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Efficiency of PID Controller Based on Genetic Algorithm for controlling a Quarter Car Suspension System

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***Abstract**: the purpose of this paper is to improve the performance of a car's active suspension system (a quarter model), with two degrees of freedom , a combination of components and mechanisms ensure both passengers' comfort and driving safety, the stability and ride performance depends generally on the quality of the suspension , and this is why car manufacturers are turning to an adjustable suspension that can be adapted to any type of road surface as it controls vertical movement for car wheels. In this work we show how proportional integral differential (PID) controller tuned by using two methods, Ziegler Nichols and genetic algorithms (GA) can used to achieve a good performance of the active suspension system, The simulation results show the robustness and effectiveness of genetic algorithm (GA) in providing good ride quality and good road handling, however the presence of a time delay.*

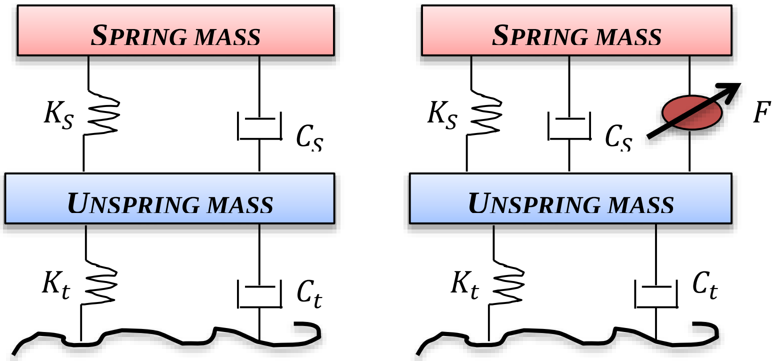
Keywords: Active Suspension, Genetic Algorithm (GA), Classical PID Controller, Ziegler-Nichols, a quarter-car system.

1. INTRODUCTION

Suspensions are installed between the vehicle body and the wheel to absorb unwanted vibrations that occur due to road conditions [1]. Depending on road conditions, it is not possible to get a "strong" response from the configuration of this equipment [2]. Those systems are low price because they often have a few devices in comparison to some other version [3]-[4]-[5]. The suspension provides better vibration isolation, a small acceleration of the frame's mass, which is the maximum allowable relative displacement [6]. The passive suspension can store the energy by the spring and the damper releases it. Its parameters are commonly constant [7]. A suspension passive uses simple springs and shock absorbers to respond to the changes in the road, active suspension system is how the system causes the wheels to interact with the road [8]-[9]. In [10] E. Akbari and all compared sliding mode control (SMC) with LQR control and passive suspension, the simulation proved that SMC strategies have better performance than LQR control and passive suspension. In reference [11] H. Du and N. Zhang used the H∞ controller for active vehicle suspension systems with actuator time delay, the simulation proved the effectiveness of the proposed controller in the optimal performance and stability for active suspension. Fuzzy logic control (FLC) proposed in [12] to implement a new sort of active suspension system with comparisons between LQR control and conventional passive suspension systems. Results show benefits that could be achieved from fuzzy system against other systems. The active suspension system based on PID controller for a quarter car model is compared with passive suspension system in [13] to improve ride comfort and better road handling. The robustness of LYAPUNOV theory is proved on the active suspension system in [14]-[15]. N.Al-Holou et al. applied Neural Networks method in the active car suspension field in [16]. This study will make us to determine the mathematical models of passive suspension and active suspension, the last one is controlled by a classical PID by Ziegler-Nichols method after that we tried to optimize the parameters of PID by genetic algorithms. In this paper a mathematical equation of a quarter-car model is studied, the system performance is examined using classical PID tuned by two methods (Ziegler-Nichols, genetic algorithms GA). This paper is organized as follows: In section 2 the mathematical model of the car suspension system is devoted. The proposed control methods are presented in section 3. section 4 covers our simulations and discussion for comparing a Simulink car suspension system using the two methods. The last section of this paper offers the conclusion of the performed work.

Vehicle Model

The quarter car suspension model with two degrees of liberty (2-DOF) and the physical parameters studied in this paper are shown in Figure 1 and Table 1 respectively [17]-[18].



(a) (b)

Fig. 1 : (a) Passive model, (b) Active Model

As shown the passive suspension is uncontrolled system, however a bounded controller F is implemented within the active suspension, in this case the system should considerably improve the ride comfort and road handling [19]-[20].

A. Modeling Passive and active suspension system of a quarter car system

The following are the equations of a quarter car suspension [21]-[22]:

- Passive suspension system

$$\begin{cases} M_s\ddot{Z}_s = -K_s(Z_s - Z_u) - C_s(\dot{Z}_s - \dot{Z}_u) \\ M_u\ddot{Z}_u = K_s(Z_s - Z_u) + C_s(\dot{Z}_s - \dot{Z}_u) - K_t(Z_u - Z_r) - C_t(\dot{Z}_u - \dot{Z}_r) \end{cases} \tag{1}$$

- Active suspension system

$$\begin{cases} M_s\ddot{Z}_s = -K_s(Z_s - Z_u) - C_s(\dot{Z}_s - \dot{Z}_u) + F \\ M_u\ddot{Z}_u = K_s(Z_s - Z_u) + C_s(\dot{Z}_s - \dot{Z}_u) - K_t(Z_u - Z_r) - C_t(\dot{Z}_u - \dot{Z}_r) - F \end{cases} \tag{2}$$

The parameters of quarter car suspension given in Table 1:

Table1: Parameters of quarter car suspension model

Vrabel	**Description and Parameters**		
	Description	**Value**	**Unit**
M_s	Sprung Mass	972.2	Kg
M_u	Unsprung Mass	113.6	Kg
K_s	Spring of suspension system	42,719.6	N/m
K_t	Spring of wheel and tire	101,115	N/m
C_s	Damping of suspension system	1,095	N.s/m
C_t	Damping of wheel and tire	14.6	N.s/m

Where

F is the actuator force,(X_s, X_u) is Body and Wheel displacement, r is road profile input.

B. PID Controller Using Ziegler Nichols Method (ZN)

Fig. 2 shows a PID controller or three-term controller stands Proportional, Integral and Derivative who designed to reduce errors through the derived nature of the controller. The error is defined as a difference between the desired and actual signal [23]-[24].

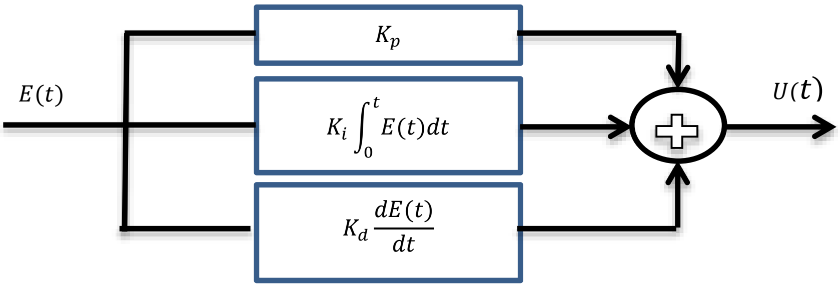


Fig. 2 :PID controller

To apply the Ziegler-Nichols closed-loop tuning method, we must perform the following steps:

- Step 01: Input closed-loop transfer function, and display the step response;
- Step 03: Check the stability;
- Step 04: Determine K_u and T_u and display step response using PID controller, where $T_u$is the period of the oscillation, and K_u the final gain when the system started oscillating [25].

Because of the disadvantages of this technique as the little chance of correctness and weak control quality performance, we tried in this paper to optimize the PID controller parameters using a Genetic Algorithm (GA), which is a random search method that can be used to solve nonlinear system of equations and optimize complex problems.

C. Genetic Algorithms

The first one suggested the basic principles of GA was Holland [26]. This technique is inspired by the process of natural selection which is a part of a larger class of evolutionary algorithms [27]. GA consists of three fundamental operators: reproduction, crossover, and mutation. The optimization by genetic algorithms encodes parameters as are binary models [28].

- Object Function and Fitness value

The performance criterion is related to fitness function and best PID parameters are derived by minimizing the target, which generates a weighted combination of Integration of time multiplied by absolute error (ITAE) [29]:

$$I_{ITAE} = \int_0^T t|e(t)|\,dt \tag{3}$$

The PID controller is used to reduce the error presented by the equation (3), the fitness of the chromosomes is defined as [30]:

$$Fitness\ value = \frac{1}{Performance\ index} \tag{4}$$

The following Figure revealed the description of GA, and numeric parameters of PID are presented in Table 2:

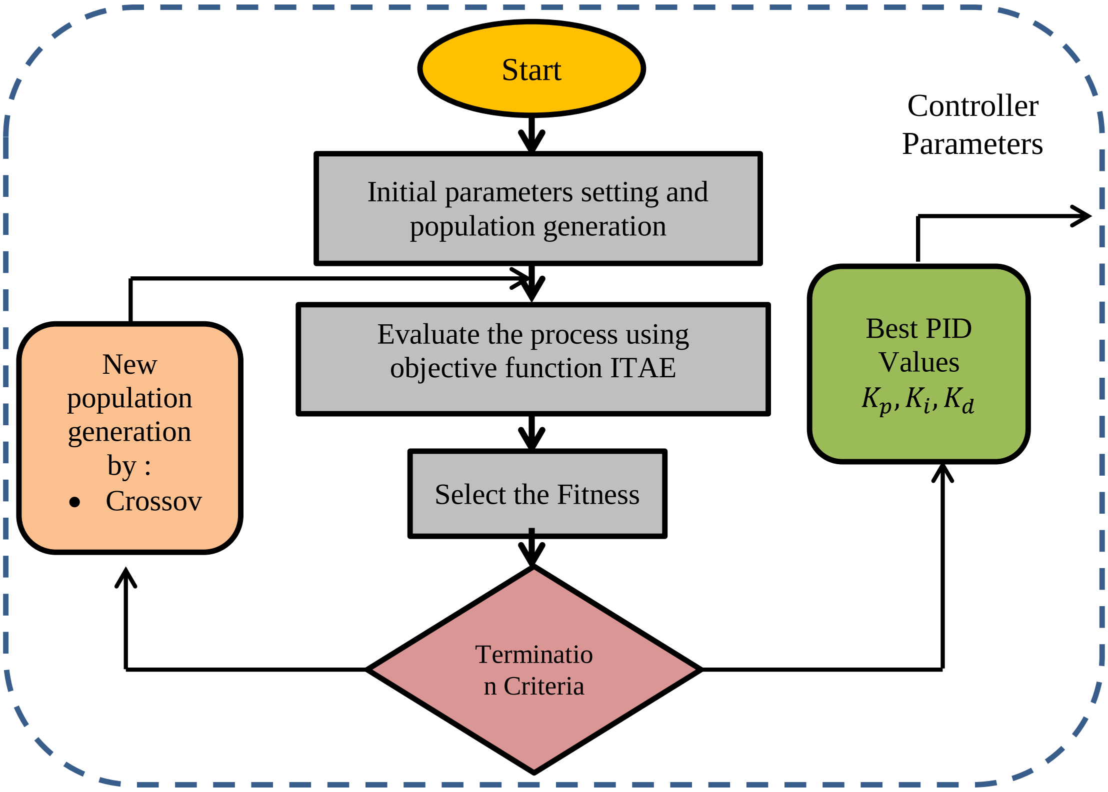


Fig. 3 :Diagram of Genetic Algorithm

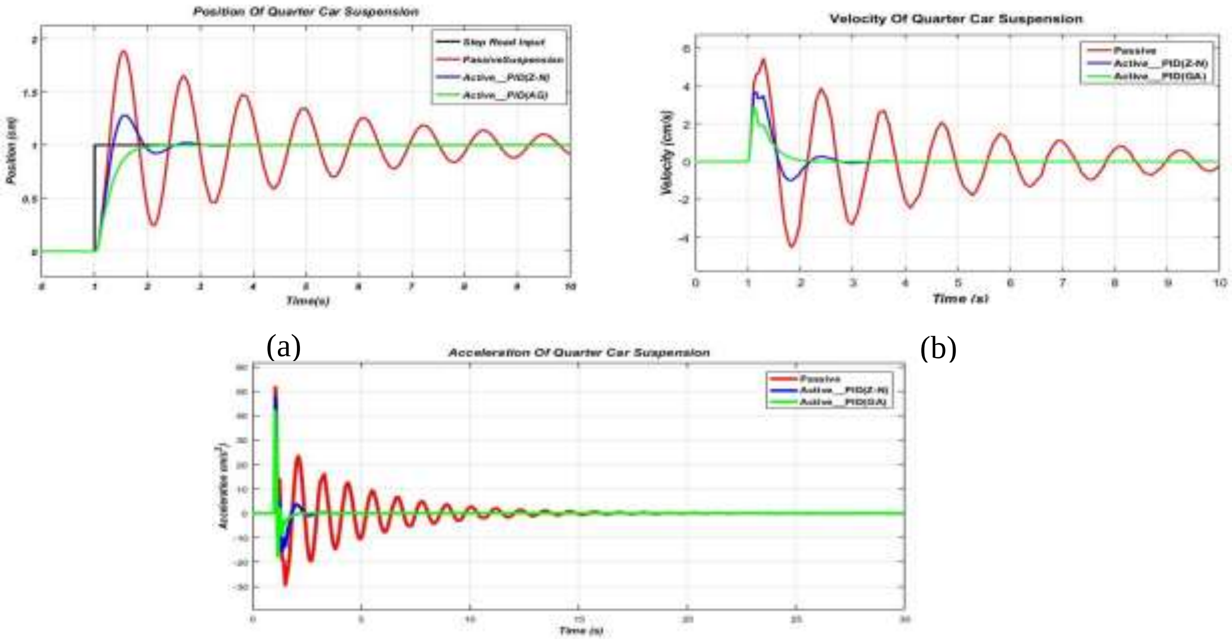
Table 2: PID Parameters tuning by ZN and GA methods

Methods	**PID Parameters**		
	$\boldsymbol{K_p}$	$\boldsymbol{K_i}$	$\boldsymbol{K_d}$
ZN	12	0.00719	$5.004e^3$
GA	9.955	10	$13.224e^3$

2. RESULTS AND DISCUSSION

The simulation results of the active suspension system are discussed. The ride quality of the suspension will be shown, with road dispersion assumed as an input of the system. The following figures show the `body velocity`, body acceleration and the displacement of the quarter car model in different road conditions:(Step Input, Bumpy Road Input, and Random Input).

Figure 4 shows the output of a of passive and active suspension quarter car model for a step road input.

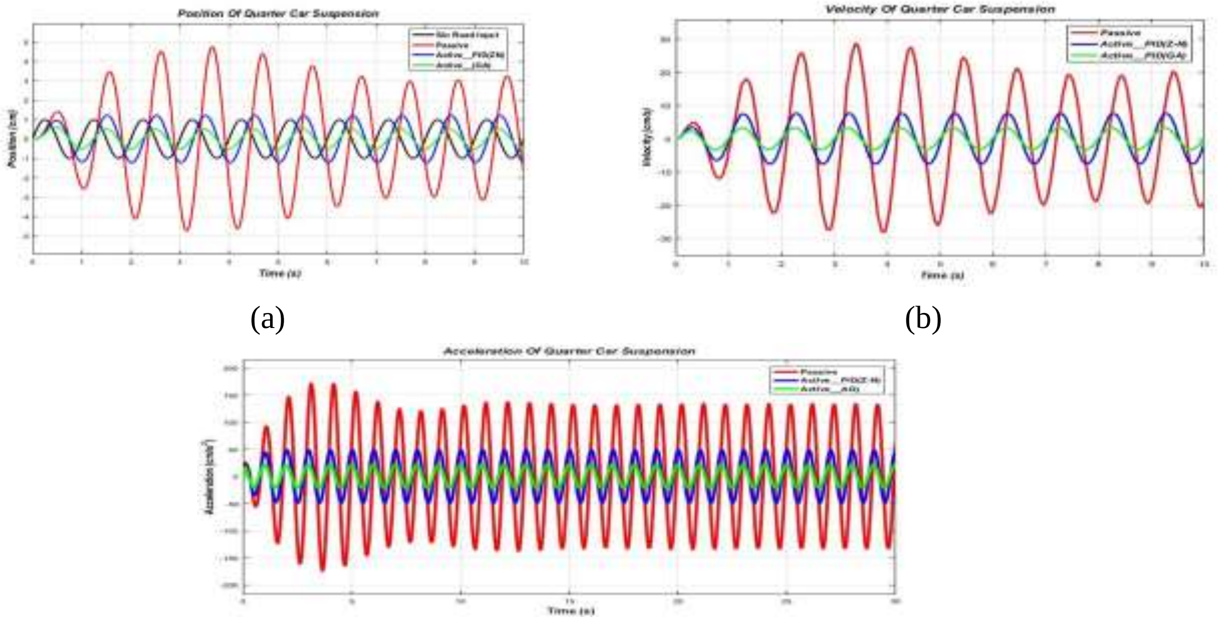


(a) (b)

(c)

Fig. 4 The step responses of passive and active suspension :(a) Body Position, (b) Body Velocity, (c) Body Acceleration

The second road profile input is a bumpy which is simulated by sinusoidal signal , the results are presented as follows:

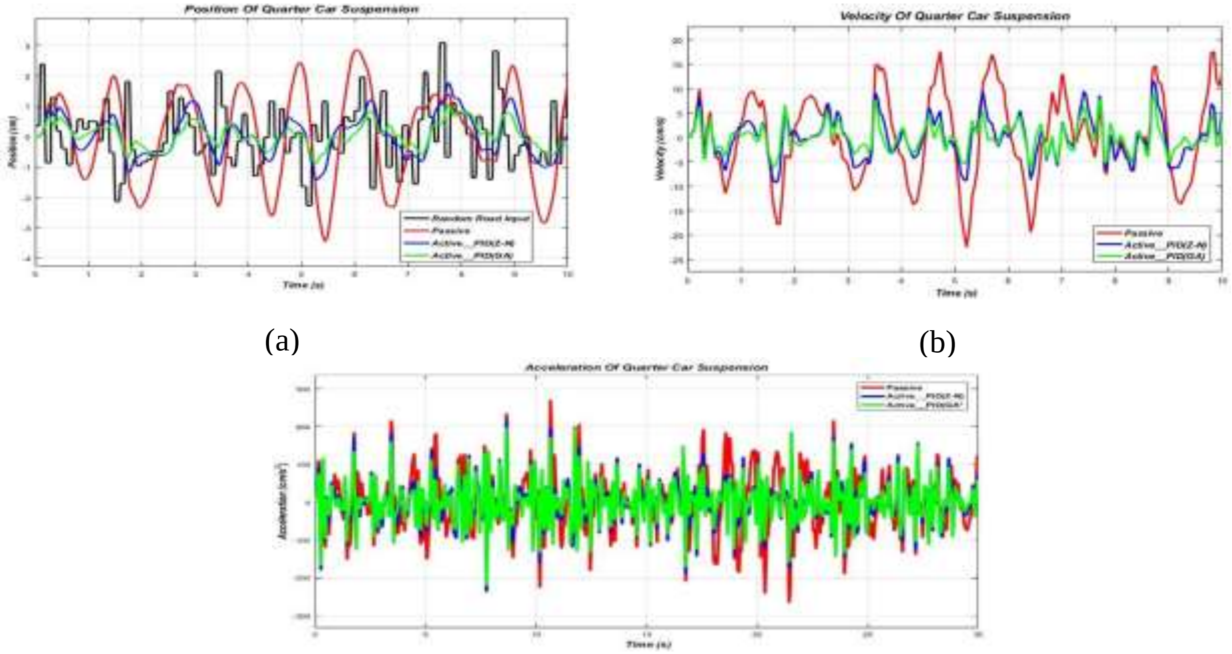


(a) (b)

(c)

Fig. 5 The responses of passive and active suspension for bumpy road input :(a) Body Position, (b) Body Velocity, (c) Body Acceleration

The following figures present the responses for the Noise input profile which is simulated as Random input



(a) (b)

(c)

Fig. 6 The responses of passive and active suspension for noise road input :(a) Body Position, (b) Body Velocity, (c) Body Acceleration

In this paper, the quarter active car suspension system is studied with PID controller: the ZN and the GA is used as tuning approach to evaluate the optimum parameters for the PID controller after exposing to road variations. The proposed fitness function used is based on the Root Mean Squared Error (RMSE) in position responses which defined by the following equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(X_i - Y_i)^2}{N}} \tag{5}$$

Where, X_i = Actual value, Y_i = Observation value, N = Forecast/ Observation pairs.

All eight figures above show that Genetic Algorithm applied in PID controller gives the smallest values of (RMSE) than the corresponding Ziegler-Nichols method despite the existence of the time delay in digging road (step input) Fig 4 (a), reverse road disturbances like random in (Fig 5), and bumpy road (Fig 6), PID controller tuned by GA provides a faster response and reduction of RMS error variation of 13% of minimum and 85% of maximum value, in comparison to PID controller based on a classical method where the variation of RMS error reduction is 8% of minimum and 68% for maximum value.

3. CONCLUSIONS

The suspension system plays an important role in the modern car and it is a very important element to provide comfort while driving. In this paper, we controlled the suspension quarter car using PID, the parameters K_p, K_i, and K_d, are adjusted with Ziegler-Nichols which considered as the classical method, and Genetic algorithms, the PID controller tuned by GA displayed a better achievement for riding than the classical PID , The proposed controller can provide shorter settling time in system response , it can ensure the minimum car displacement and oscillation under road disturbances..

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