Topic ICT Conference (IMTIC)*, pp. 1-6, 2021, https://doi.org/10.1109/IMTIC53841.2021.9719736.

[18] D. Izci, S. Ekinci, A. Demirören and J. Hedley, "HHO Algorithm based PID Controller Design for Aircraft Pitch Angle Control System," *2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, pp. 1-6, 2020, https://doi.org/10.1109/HORA49412.2020.9152897.

[19] V. Kaçtı, S. Ekinci, D. İzci, "Henry Gaz Çözünürlük Optimizasyonu ile Uçak Eğim Kontrol Sistemi için Etkin Kontrolör Tasarımı," *DÜMF MD*, vol. 11, no. 3, pp. 953–964, 2020, https://doi.org/10.24012/dumf.709449.

[20] C. S. Mohanty, P. S. Khuntia, D. Mitra, "Design of Stable Nonlinear Pitch Control System for a Jet Aircraft by Using Artificial Intelligence," *Proceedings of the National Academy of Sciences India Section A - Physical Sciences*, vol. 89, pp. 57–66, 2019, https://doi.org/10.1007/s40010-017-0396-z.

[21] L. Wang, Q. Cao, Z. Zhang, S. Mirjalili, W. Zhao, "Artificial rabbits optimization: A new bio-inspired meta-heuristic algorithm for solving engineering optimization problems," *Engineering Applications of Artificial Intelligence*, vol. 114, p. 105082, 2022, https://doi.org/10.1016/j.engappai.2022.105082.

[22] I. R. Khan *et al.*, "An Automatic-Segmentation- and Hyper-Parameter-Optimization-Based Artificial Rabbits Algorithm for Leaf Disease Classification," *Biomimetics*, vol. 8, no. 5, p. 438, 2023, https://doi.org/10.3390/biomimetics8050438.

[23] R. M. Rizk-Allah, S. Ekinci, D. Izci, "An improved artificial rabbits optimization for accurate and efficient infinite impulse response system identification," *Decision Analytics Journal*, vol. 9, p. 100355, 2023, https://doi.org/10.1016/j.dajour.2023.100355.

[24] S. S. D. and S. Mohanty, "Artificial Rabbits Optimized Neural Network-Based Energy Management System for PV, Battery, and Supercapacitor Based Isolated DC Microgrid System," *IEEE Access*, vol. 11, pp. 142411-142432, 2023, https://doi.org/10.1109/ACCESS.2023.3340856.

[25] D. Izci, R. M. Rizk-Allah, V. Snášel, S. Ekinci, F. A. Hashim, L. Abualigah, "A novel control scheme for automatic voltage regulator using novel modified artificial rabbits optimizer," *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 6, p. 100325, 2023, https://doi.org/10.1016/j.prime.2023.100325.

[26] M. Kharrich, M. H. Hassan, S. Kamel, J. Kim, "Designing an optimal hybrid microgrid system using a leader artificial rabbits optimization algorithm for domestic load in Guelmim city, Morocco," *Renewable Energy*, vol. 223, p. 120011, 2024, https://doi.org/10.1016/j.renene.2024.120011.

[27] D. Izci, S. Ekinci, E. Eker, A. Demirören, "Multi-strategy modified INFO algorithm: Performance analysis and application to functional electrical stimulation system," *Journal of Computational Science*, vol. 64, p. 101836, 2022, https://doi.org/10.1016/j.jocs.2022.101836.

[28] M. Ćalasan, M. Micev, M. Radulović, A. F. Zobaa, H. M. Hasanien, S. H. E. A. Aleem, "Optimal PID Controllers for AVR System Considering Excitation Voltage Limitations Using Hybrid Equilibrium Optimizer," *Machines*, vol. 9, p. 265, 2021, https://doi.org/10.3390/machines9110265.

[29] A. K. Şahin, Ö. Akyazı, E. Sahin, O. Çakır, "Uçak eğim kontrol sistemi için ölüm oyunu optimizasyonuna dayalı PID-F denetleyicisi tasarımı," *Gümüşhane Üniversitesi Fen Bilimleri Dergisi*, vol. 12, no. 2, pp. 539-549, 2022, https://doi.org/10.17714/gumusfenbil.1008563.

[30] S. Ekinci, D. Izci and M. Yilmaz, "Efficient Speed Control for DC Motors Using Novel Gazelle Simplex Optimizer," *IEEE Access*, vol. 11, pp. 105830-105842, 2023, https://doi.org/10.1109/ACCESS.2023.3319596.

[31] E. Eker, S. Ekinci, D. İzci, "Optimal PID Controller Design for Liquid Level Tank via Modified Artificial Hummingbird Algorithm," *Computer Science, IDAP-2023: International Artificial Intelligence and Data Processing Symposium (IDAP-2023)*, pp. 37–43, 2023, https://doi.org/10.53070/bbd.1346269.

[32] S. Ekinci, H. Çetin, D. Izci, E. Köse, "A Novel Balanced Arithmetic Optimization Algorithm-Optimized Controller for Enhanced Voltage Regulation," *Mathematics*, vol. 11, no. 23, p. 4810, 2023, https://doi.org/10.3390/math11234810.

[33] D. Izci, S. Ekinci, "Optimizing Three-Tank Liquid Level Control: Insights from Prairie Dog Optimization," *International Journal of Robotics and Control Systems*, vol. 3, no. 3, pp. 599–608, 2023, https://doi.org/10.31763/ijrcs.v3i3.1116.

[34] S. Ekinci, D. Izci, R. Abu Zitar, A.R. Alsoud, L. Abualigah, "Development of Lévy flight-based reptile search algorithm with local search ability for power systems engineering design problems," *Neural Computing and Applications*, vol. 34, pp. 20263–20283, 2022, https://doi.org/10.1007/s00521-022-07575-w.

[35] D. Izci, L. Abualigah, Ö. Can, C. Andiç, S. Ekinci, "Achieving improved stability for automatic voltage regulation with fractional-order PID plus double-derivative controller and mountain gazelle optimizer," *International Journal of Dynamics and Control*, 2024, https://doi.org/10.1007/s40435-023-01381-5.

[36] D. Izci, S. Ekinci, "Fractional order controller design via gazelle optimizer for efficient speed regulation of micromotors," *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 6, p. 100295, 2023, https://doi.org/10.1016/j.prime.2023.100295.

[37] S. Ekinci, Ö. Can, D. Izci, "Controller design for automatic voltage regulator system using modified opposition-based weighted mean of vectors algorithm," *International Journal of Modelling and Simulation*, pp. 1-18, 2023, https://doi.org/10.1080/02286203.2023.2274254.