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# FRACTIONAL ORDER-BASED PID CONTROLLER DESIGN WITH GENETIC ALGORITHM (FOPID-GA) FOR AIRCRAFT LANDING GEAR SHOCK ABSORBER MECHANISM

## UÇAK İNİŞ TAKIMI AMORTİSÖR MEKANİZMASI İÇİN KESİR DERECELİ PID KONTROLÖRÜN GENETİK ALGORİTMA (FOPID-GA) İLE TASARIMI

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## Abstract

Deterioration conditions of the runway surface (deep track, cracking, raveling, and potholes ) and contaminants greatly affect the landing performance of the aircraft. In this research study, an optimal fractional order proportional integral and derivative controller (FOPID-GA) is designed with a genetic algorithm for the smooth operation of aircraft landing gear systems. To prove the effectiveness, performance, and accuracy of the proposed approach, a comparative study of the new technique and the traditional controllers such as PID, PID-TD, FOPID-TD, and PID-GA controllers was conducted on the MATLAB/Simulink platform. The simulation results clearly show that the proposed FOPID-GA controller outperforms the existing controllers in terms of performance, and damping accuracy. The effectiveness of the FOPID-GA controller is evaluated through simulation studies, demonstrating its potential to enhance aircraft landing gear performance and safety under adverse conditions.
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**Keywords:** FOPID controller, landing, MATLAB/Simulink, runway, performance.

## Öz

Hava araçlarına yönelik pist yüzlerinde meydana gelen bozulmalar (derin iz, çatlama, çökme ve çukurlar) ve kirletici yabancı maddeler uçağın iniş performansını büyük ölçüde etkiler. Bu çalışmada, uçak iniş takımı sistemlerinin sorunsuz çalışması için genetik algoritma kullanılarak, optimal kesirli dereceli oransal integral ve türev kontrolör (FOPID-GA) tasarlanmıştır. Önerilen yaklaşımın etkinliğini, performansını ve doğruluğunu göstermek amacıyla, PID, PID-TD, FOPID-TD ve PID-GA kontrolörleri gibi geleneksel kontrolörlerin MATLAB/Simulink platformu üzerinde karşılaştırmalı bir çalışması yapılmıştır. Simülasyon sonuçları, önerilen FOPID-GA denetleyicinin performans ve sönümleme doğruluğu açısından mevcut geleneksel kontrolörlerden daha iyi performans gösterdiğini açıkça göstermektedir. FOPID-GA kontrolörünün etkinliği simülasyon çalışmaları ile irdelenmiş, olumsuz koşullar altında uçak iniş takımı performansını ve güvenliğini artırma potansiyeli gösterilmiştir.

**Anahtar Kelimeler:** FOPID kontrolörü, iniş, MATLAB/Simulink, performans, pist.

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## 1. INTRODUCTION

The condition of the road surface is one of the factors affecting driver comfort, working rate, service capability, and road safety. Although many studies have newly been supervised to examine the impact of different road characteristics on traffic flow performance, most of them have not focused on the effect of road roughness regarding the operating speeds. Road bumpiness is determined as road roughness and is a globally acknowledged measure for assessing pavement condition and concerns about the circumstances noticed by road operators (Yu et al., 2023). Thus, research (Loprencipe et al., 2017) examines the effect of road roughness on speed qualities for different road sections under changed stream stages and different approaches are used to evaluate the road roughness. (Kamaraddinovich et al., 2022) states that pavement roughness is one of the most critical indicators of transportation and operational status. Road roughness doesn't have a major impact not only on comfort, safety, and speed but also on transportation costs, the lifespan of roads and vehicles, and fuel consumption. Therefore, it is essential to monitor and evaluate the effect of irregularities on road pavement surfaces (Loprencipe et al., 2019a). Moreover, (Sandamal & Pasindu, 2022) declares that roads need to be kept in suitable condition to meet the transportation demands of pastoral communities. In the thought, a correctly defined road unevenness assessment technique will reduce the operational risks of the airport, extend the life of aircraft landing gear, and improve the pavement protection decision-making process, which collectively together will completely help the whole sustainability of the airport (Tian et al., 2021). For this reason, an accurate and appropriate evaluation of airport pavement surface quality is essential to confirm the presence of any randomness that may adversely affect flight operations. In addition, a deteriorating runway can increase the maintenance costs of aircraft runways and landing gear and shorten their service life due to an increase in dynamic loads and fatigue incidents on the structural elements of the aircraft (Loprencipe et al., 2019b). Research has been initiated to control the pavement profile to minimize casualties and other fundamental problems produced by irregular pavement profiles (Arora et al., 2020).

To solve these mentioned road roughness problems, some controller techniques are required to mitigate the recurrent issues related to pavement unevenness. Therefore, in current studies, many researchers considered the PID controller tuning technique with reference as the most famous approach where (Kumar & Rana, 2023) proposes a novel PID-based Fuzzy controller for an extremely nonlinear active suspension system. Due to the variation of the road surface, (Huang & Lin, 2003) proposes an adaptive fuzzy sliding mode controller to suppress the oscillation of the sprung mass position. For the same purpose as the active suspension system, (Mahmoodabadi & Nejadkourki, 2020) utilizes an optimal fuzzy adaptive robust PID controller. (Jamal et al., 2021) investigated a new method with static output feedback for non-linear suspension systems. Moreover, (Munawwarah & Yakub, 2021) combines linear quadratic regulator PID-LQR and Fuzzy-PID controller to maximize ride comfort by maintaining the wheels of the car and the road surface in contact. Some dynamic problems such as external disturbances, nonlinearity, and parametric uncertainties cause limitations to the control performance, (Aela et al., 2022) proposes a united adaptive radial-based neural network system with the backstepping controller to overcome the related dynamic issues. This research, (Robert et al., 2022) works on fuzzy control of an active suspension system based on a quarter-car model which performs better in terms of body acceleration and displacement as compared to the existing techniques. (Hsiao & Wang, 2022) design a self-tuning fuzzy sliding mode controller for the evaluation of ride comfort by incorporating a damper into a quarter car for its active suspension systems. Moreover, (Li et al., 2024) introduces a fractional order PID control approach. This, (Gao & Li, 2022) proposes tuning parameters of the fractional order PID-LQR controller for random pavement simulation. Thus, (Hu et al., 2024) provides work on fractional order PID controllers for control and optimization basis nonlinear suspension systems. Research (Lee et al., 2022), used deep reinforcement learning for the car suspension system to solve the optimal control problems. In our research paper which aims to reduce or minimize the disturbances of rough roads, we design a novel fractional order PID-based genetic algorithm controller (FOPID-GA)In this study, we propose a Fractional Order-based Genetic Algorithm (FOPID-GA) controller design for the aircraft landing gear shock absorber mechanism. The FOPID-GA controller aims to enhance the damping characteristics of the shock absorber system, improving its ability to handle varying surface conditions and contaminants. Through the integration of fractional order control and genetic algorithm optimization, the proposed controller offers improved robustness and adaptability, crucial for maintaining safe and efficient aircraft landings in challenging environments. The effectiveness of the FOPID-GA controller is evaluated through simulation studies, demonstrating its potential to enhance aircraft landing gear performance and safety under adverse conditions. The design of a PID controller often leads to a nonconvex optimization problem. This is because the optimization landscape can have multiple local minima, making it challenging to find the global optimum using traditional optimization methods. Genetic algorithms are well-suited for this type of problem because they perform a global search and can effectively navigate complex, nonconvex spaces. The genetic algorithm's capability to effectively navigate the nonconvex optimization landscape is a key factor in achieving superior controller performance.

### 1.1. Contributions of The Paper

The fractional order proportional integral and derivative-based genetic algorithm (FOPID-GA) is presented in this work to reduce disturbance effects during landing caused by road roughness or bad runway. In aviation safety and comfort are two prominent things that should be taken care of while carrying passengers onboard. The recurrent problems related to safety are mostly due to the pilot performance, the runway situation (road roughness), and the aircraft operating systems. By the objective (cost) function of the genetic algorithm using the integral of time weight absolute error (ITAE) and FOPID controller parameters setting, the proposed FOPID-GA controller has been regulated to ensure the stability, performance of the system under the roughness road conditions. The main contributions of the paper encompass:

- Tuning simplicity of genetic algorithm with FOPID parameters
- Incorporation of the combined FOPID-GA to damp down the important fluctuation or unwanted roughness road effects
- Enhancement of stability, safety, and comfort of the system
- Superiority evidence of the proposed FOPID-GA controller over existing PID, PID-TD, FOPID-TD, and PID-GA controllers
- Proving effectiveness and reliability of genetic algorithm and FOPID controller.

This research work is organized as follows: Section 1, the introduction part; section 2, aircraft landing gear and suspension system; section 3, controller modeling; section 4, results and discussion, and finally conclusion section 5.

## 2. AIRCRAFT LANDING GEAR AND SUSPENSION SYSTEMS

### 2.1. Description of Cessna 182 Airplane Landing Runway

The safe and successful landing of an aircraft during its ended flight path is based on many factors such as the pilot's skills and handling performance, the adverse wind, and the runway conditions. Many airport runway surfaces have been made from appropriate road specifications. However, roughness is one of the factors that road and airport conditions diverge. The International roughness index (IRI) (Emery et al., 2015), is defined as the riding comfort measurement mainly used and identified for roads. Comparatively, the runway roughness is the vibrations of the cockpit and the extreme g-forces based on the fatigue on the aircraft structure (airframe) and other factors. The smoothness or roughness of the airport runway is free of bumps and unwanted that can prejudice safe operations, leading to the destruction of the aircraft structure due to fatigue. Aircraft suspension systems are primarily used to absorb expended energy during landing. They experienced the less dampening impact of surface unevenness caused by the energy magnitude addressed during landing. The Cessna 182 aircraft landing scheme is presented in Figure 1.

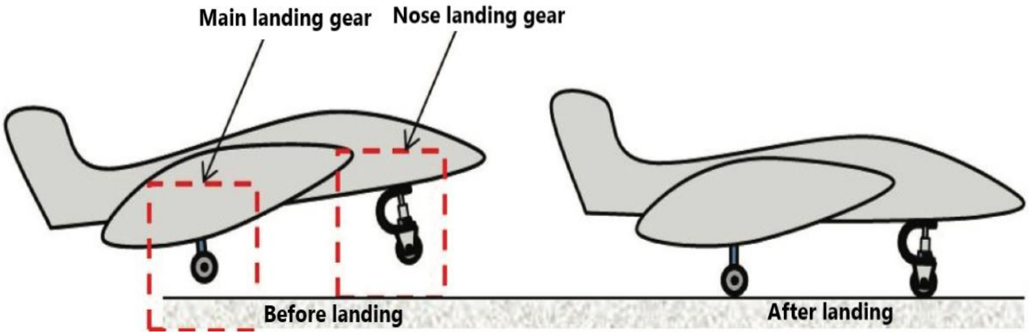

Figure 1. Aircraft Landing Gear Shock Absorber System

## 2.2. Mathematical Modeling of Aircraft Landing Gear System

The shock absorber is the passive element of the landing gear. It has two chambers, lower and upper chambers. They are connected by orifices. The lower and upper-bottom chambers are filled with oil and the rest of the upper chamber's volume is filled with nitrogen gas. The absorber system has both spring and damping features. The shock absorber compresses due to the landing mechanism and the runway irritation and the oil flows through the orifice from the lower chamber to the upper chamber. The shock struck extends and the oil flows through the orifice during the stored energy release. The compression and expansion of bouncing effects continue until the entire landing gear energy disperses.

The dynamic equilibrium of the two masses is presented in Figure 2. By using Newton's second law of motion, we describe the dynamics of Equations (1) and (2) as follows:

$$m_1\ddot{x}_1 = -F_a - F_d - Fq \tag{1}$$

$$m_2\ddot{x}_2 = F_a + F_d + F_g + Fq \tag{2}$$

Where $F_a$ and $F_d$ are the spring and damping forces of the shock absorber respectively. $F_g$ is the ground supporting force and $F_q$ is the active control force. These are the forces involved in the landing gear's physical nonlinear mechanisms. The aircraft fuselage mass to which the aerodynamic lift is applied is $m_1$ and the aircraft landing gear tyre mass is $m_2$. The forces involved in the landing gear's physical mechanisms exhibit nonlinearity due to factors such as variable stiffness, damping characteristics, and the nonlinear behavior of materials under different load conditions.

Landing gear physical nonlinearity forces are expressed in (3), (4) and (5).

- Damping Force

$$F_d = \frac{1}{2}\rho\frac{A^3}{\xi^2 A_0^2} \tag{3}$$

- Spring Force

$$F_a = P_0 A\left[\frac{1}{1-\frac{y_1-y_2}{y_0}}\right]^n \tag{4}$$

- Active Control Force

$$F_q = k_a Q + k_b Q|Q| \tag{5}$$

with $$Q = C_d w x\sqrt{\frac{[P_s - P_l]}{\rho}} \tag{6}$$

Where $w$ defines the gradient area of the servo valve port and $x$ is the servo valve displacement. $k_a$ and $k_b$ are the characteristic constants. $C_d$ represents a non-dimensional discharge coefficient. A is the piston cross-sectional area, and $A_0$ represents the orifice area.

$\xi$ is an orifice discharge coefficient. $\rho$ is the oil mass density. $y_0$ is the gas cylinder length. The displacement $y_1 - y_2$ represents the shock absorber stroke. $Q$ denotes the flow quantity, $P_s$ is the oil reservoir pressure, $P_l$ is the pressure difference between lower and upper chambers, and $P_0$ is the initial pressure, and n is the gas constant value ( mostly it takes the value of 1.1).

## 2.3. Aircraft Suspension Systems

Before take-off and after landing, crew and passenger comfort and safety are at the forefront of the flight requirements. Therefore the landing gear systems should be designed properly so that the vertical energy of the touch-down is absorbed. The design should take into consideration the hard landing situations that might occur in some circumstances. Although landing gear systems are too cumbersome and complex, the part called the shock absorber is designed to reduce damping disturbances. Some active and semiactive suspension mechanisms are also used to solve the frequent bouncing due to road roughness and reduce fuselage vibration effects. Landing gear assembly consists of a strut attached to the fuselage which is linked to the ground via the wheels with tires situated on an axle (Thota et al., 2008). The controller is used to get satisfactory damping performance of the landing gear, if the controller fails to operate, the active dampers become unstable. Due to their structure flexibility, active dampers can be tuned as compared to passive dampers. The aircraft landing gear is modeled as shown in Figure 2. The assembly is composed of the subsystems which are tyre system and suspension system. The tyre system is the wheel mass $m_2$, whereas the suspension system represents the spring-mass $m_1$. The wheel's pneumatic compressibility is denoted by $k_2$. The aircraft simulation parameters are depicted in Table 1.

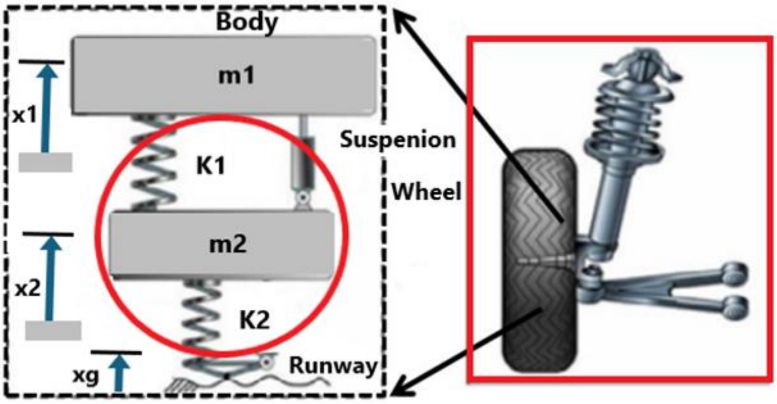

Figure 2. Landing Gear System Assembly (Provatas & Ipsakis, 2023)

$$(m_1 s^2 + c_1 s + k_1) X_1(s) - (c_1 s + k_1) X_2(s) = 0 \tag{3}$$

$$-(c_1 s + k_1) X_1(s) + (m_2 s^2 + c_1 s + k_1 + k_2) X_2(s) = k_2 Y(s) \tag{4}$$

$$R_1(s) = \begin{vmatrix} 0 & -(c_1 s + k_1) \\ k_2 & (m_2 s^2 + c_1 s + k_1 + k_2) \end{vmatrix} = k_2 (c_1 s + k_1) \tag{5}$$

The aerodynamic force coefficients are expressed in equations 4, 5, and 6.

$$R_2(s) = \begin{vmatrix} (m_1 s^2 + c_1 s + k_1) & -(c_1 s + k_1) \\ -(c_1 s + k_1) & (m_2 s^2 + c_1 s + k_1 + k_2) \end{vmatrix}$$

$$= (m_1 s^2 + c_1 s + k_1)(m_2 s^2 + c_1 s + k_1 + k_2) - (c_1 s + k_1)^2 \tag{6}$$

To determine the characteristics polynomial and the transfer function, we use the determinant method, where $R_1(s)$ and $R_2(s)$ are the numerator and the denominator of the transfer function (general case) respectively.

Table 1. Aircraft Numerical Simulation Parameters (Sivaprakasam, 2016)

| **Description** | **Symbol** | **Value** | **Units** |
|---|---|---|---|
| Aircraft fuselage mass | $m_1$ | 8800 | Kg |
| Landing gear tire mass | $m_2$ | 260 | Kg |
| Landing gear shock strut stiffness | k1 | 4,08e5 | N/m |
| Landing tire stiffness | k2 | 4,08e5 | N/m |
| Landing gear shock strut damping coefficient | $c_1$ | 41944 | N.s/m |
| Landing tire damping coefficient | $c_2$ | 37411 | N.s/m |

## 3. CONTROLLER MODELING

### 3.1. FOPID Controller Design

Fractional Order Proportional Integral and derivative (FOPID) is one of the conventional PID controller types which is considered a sophisticated control approach used for modern control systems. It provides an additional degree of freedom and two factors of integral and derivative denoted λ, μ respectively. Besides FOPID controller enhances the existing PID stability, and effectiveness by the fractional calculus concepts based on uncertainties of different variables of the systems with dynamics and nonlinear characteristics. The fractional order components of the FOPID controller give extra flexibility in the dynamic behavior of the intricate systems. The FOPID controller besides enhancing the performance of the PID controller, provides faster response, expands the margin stability limits, and reduces overshooting. The FOPID controller's basic structure is based on fractional calculus, which studies derivatives and integrals of non-integer orders. It adapts control actions based on the system's behavior by incorporating fractional-order proportional, integral, and derivative components. Compared to the Integral-Only PID (IO-PID) controller, the addition of non-integer integral-differential orders to the traditional PID controller gains is an improvement that enhances the capabilities of the control system. The FOPID controller diagram is depicted in Figure 3.

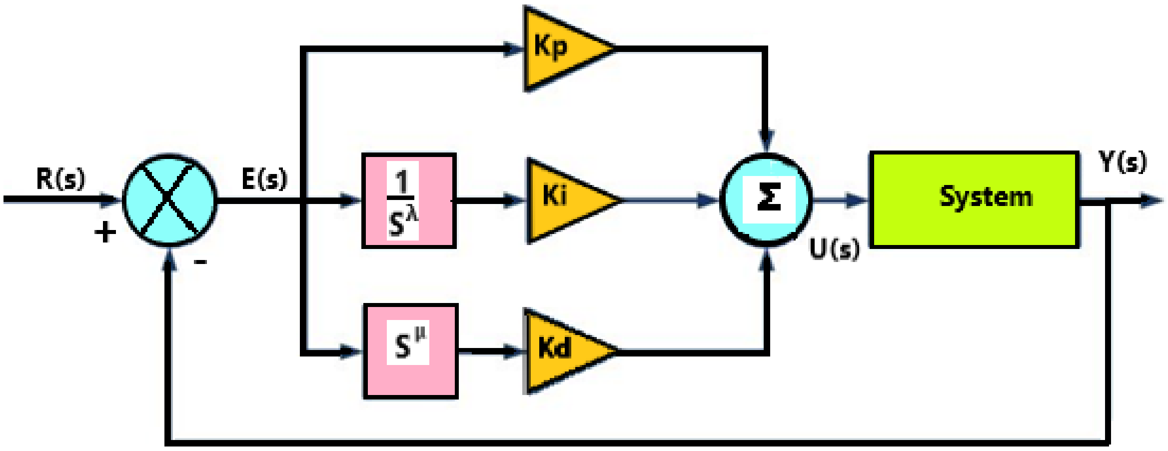

Figure 3. FOPID Controller Scheme

The transfer function equations of the FOPID controller are given as follows:

$$u(t) = K_i D^{-\lambda} e(t) + K_p e(t) + K_d D^{\mu} e(t) \tag{7}$$

$$C(s) = \frac{U(s)}{R(s)} = K_p + \frac{K_i}{s^\lambda} + K_d S^\mu \tag{8}$$

The controller gain of fractional order integral-differential operators *kp*, *ki*, *kd*, {λ, μ}, are the five independent tuning knobs of a typical controller structure. The controller structure becomes the conventional PID controller in parallel structure for, λ = 1 and μ = 1. The whole system overview diagram is shown in Figure 4.

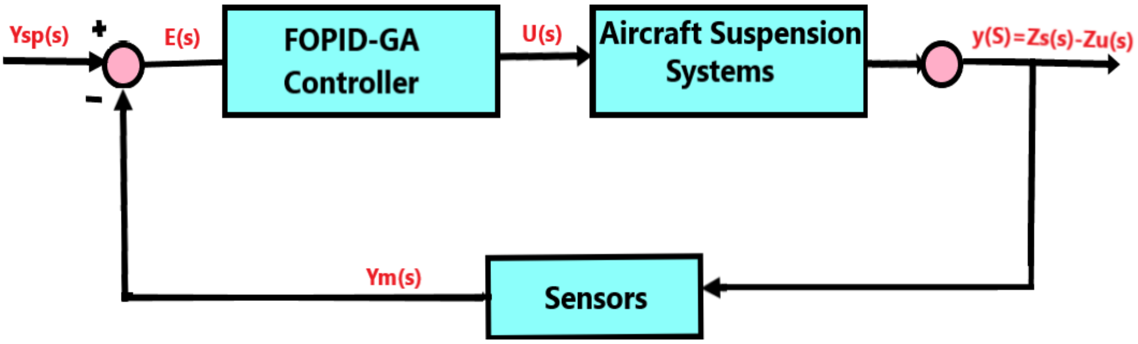

Figure 4. Overview of The Proposed FOPID-GA Design System

During sudden load demand or some external disturbances, the design controller dynamic response should provide fast relaxation time with the least peak overshoot and undershoot values. Previous works give proven evidence that numerous bio-inspired algorithms are used to find optimum gain values of the controller. In this paper, the FOPID-GA controller is proposed to optimize the controller gain values with cost function by using ITAE. Proportional integral and derivative (PID) (Nagarkar et al., 2011), Proportional integral and derivative with time delay (PID-TD) (George et al., 2022), Proportional integral and derivative with genetic algorithm (PID-GA) ) (Nie et al., 2020), Fractional Order Proportional Integral and derivative with time delay (FOPID-TD) (Suseno et al., 2021), and the proposed Fractional Order Proportional Integral and derivative with genetic algorithm ( FOPID-GA) controllers parameters are presented in Table 2, and Table 4.

Table 2. PID and FOPID parameters

| **Parameters** | **PID** | **FOPID** | **PID-TD** | **FOPID-TD** |
|---|---|---|---|---|
| Kp | 5,8 | 9 | 5,8 | 9 |
| KI | 0,8 | 2 | 0,8 | 2 |
| Kd | 0,7 | 1,5 | 0,7 | 1,5 |
| λ | --- | 0,5 | --- | 0,5 |
| μ | --- | 0,35 | --- | 0,35 |
| $\alpha$ | --- | --- | 24e-3 | 5e-3 |

### 3.2. Genetic Algorithm

A genetic algorithm (GA) is defined as an evolutionary algorithm simulating the natural selection method and inheritance to get an optimum result. It has a fast convergence speed and tracks a global optimal solution which makes it an efficient optimization algorithm. Many researchers use GA using various variants to improve its performance and solve different complex problems. In this paper, we use the genetic algorithm to complement the FOPID controller for the road hump applied to aircraft landing gear suspension systems. This was very promising in improving the road roughness in a short duration. In the genetic algorithm design with chromosome structure, the population is initiated randomly with 50 individuals, and other parameters are presented in Table 4 and a comparative of all the controllers based on the transfer function step response is presented in Table 3. By the objective (cost) function of a genetic algorithm using the integral of time weight absolute error (ITAE) and FOPID controller parameters. The genetic algorithm code was written in the MATLAB workspace and linked to the FOPID controller from the Simulink platform. The FOPID parameters such $as\ k_p, k_d, k_i$, λ, and μ are sensed directly from the code. The pseudo-code of the proposed FOPID-GA controller is presented as follows:

#### 3.2.1. Pseudo code of FOPID-GA controller

```
% Population Initialization
-Identify the number of population (P= 50);
-Define the parameters ($k_p, k_d, k_i$, λ, μ);
% GA options
-Define the objective function
  obj_fn = optimization_FOPID ($k_p, k_d, k_i$, λ, μ);
-Select individuals based on their fitness values,
    if the random individual value is less than the selected parents;
    otherwise, return;
-Perform crossover to generate new parents;
-Apply the FOPID parameters;
```

```
-Perform mutation with certain probability;
-Compare the new fitness values with the previous values;
% Cost function
-Define the cost function
   Cost_fn = optimization_FOPID ($k_p, k_d, k_i$, λ, μ);
-Combine the parameters of parents to produce a new generation;
-Change randomly the value of ($k_p, k_d, k_i$, λ, μ);
-Verify the performance criteria;
-Condition verified;
 end.
```

Table 3. The Quantitative Comparison of Different Approaches

| Controller Type | Overshoot | Settling time | Rised time | Peak time |
|---|---|---|---|---|
| PID | 5% | 10s | 4,5s | 4,5s |
| PID-TD | 2,2% | 5s | 2s | 2s |
| PID-GA | 0,3% | 3s | 1,8s | 1,8s |
| FOPID-TD | 0,8% | 1,5s | 1,5s | 1,5s |
| FOPID-GA | 0,1% | 1,5s | 1,2s | 1,2s |

### 3.3. PID Controller Design

The proportional integral and derivative (PID) controller is very simple and easy to design, it is generally used in modern industrial applications where various devices are tuned. The dynamics of the PID controller are depicted in Figure 2. The PID controller is used to evaluate the landing gear system and its derived other nature-inspired algorithms. Ziegler-Nichols method is used for the tuning process.

PID controller is defined by Equation 9.

$$G_C = K_p e(t) + K_i \int_0^t e(t) + K_d \frac{de(t)}{dt} \tag{9}$$

Gc is the controller input and e(t) is the error function in Equation 10, which is the difference between the feedback signal and the reference signal. These signals are measured by sensors located at the landing gear system. Kp, Ki, and Kd are proportional gain, integral gain, and differential gain respectively.

$$e(t) = \dot{r}(t) - (\dot{x}_1 - \dot{x}_2) \tag{10}$$

The movement of the landing gear servo valve is expressed in Equation 11. The measured signal is the specific output of the system we are monitoring and controlling, here in our problem, the displacement of the landing gear and the error signal is the difference between the desired setpoint and the measured signal, which drives the control action to achieve the desired system performance.

$$l_{disp} = K_p\{r(t) - [\dot{x}_1(t) - \dot{x}_2(t)]\} + K_i\{r(t) - [x_1(t) - x_2(t)]\} + K_d\{r(t) - [\ddot{x}_1(t) - \ddot{x}_2(t)]\} \tag{11}$$

Table 4. Genetic-Based PID and FOPID Parameters

| **Parameters** | **PID-GA** | **FOPID-GA** |
|---|---|---|
| Kp | 5,8 | 9 |
| KI | 0,8 | 2 |
| Kd | 0,7 | 1,5 |
| $\lambda$ | --- | 0,5 |
| $\mu$ | --- | 0,35 |
| Low bound (lb) | [0 0 0] | [0 0 0] |
| Upper bound ($\mu$b) | [200 200 200] | [200 200 200] |
| Number of variable (no_var) | 3 | 3 |
| Number of iteration | 25 | 25 |
| Size of population | 50 | 50 |

## 4. RESULTS AND DISCUSSION

In this simulation, the Cessna aircraft model is investigated which has its parameters in Table 1. The design controller consists of the FOPID controller and the tuned genetic algorithm where parameters are in Table 4. The tuned genetic algorithm is implemented with an optimized cost function using the ITEA. The performance of the proposed Fractional Order Proportional Integral and Derivative-based Tuning Genetic Algorithm (FOPID-GA) controller was evaluated against several other controllers through simulation studies. As seen in Figure 6, the FOPID-GA controller offers reduced settling time and overshoot, indicating improved transient response characteristics compared to the other controllers.

The closed loop system with FOPID-GA controller demonstrated overall better response characteristics. Due to its superior performance, the FOPID-GA controller was selected for further testing under challenging conditions. A simulated road roughness given in Figure 7 (a), although not realistic, was created to impose a challenging condition on the system and measure the enhancement provided by the controller. To maintain clarity and conciseness, only the response of the FOPID-GA controller under the simulated road roughness condition was presented in this paper. Providing the behavior of all controllers would have been impractical and would have significantly increased the length of the paper. The results of the simulation under road roughness conditions show that the closed-loop system with the proposed FOPID-GA controller outperformed the passive system, which does not incorporate any controller effects as seen in Figure 7. The simulation figures demonstrate the effectiveness of the FOPID-GA controller in improving ride comfort and control stability during aircraft landing. The system model used for the controller design in this study is based on the dynamics of the aircraft landing gear suspension system. The model incorporates the physical properties and forces acting on the landing gear, including:

Spring-Damper System: The landing gear is typically modeled as a spring-damper system where the spring represents the elastic components (such as tires and struts) and the damper represents the shock absorbers.

Aircraft Dynamics: The model also incorporates the dynamics of the aircraft during landing, such as vertical motion and the interaction between the landing gear and the runway surface.

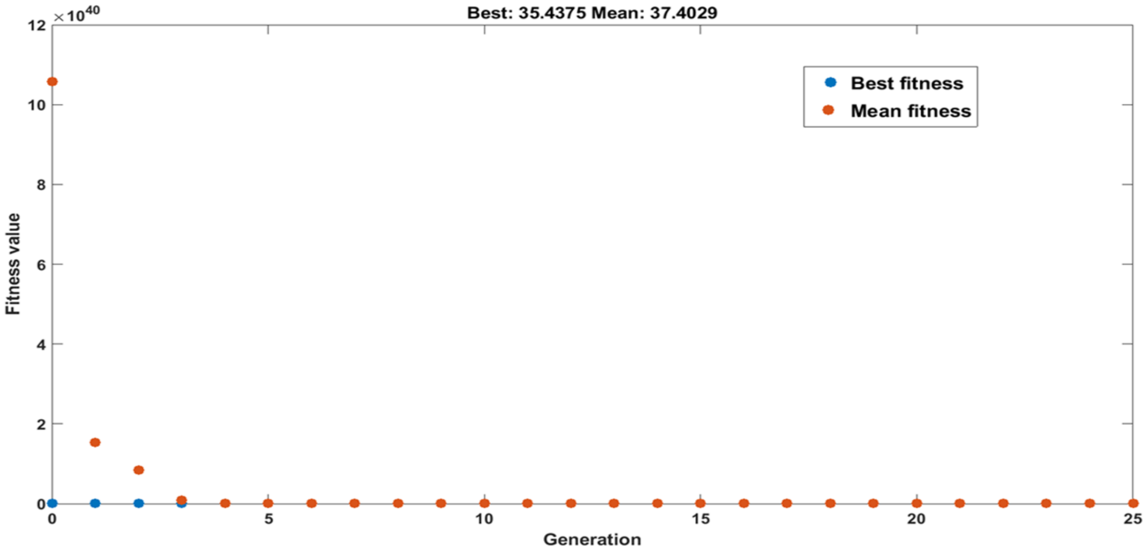

Figure 5. Genetic Algorithm (GA) Fitness Feature with Best Fitness Convergence Starting from Zero and Coinciding with The Mean Fitness at The Third (3rd) Iteration Out of 25 Generations

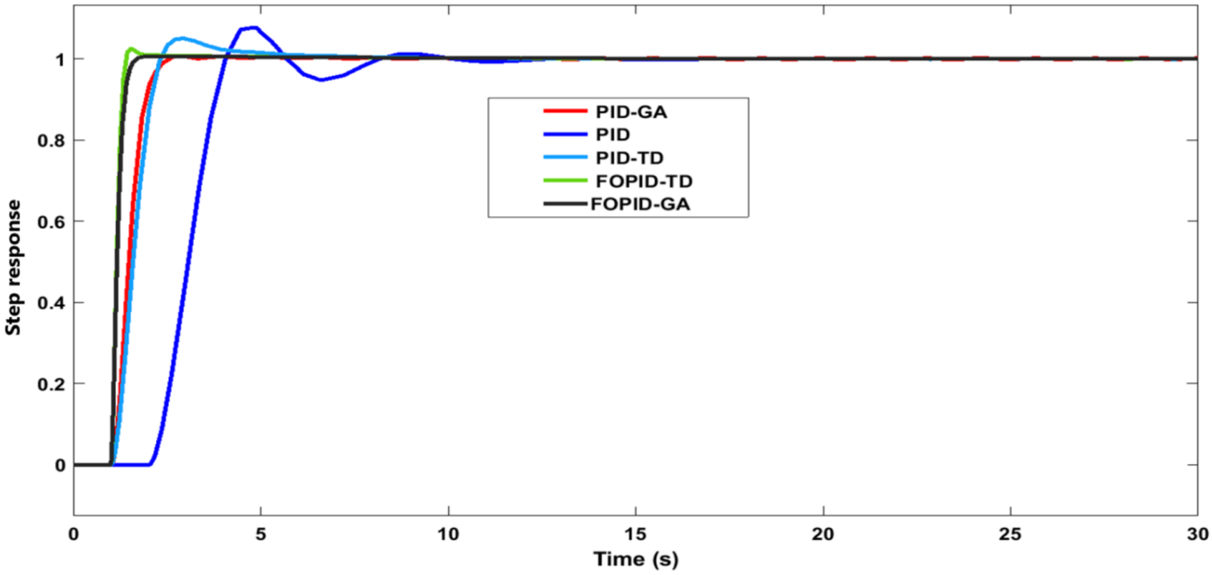

Figure 6. The Proposed FOPID-GA Controller Works Quite Better and Provides Better Results with Smaller Settling Time, and Overshoot

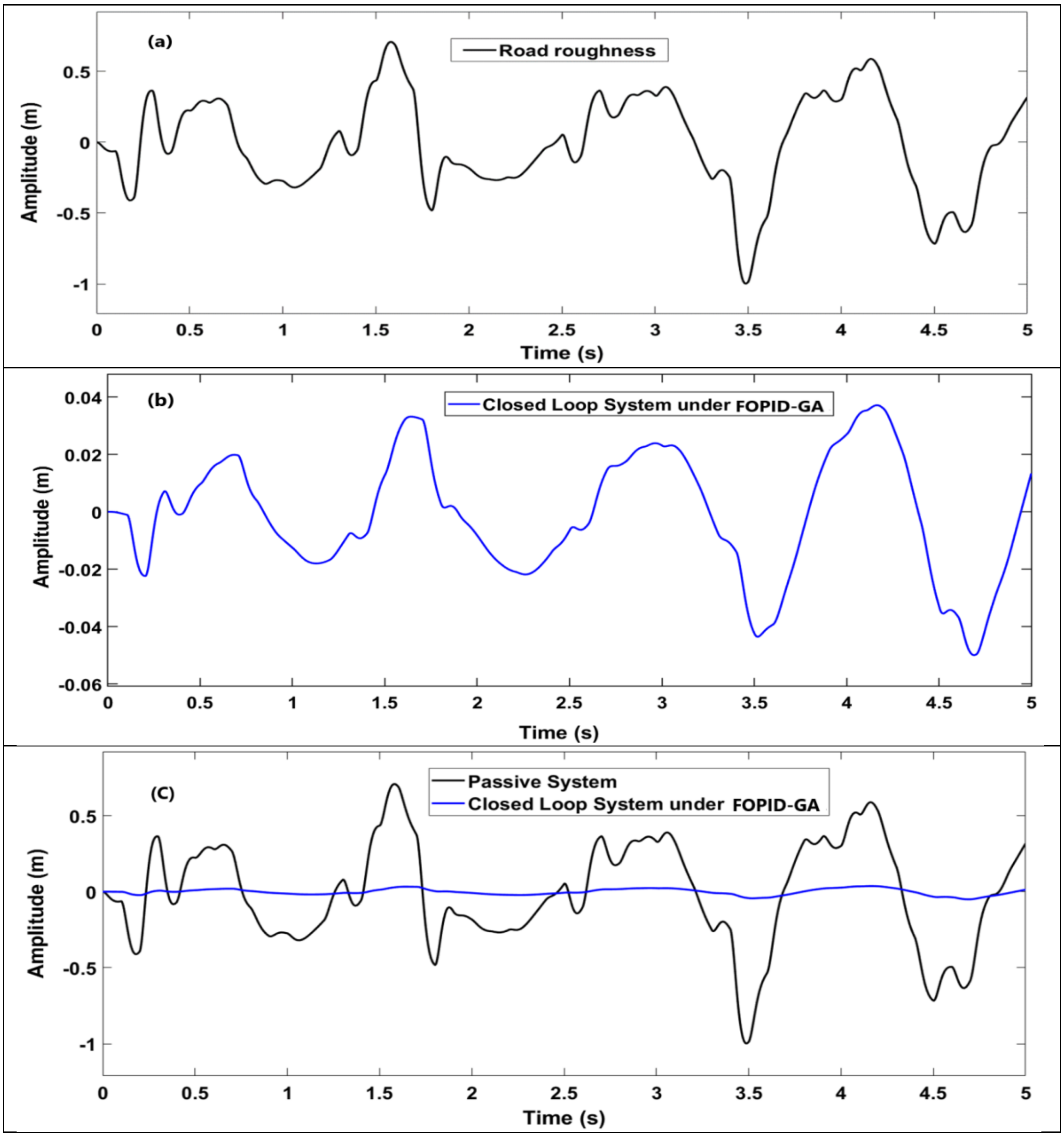

Figure 7. Under The Road Roughness Condition, The Proposed FOPID-GA Controller Shows A Smooth and Good Fluctuation Reduction (c).

## 5. CONCLUSION

In this study, we have presented a reasonably good approach for reducing roughness fluctuations experienced by aircraft during landing through the development of a Fractional Order Proportional Integral and Derivative-based Tuning Genetic Algorithm (FOPID-GA) controller. The proposed FOPID-GA controller has demonstrated significant improvements in ride comfort, and overall performance compared to other controllers and the passive system.

The superior performance of the FOPID-GA controller can be attributed to the genetic algorithm's optimization capabilities. Genetic algorithms are powerful tools for searching large and complex solution spaces, enabling the identification of optimal or near-optimal controller parameters that enhance overall system performance. By exploring a wide range of potential solutions and iteratively refining them, the genetic algorithm effectively adapts the FOPID controller to achieve the desired damping characteristics and enhancement.

Future research could focus on further optimization of the FOPID-GA controller to address additional challenges in aircraft landing gear systems. Potential areas for exploration include the integration of machine learning techniques to enhance the controller's adaptability to varying conditions, the application of the controller to different types of aircraft and landing scenarios, and the development of hybrid control strategies that combine the strengths of genetic algorithms with other optimization methods.

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**Conflict of Interest**
The authors declare that there is no potential conflict of interest for this manuscript.

**Ethical Approval**
Not applicable to this manuscript.

**Informed Consent**
Not applicable to this manuscript.

**Authors Contributions**
Idriss Dagal: Design; writing review; editing and funding.
Bilal Erol: Investigating and editing the original draft.

**Data Availability Statement**
There is no available data for this submission.

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