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Numerical Survey of Vibrational Model for Third Aircraft based on HR Suspension System Actuator Using Two Bee Algorithm Objective Functions

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ABSTRACT

This research explains airplane model with two vertical vibrations for airframe and landing gear system. The purpose of this work is to advance vibrational model for study of adjustable vibration absorber and to plan Proportional-Integration-Derivative approach for adapting semi active control force. The coefficients of this method are modified as stated by Bee multiobjective optimization using minimizing accelerations and impact forces as objective functions. The consequences implies that the semi active shock absorber system based on artificial Bee colony improves passengers and ride comfort and fatigue life of fuselage, shock strut and tyre by reducing movement of body, suspension system and impact load in an important way compared to passive performance during touchdown phase with various sink speeds and runway surfaces for robustness and sensitivity investigation of optimization performance.

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NOMENCLATURE

A	Effective area	k_p	Proportional coefficient
A_o	Orifice area	k_i	Integration coefficient
y_s	Suspension travel	k_d	Derivative coefficient
P_0	Initial pressure	$E(t)$	Error signal
C_2	Tyre damping coefficient	$ITAE$	Integral of the time weighted absolute value of the error
K_2	Tyre stiffness coefficient	Y_g	Runway excitation

1. INTRODUCTION

Shock absorber characteristics of passive landing gear system are steady in various situations while in semi active performance they are adjustable. The passive suspension system has stable damping whilst in semi active suspension system, the hydraulic fluid flow to the shock absorber is adopted depending on impact loads during touchdown, by that means modifying the hydraulic damping. So the focus on semi active system is essential to conquer the hardships in conventional system.

Fighter aircraft vibration absorber system has been inspected on the basis of analysis and test procedure [1-5]. The aircrafts employ landing gears with passive procedure that are planned by the directors [6, 7]. Some research studies [8-10] focused on shock absorbers with active control for a domain of airplane speeds and for different runway surfaces. The investigation done in references [11, 12] has been undertaken for proving advantages of semi active and active shock strut compared to passive system using Bees algorithm.

Study performed in references [13-15] shows that active suspension system for full aircraft model has good performance compared to passive approach using LQR technique. Distinction of active shock absorber against passive system for aircraft model with two

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degrees of freedom using Bees single objective method has been justified in the literature [16, 17]. Fuzzy logic as a intelligent control technique is applied for improvement of semi active performance in landing gear system with input constraint of orifice area [18-20].

In the second step, the mechanical model of passive and semi active suspension system as well as vibrational equations are obtained. The semi active control force caused by suspension system and control law for improvement of system performance is defined. In the next step, method of Bees multi objective algorithm for tuning of PID controller is described. In fifth step, dynamic responses for two sink speeds for passive and semi active performances consisting of fuselage bounce, suspension travel and air spring force are represented. At the end, conclusion and future work is deduced.

2. MODEL OF PASSIVE AND SEMI ACTIVE LANDING GEAR SYSTEM

The semi active combination betters the performance of the suspension subsystem compared to passive approach by modifying quantity of oil flow [21-23]. The latter consists of a servo valve, an electronic controller and feedback transducers. When an aircraft lands, the shock absorber stroke is influenced by the aircraft's payload and varies depending on runway excitation [14, 24, 25]. The stroke is measured by the transducers and their signals input into the electronic controller. Figure 1 is two degrees of freedom of aircraft model. They are the vertical displacement (bouncing) of sprung mass or body (y_1) and vertical displacement of unsprung mass or tyre (y_2) [26].

2. 1. Vibrational Equations of Semi Active Landing Gear System

$$
\begin{aligned}
m_1\ddot{y}_1 &= m_1 g - L - F_c - F_k - f \\
m_2\ddot{y}_2 &= m_2 g - F_t + F_c + F_k + f
\end{aligned}
\tag{1}
$$

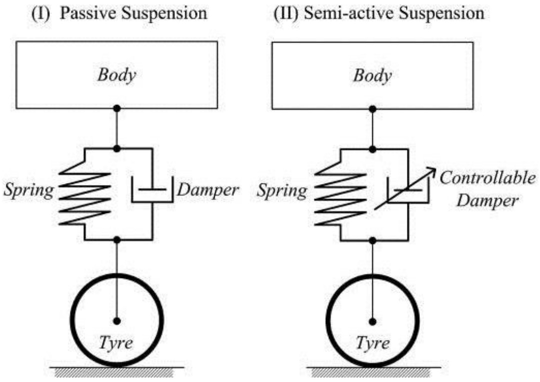

Figure 1. Mechanical model of passive and semi active suspension system for airplane

2. 2. Damping Force as Nonlinear Function

$$
\begin{aligned}
F_c &= F[A, A_o, (\dot{y}_1 - \dot{y}_2)] = F[\mathrm{A}, \mathrm{A}_o, \dot{y}_s] \\
&= \frac{\gamma A^3}{2\mu_o^2 A_o^2}(\dot{y}_1 - \dot{y}_2)^2 \operatorname{sgn}(\dot{y}_1 - \dot{y}_2)
\end{aligned}
\tag{2}
$$

2. 3. Spring Force as Nonlinear Function

$$
\begin{aligned}
F_k &= F[\mathrm{p}_0, (y_1 - y_2)] = F[\mathrm{p}_0, y_s] \\
&= p_0 A(1 - \frac{y_1 - y_2}{y_0})^{-\alpha}
\end{aligned}
\tag{3}
$$

2. 4. Tyre Force

$$
F_t = c_2(\dot{y}_2 + \dot{y}_g) + k_2(y_2 + y_g)
\tag{4}
$$

3. PID TECHNIQUE

The semi active control force caused by suspension system and control law for improvement of system performance is defined [27]. Error signal as controller input:

$$
e(t) = \dot{r}(t) - (\dot{\mathrm{y}}_1 - \dot{\mathrm{y}}_2)(t)
\tag{5}
$$

The semi active control force for landing gear:

$$
Q(t) = k_p e(t) + k_i \int_0^t e(t) + k_d \frac{de(t)}{dt}
\tag{6}
$$

So,

$$
\begin{aligned}
Q(t) &= k_p \{\dot{r}(t) - (\dot{\mathrm{y}}_1 - \dot{\mathrm{y}}_2)(t)\} \\
&+ k_i \{r(t) - (\mathrm{y}_1 - \mathrm{y}_2)(t)\} \\
&+ k_d \{\ddot{r}(t) - (\ddot{\mathrm{y}}_1 - \ddot{\mathrm{y}}_2)(t)\}
\end{aligned}
\tag{7}
$$

where,

$$
Q_{semiactive}(t) = F_c(t)
\tag{8}
$$

So,

$$
\begin{aligned}
\mathrm{A}_o(t) &= k_p \{\dot{r}(t) - (\dot{\mathrm{y}}_1 - \dot{\mathrm{y}}_2)(t)\} \\
&+ k_i \{r(t) - (\mathrm{y}_1 - \mathrm{y}_2)(t)\} \\
&+ k_d \{\ddot{r}(t) - (\ddot{\mathrm{y}}_1 - \ddot{\mathrm{y}}_2)(t)\}
\end{aligned}
\tag{9}
$$

4. BEE MULTIOBJECTIVE METHOD

Method of Bees multiobjective algorithm for tuning of PID controller in Equations (10)-(12) is described in the following steps [28].

- ❖ N random numbers according to equation are choosed for each of the three PID gains.
- ❖ These random numbers are introduced in coefficients of PID controller.
- ❖ Six degrees of freedom simulink model is run.
- ❖ Objective function for accelerations and impact forces is calculated.
- ❖ These N numbers are sorted in accordance with quantity of objective functions.
- ❖ First M numbers are kept and rest of them is removed.
- ❖ Nep random numbers for first E numbers in neighbourhood of Ngh are selected.
- ❖ Nsp random numbers for first M-E numbers in neighbourhood of Ngh are selected.
- ❖ Quantity of objective functions for Nep and Nsp is calculated.
- ❖ The most minimum objective functions for every neighbourhood is selected and residue are omitted.
- ❖ N-M random numbers for input margins of kp, ki and kd are choosed.
- ❖ Refering to five step, this action is lasted until multiobjective function is minimized.

$$[ITAE]_1 = \{\int_0^\infty t\,|e(t)|.dt\}_{\ddot{y}_1} + \{\int_0^\infty t\,|e(t)|.dt\}_{\ddot{y}_2} \qquad (10)$$

$$[ITAE]_2 = \{\int_0^\infty t\,|e(t)|.dt\}_{F_C} + \{\int_0^\infty t\,|e(t)|.dt\}_{F_k} \qquad (11)$$

$$[ITAE]_T = [ITAE]_1 + [ITAE]_2 \qquad (12)$$

5. NUMERICAL SIMULATION

The dynamic responses for A6 airplane model using numerical simulation in MATLAB Simulink environment (type: variable-step and solver: ode45) are acquired in touchdown phase with sink speed of 3 m/s and 5 m/s. Simulink model for semi active system is illustrated in Figure 2 [29].

5. 1. Dynamic Responses of the Aircraft for Two Sink Speeds and Uniform Runway

In this part, numerical simulation is obtained based on uniform runway. The aircraft is in touchdown phase. Three sink speeds are considered (3 m/s as light landing and 5 m/s as hard landing). Suspension travel is investigated as the most important parameter for evaluation of passive and semi active performances and comparison of them for passengers comfort and fatigue life of body and shock strut. This simulation is performed during 4 seconds as sample time.

Figures 3-8 show that the parameters of displacement consisting of body bounce and shock absorber travel are increased with enhancement of sink speed. Table 1 is a comparison between dynamic responces for distinct velocities at touchdown moment. As the result of Table 1, the shock absorber displacements is bettered with increment of touchdown velocity about 85, 89 and 75%, respectively.

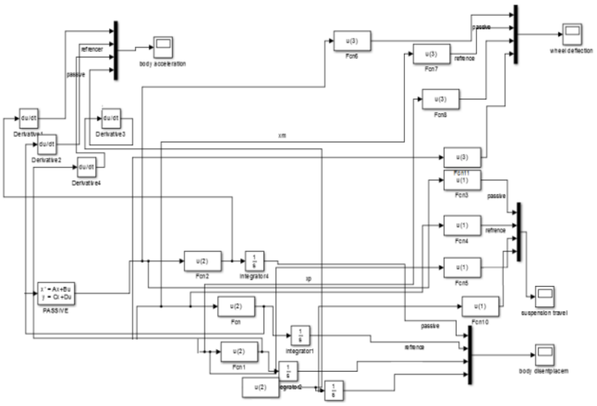

Figure 2. Simulink model for semi active control system

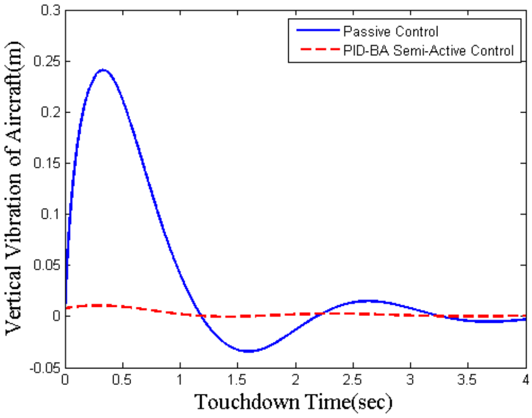

Figure 3. Time response of body bounce for sink speed=3 m/s

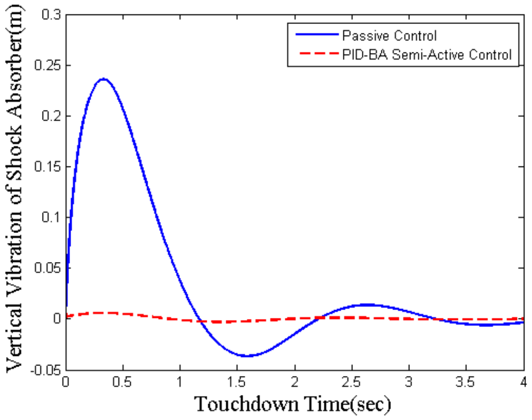

Figure 4. Time response of shock strut travel for sink speed=3 m/s

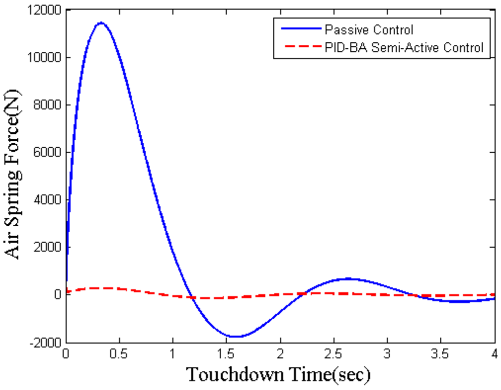

Figure 5. Time response of air spring force for sink speed=3 m/s

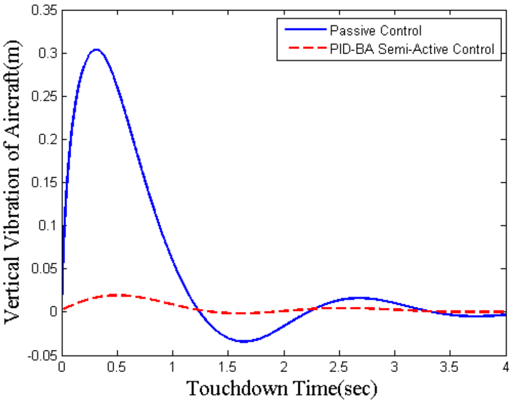

Figure 6. Time response of body bouncefor sink speed=5 m/s

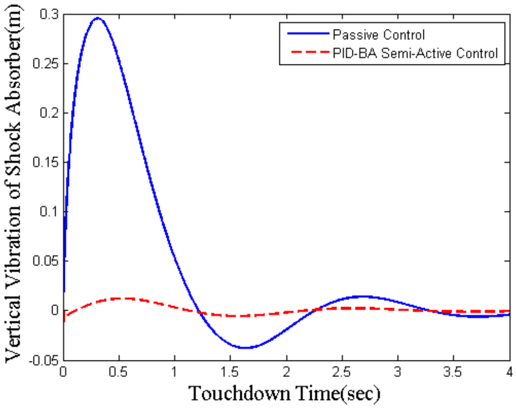

Figure 7. Time response of shock strut travel for sink speed=5 m/s

5. 2. Dynamic Responses of the Aircraft for Two Sink Speeds and Sine Wave Runway

In this part, numerical simulation is obtained based on sine wave runway according to Equation (13).

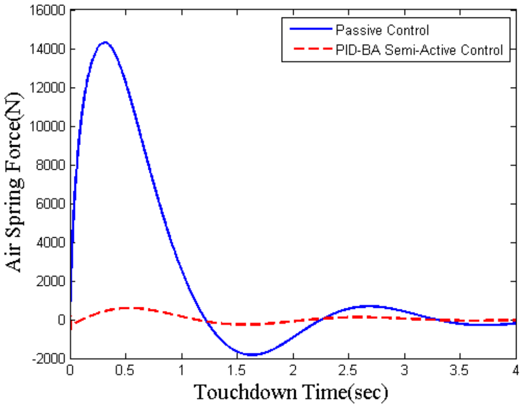

Figure 8. Time response of air spring force for sink speed=5 m/s

TABLE 1. Comparison of dynamic responses under uniform runway

Sink speed (m/s)	Suspension travel for passive system (m)	Suspension travel for semi active system (m)
3	0.24	0.01
5	0.29	0.03

The aircraft is in touchdown phase. Three sink speeds are considered (3 m/s as light landing and 5 m/s as hard landing). Body displacement, suspension travel and air spring force as impact force are investigated as important parameters for deliberation of passive and semi active performances and contrast of them for passengers comfort and fatigue life of body and shock absorber. This simulation is carried out during 4 seconds as simulation time.

where, the runway excitation:

$$y_g = 0.1(1 - \cos 7.85t) \qquad 0 < t < 0.4 \tag{13}$$

Figures 9-11 show that the parameters of displacement consist of fuselage and landing gear and impact force made up of air spring force decreases using semi active system significantly. Table 2 is a comparison between dynamic responces for velocity of 3 m/s at touchdown moment. As the result of Table 2, the fuselage and shock absorber displacements are improved with this touchdown velocity about 67, 58 and 50%, respectively, that deduces and represents making better body and landing gear structure life and passengers comfort.

Figures 12-14 show that the parameters of displacement consisting of fuselage and suspension travel increase with enhancement of sink speed. Table 3 is a comparison between dynamic responces for distinct velocities at touchdown moment.

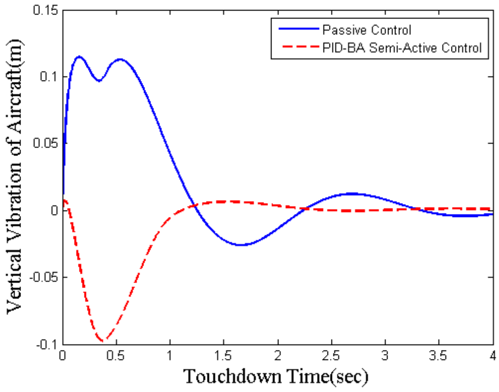

Figure 9. Time response of body bounce for sink speed=3 m/s under ranway impact

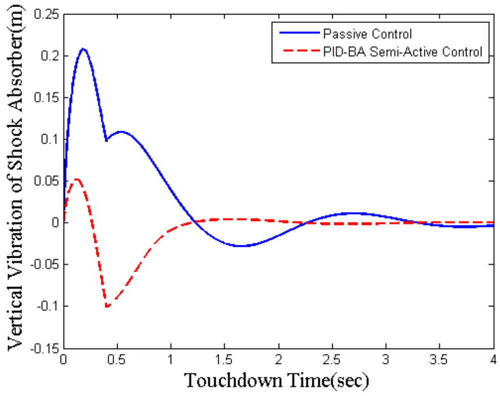

Figure 10. Time response of shock strut travel for sink speed=3 m/s under runway impact

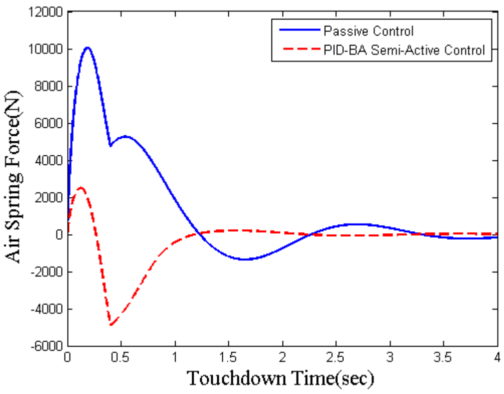

Figure 11. Time response of air spring force for sink speed=3 m/s under runway impact

TABLE 2. Comparison of dynamic responses under sine wave runway and sink speed=3 m/s

Parameter (m)	Passive	Semi active
Fuselage bounce	0.11	0.01
Shock absorber travel	0.21	0.05
Impact force	10000	2000

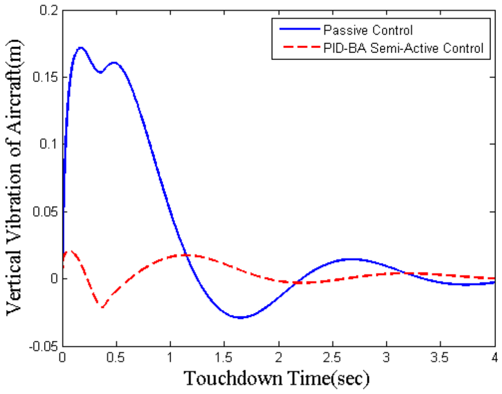

Figure 12. Time response of body bounce for sink speed=5 m/s under runway impact

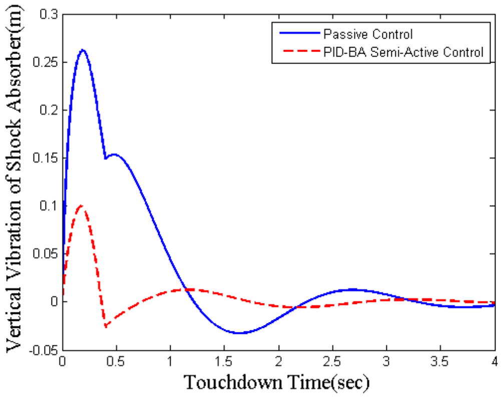

Figure 13. Time response of shock strut travel for sink speed=5 m/s under runway impact

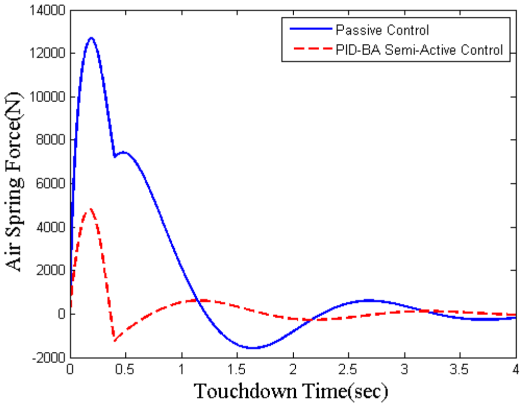

Figure 14. Time response of air spring force for sink speed=5 m/s under runway impact

TABLE 3. Comparison of dynamic responses under sine wave runway and sink speed=5 m/s

Parameter (m)	Passive	Semi active
Fuselage bounce	0.142	0.05
Shock absorber travel	0.24	0.13
Impact force	11500	6500

As the result of Table 3, the fuselage and shock absorber displacements increase with increment of touchdown velocity by about 67, 38 and 39%, respectively.

The landing gear travel using Bee algorithm based PID technique for semi active system had improvement percentage of 66.5% and the fuselage movement decreased 47% compared to passive performance and air spring force reduced 68% that deduces amelioration of body and landing gear structure life and passengers comfort.

5. 3. Dynamic Responses of the Aircraft for Two Sink Speeds and Sine Wave Runway During Impact Time

Figures 15-20 show that the parameters of displacement consisting of fuselage, landing gear and shock absorber increase with accretion of landing speed. Table 4 is a resemblance between dynamic responces for distinct performances at touchdown moment. As the result of Table 4, the fuselage and vibration absorber displacements and stiffness load increase with addendum of impact velocity by about 57, 48 and 41%, respectively.

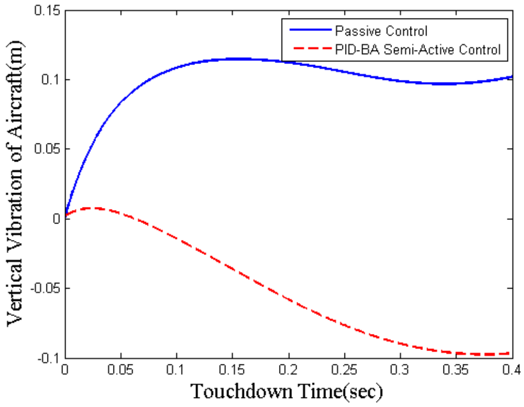

Figure 15. Time response of body bounce for sink speed=3 m/s during runway impact time

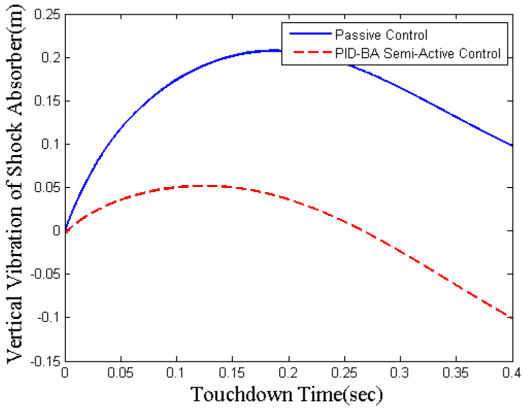

Figure 16. Time response of shock strut travel for sink speed=3 m/s during runway impact time

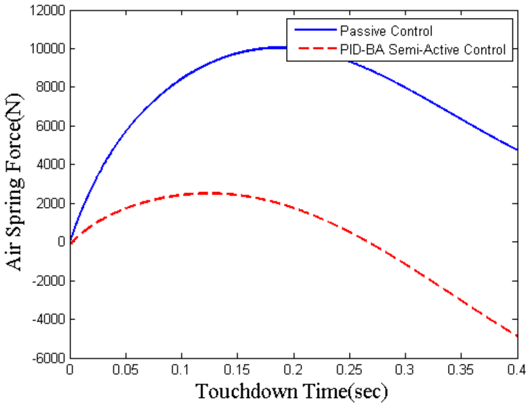

Figure 17. Time response of air spring force for sink speed=3 m/s during runway impact time

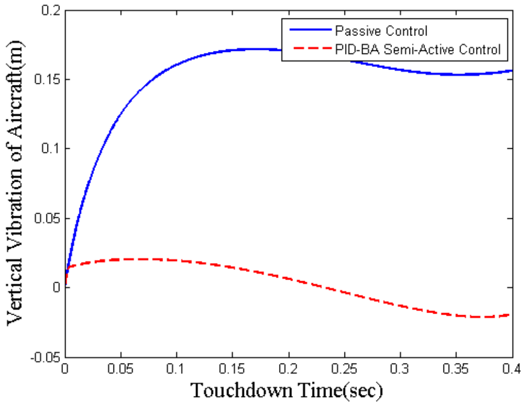

Figure 18. Time response of body bounce for sink speed=5 m/s during runway impact time

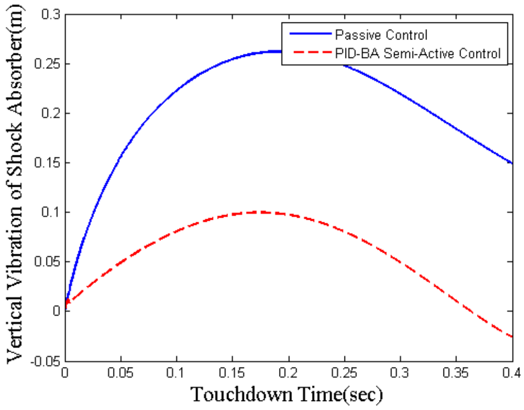

Figure 19. Time response of shock strut travel for sink speed=5 m/s during runway impact time

According to Figures 3-20, it can be deduced that dissociation phenomenon of aircraft wheel from runway at contact moment as shown is bettered for semi active performance on the basis of Bee intelligent method for two touchdown speeds compared to others.

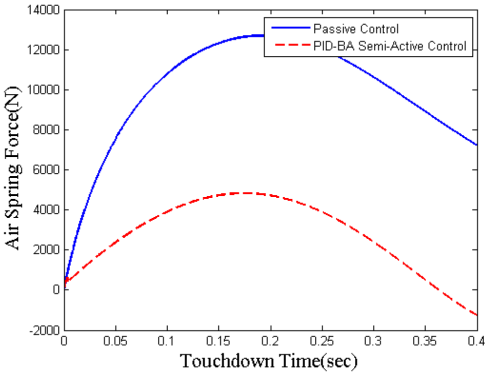

Figure 20. Time response of air spring force for sink speed=5 m/s during runway impact time

TABLE 4. Comparison of dynamic responses under sine wave runway during impact time

Parameter (m)	Passive	Semi active
Fuselage bounce	0.17	0.02
Shock absorber travel	0.27	0.1
Impact force	12500	5000

5. 4. Validation and Comparison

As validation and collation, results for three parameters include airframe and landing gear movements and the air spring force as installment of impact load are verified by reference [8] that performance of semi active landing gear is modified using fuzzy logic technique based on Bees single objective optimization. Variance between max overshoot and stability time for them is due to type and quantity of objective functions and control approach. The improvement percentage of PID semi active system on the basis of Bees multiobjective method is compared to semi active performance according to fuzzy-BA single objective procedure [8] and Tables 5 and 6 are about 57, 42 and 68%, averagely.

TABLE 5. Comparison of dynamic responses for PID-BA and Fuzzy-BA under uniform runway

Parameter (m)	PID-BA	FUZYY-BA
Fuselage bounce	0.05	0.13
Shock absorber travel	0.07	0.17
Impact force	3000	7000

TABLE 6. Comparison of dynamic responses for PID-BA and Fuzzy-BA under sine wave runway

Parameter (m)	PID-BA	FUZZY-BA
Fuselage bounce	0.04	0.1372
Shock absorber travel	0.06	0.1864
Impact force	2800	6400

6. CONCLUSION and FUTURE WORK

The major purpose of this research to introduce multi objective optimization method pursuant Bees algorithm as a new procedure for improvement of suspension system performance in airplane. In this approach, two objective functions consisting of accelerations of body and gear and impact forces including damping force, stiffness force and friction force are minimized for reduction of displacements and impact load, simultanously. The main advantages of this way are represented as follow:

- Simplicity, flexibility and robustness
- Use of fewer control parameters compared to many other search techniques
- Ease of hybridization with other optimization algorithms
- Ability to handle the objective cost with stochastic nature
- Ease of implementation with basic mathematical and logical operations
- Finding global optimization solution

Practical result of this algorithm is passengers and ride comfort and modification of fatigue life by decreasing body and shock absorber movements and air spring force as impact load.

Semi active performance with ER and MR actuator as intelligent fluid will be studied and classical controller will be combinated with adaptive and robust techniques based on Bees multiobjective optimization.

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Numerical Survey of Vibrational Model for Third Aircraft based on HR Suspension System Actuator Using Two Bee Algorithm Objective Functions

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چکیده

این تحقیق مدل هواپیما با دو ارتعاش عمودی برای بدنه و سیستم ارابه فرود را تشریح می کند. هدف این کار بسط مدل ارتعاشی برای مطالعه جاذب ارتعاش تنظیم پذیر و طراحی روش تناسبی-انتگرالی-مشتق گیر برای تطبیق نیروی کنترل نیمه فعال می باشد. ضرائب این تکنیک بر طبق بهینه سازی چندهدفه زنبورعسل با استفاده از مینیموم کردن شتاب ها و نیروهای ضربه به عنوان توابع هدف اصلاح می گردد. نتایج نشان می دهند که سیستم جاذب ضربه نیمه فعال بر مبنای کلونی زنبور عسل مصنوعی، راحتی مسافران و سواری و عمر خستگی بدنه، پایه ضربه و تایر را توسط کاهش جابجایی بدنه، سیستم تعلیق و بار ضربه بطور چشمگیری در مقایسه با عملکرد غیرفعال در طول فاز فرود با سرعت های نشست و سطوح باند فرود مختلف برای بررسی مقاومت و حساسیت عملکرد بهینه سازی بهبود می بخشد.

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