2021 20th International Symposium on Distributed Computing and Applications for Business Engineering and Science (DCABES)

Coefficient Optimization Based on Genetic Algorithm for Hybrid Control of Semi-active Suspension System

Li Wei
School of Automotive Engineering
Wuhan University of Technology
Wuhan, China
1490239828@qq.com

Zhang Chengcai
School of Automotive Engineering
Wuhan University of Technology
Wuhan, China
zhangchc@whut.edu.cn

***Abstract*—Composed of sky-hook control and ground-hook control, hybrid control used for a semi-active suspension system is of great significance for enhancing vehicle comfort, stability, and safety. The former hybrid control is highly difficult in coefficient selection to lead to has a low degree of improvement in suspension performance. In this paper, based on a genetic algorithm, a coefficient optimization method (COGA) is presented for hybrid control of a semi-active suspension system. A genetic algorithm is used to optimize the selection of suspension control system coefficients. Computer simulation of the quarter-vehicle suspension system model is conducted by MATLAB/SIMULINK software. The vehicle comfort and handling characteristics of the suspension systems are predicted under a random road input simulation model. Passive suspension system performance is compared with the semi-active suspension system using hybrid control. The experimental results show that the semi-active suspension hybrid control system with COGA has a minimal root-mean-square value of sprung mass acceleration, suspension dynamic deflection, and dynamic tire load. It can be proved that COGA can effectively coordinate and ameliorate the function of hybrid control.**

Keywords-hybrid control; semi-active suspension system; genetic algorithm; coefficient optimization

I. INTRODUCTION

The vehicle suspension system plays an important role in a vehicle by providing vehicular stability and comfort during driving by isolating its passengers and goods for vibration caused by the road surface as a result of irregularities like potholes, speed bumps, and uneven road surfaces. Nowadays, vehicle suspension may be categorized broadly into three types: passive suspension, active suspension, and semi-active suspension. Due to its constant damping coefficients, the passive suspension system leads to a compromise between ride and handling, and can't adapt to a changing road. Both active suspension systems and semi-active suspension systems are capable of changing their damping characteristics by using an amount of external power. The active suspension system has the disadvantages of costliness, complexity, and high energy consumption, there are drawbacks of which that stop it from being extensively applied in most vehicles. Unlike an active suspension system, the semi-active suspension system is simpler, cheaper, and more reliable, which is becoming more and more popular for car manufacturers.

In 1974, Crosby et al. proposed a shy-hook control and applied it to a passive suspension system, resulting in a semi-active suspension system [1]. With the advancement of technology, there have been many control strategies for the semi-active suspension system. Such as, ground-hook control [2], PID control [3], sliding mode control [4], fuzzy control [5], optimum control [6], and neural network control [7]. However, the vehicle performance contradiction between riding comfort and handling stability under the single working model of the semi-active suspension system has always existed. For example, sky-hook control significantly improves vehicle riding comfort but doesn't work on handling stability. Ground-hook control primarily improves vehicle handling stability but will deteriorate riding comfort [8].

Ahmadian et al. put forward a hybrid control based on shy-hook control and ground-hook control to coordinate the contradiction between comfort and stability of the semi-active suspension system [9]. Hybrid control is simple, easy to implement, and has a more excellent control effect than the single control strategy, so it is widely used in vehicles. At the same time, hybrid control is often inefficient on account of the wrong choice of damping coefficients. Researchers have used a particle swarm optimization algorithm (PSO) to optimize the damping coefficients of hybrid control [10]. But the result is not optimal and can be further optimized by increasing the weight coefficient optimization. The genetic algorithm is a global search heuristic algorithm that is proposed by Holland et al [11-12]. There have been some control strategies with a genetic algorithm to optimize control system parameters to get outstanding suspension performance. As a consequence, this paper proposes a coefficient optimization method (COGA) for hybrid control of the semi-active suspension, which uses a genetic algorithm to optimize its damping coefficients and weighting coefficient.

II. MODEL OF SEMI-ACTIVE SUSPENSION SYSTEM UNDER HYBRID CONTROL

Sky-hook control realizes damping control by installing a damping element between the sprung mass and the imaginary inertial reference frame. In the same, ground-hook control realizes damping control by installing a damping element between the unsprung mass and the imaginary inertial reference frame. In this paper, a quarter vehicle dynamic suspension system model under hybrid control is established, as is shown in Figure 1. According to Newton's laws of motion, the dynamic motion equations for the quarter vehicle suspension can be expressed as:

$$\begin{cases} M_1\ddot{x}_1 = -k_0(x_1 - x_2) - c_0(\dot{x}_1 - \dot{x}_2) + F \\ M_2\ddot{x}_2 = k_0(x_1 - x_2) + c_0(\dot{x}_1 - \dot{x}_2) - k_t(x_2 - x_r) - F \end{cases} \quad (1)$$

2473-3636/21/$31.00 ©2021 IEEE
DOI 10.1109/DCABES52998.2021.00053

where M_1 is the sprung mass, M_2 is the unsprung mass, k_0 is the spring stiffness, k_t is the tire stiffness, x_r is the displacement of road input, x_1 is the displacement of the sprung mass, x_2 is the displacement of the unsprung mass, c_0 is the passive damping coefficient, c_s is the sky-hook damping coefficient, c_g is the ground-hook damping coefficient, and F is the hybrid damping force.

The control law of hybrid strategy can be stated as:

$$F = -\alpha c_s \dot{x}_1 + (1-\alpha) c_g \dot{x}_2 \quad (2)$$

When α is equal to 1, hybrid control is pure sky-hook control:

$$F = -c_s \dot{x}_1 \quad (3)$$

When α is equal to 0, hybrid control is pure ground-hook control:

$$F = c_g \dot{x}_2 \quad (4)$$

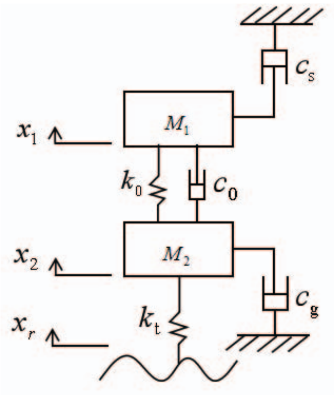

Figure 1. Suspension dynamic model with 2-DOF of hybrid control.

III. Coefficient Optimization Based on Genetic Algorithm

A genetic algorithm is a random adaptive global search method used for rapidly calculating optimization problems of multiple parameters, which is strong fault-tolerant, easy to implement, and has high computational efficiency. The genetic algorithm has been the focus of attention of researchers since it was proposed. Combining the genetic algorithm with other subjects has become the latest research trend.

Therefore, it is practicable to use a genetic algorithm to optimize suspension system control coefficients. Figure 2 shows the overall schematic diagram of COGA, which can be defined in the following steps：

1) Algorithm initialization. Initialize the entire population with completely random solutions.

2) Coefficient assignment. Respectively assign the population individuals to the sky-hook damping coefficient, the ground-hook damping coefficient, and the weighting coefficient.

3) Evaluate the fitness function. Calculate the fitness value for each member of the population. The fitness function L is constructed by suspension system performance evaluation indexes. So this paper uses the root-mean-square value of sprung mass acceleration, suspension dynamic deflection, and tire dynamic load to construct function, which formula is as follows:

$$\min L = 0.44\frac{SMA(x)}{SMA_p} + 0.28\frac{SDD(x)}{SDD_p} + 0.28\frac{DTL(x)}{DTL_p} \quad (5)$$

$$s.t. = \begin{cases} \frac{SMA(x)}{SMA_p} < 1 \\ \frac{SDD(x)}{SDD_p} < 1 \\ \frac{DTL(x)}{DTL_p} < 1 \end{cases} \quad (6)$$

Where SMA(x), SDD(x), DTL(x) is the root-mean-square value of sprung mass acceleration, suspension dynamic deflection, and tire dynamic load of the semi-active suspension, and SMA_p, SDD_p, DTL_p is the root-mean-square value of sprung mass acceleration, suspension dynamic deflection, and tire dynamic load of the passive suspension. In order to greatly improve vehicle riding comfort, the ratio of sprung mass acceleration is increased.

4) Termination condition. The maximum number of iteration is used as a termination condition. If the termination condition is met, output the optimization coefficients. if not, step five is executed.

5) Selection, crossover, and mutation. Apply mutation, crossover, and selection operators to the individuals with the smallest fitness value to generate a new population. Repeat steps two to four.

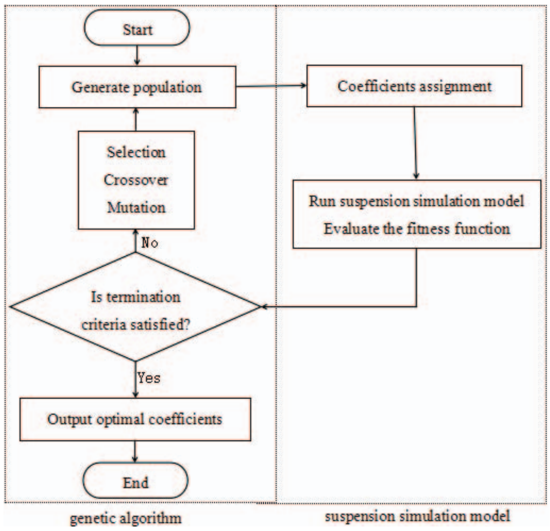

Figure 2. The process of coefficient optimization method based on genetic algorithm (COGA).

IV. Experiment

A quarter semi-active suspension hybrid control system simulation model is established in MATLAB/SIMULINK, as shown in Figure 3. As shown in Figure 4, a random road input simulation model is established by a filtered white noise signal [13], which formula is as follows:

$$\dot{x}_r(t) = -2\pi f_0 x_r(t) + 2\pi n_0 \sqrt{G_q(n_0) u} w(t) \quad (7)$$

where $G_q(n_0)$ is the road irregularity coefficient, f_0 is the lower cutoff frequency, u is the vehicle speed, w(t) is the unit white noise, n_0 is the reference space-frequency, and $x_r(t)$ is the displacement of road input.

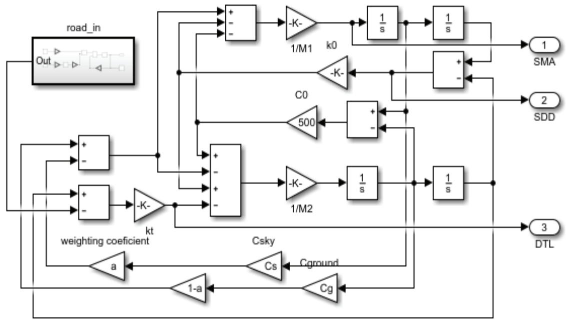

Figure 3. Semi-active suspension system simulation model.

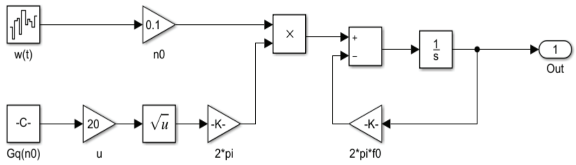

Figure 4. Random road input simulation model.

According to the parameters in Table Ⅰ, the simulation environment is set. COGA is carried out in MATLAB/SIMULINK. The value range of the sky-hook damping coefficient is [0, 10000]. The value range of the ground-hook damping coefficient is [0, 10000]. The value range of the weighting coefficient is [0.4, 0.6]. As shown in Figure 5, the coefficient optimization results are listed as follows: $c_s = 4460.9$Ns/m, $c_g = 604.7954$Ns/m, $\alpha = 0.5809$.

TABLE I. SIMULATION PARAMETERS

Parameter	Symbol	Values
Sprung mass (Kg)	M_1	250
Unsprung mass (Kg)	M_2	45
Spring stiffness (N/m)	k_0	16000
Tire stiffness (N/m)	k_t	160000
Passive damping coefficient (Ns/m)	c_0	500
Vehicle speed (m/s)	u	20
Road irregularity coefficient (m^3)	$G_q(n_0)$	256e-6
Lower cutoff frequency (Hz)	f_0	0.01
Reference space-frequency (m^{-1})	n_0	0.1
Sky-hook damping coefficient (Ns/m)	c_s	[0, 10000]
Ground-hook damping coefficient (Ns/m)	c_g	[0, 10000]
Weighting coefficient	α	[0.4, 0.6]
Population size	-	100
Elite count	-	10
Crossover fraction	-	0.8
Generation	-	20

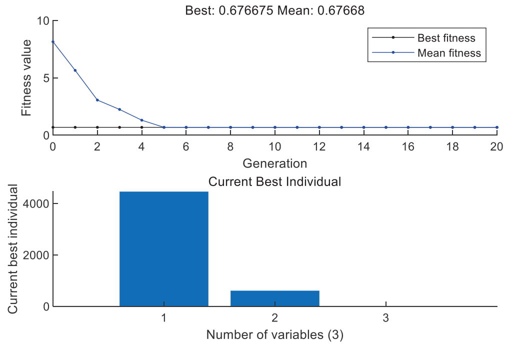

Figure 5. Result of coefficients optimization.

Figure 6 shows the response of the passive suspension system, the semi-active suspension hybrid control system with a particle swarm optimization algorithm (PSO-hybrid control), and the semi-active suspension hybrid control system with COGA (COGA-hybrid control) under the random road input simulation model. It can be seen from the image that compared with the passive suspension system, the semi-active suspension system can drastically reduce the amplitude of suspension system performance evaluation indexes. Most importantly, the semi-active suspension hybrid control system with COGA has the smallest response peak. As can be roughly seen from the figure, COGA can effectively improve the efficiency of hybrid control more than PSO.

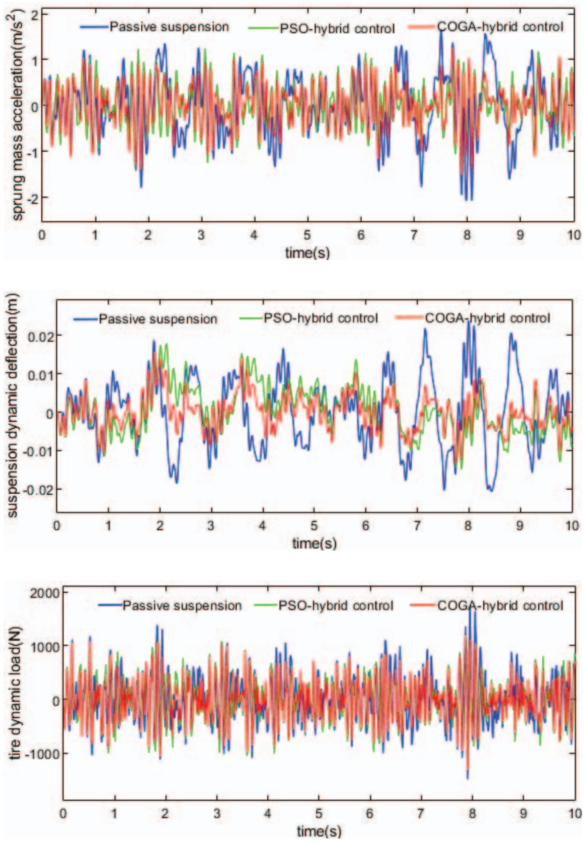

Figure 6. Responses of suspension evaluation indexes.

To further analyze the performance of the suspension systems, the root-mean-square value of evaluation indexes is calculated, and the control effect of the suspension systems is evaluated, as shown in Table Ⅱ. Table Ⅱ shows that the three indexes of the hybrid control suspension system are reduced with different degrees under the random road input simulation model. For example, under the random road input simulation model, the root-mean-square value of the sprung mass acceleration of hybrid control with COGA is reduced by 32.2% compared with that of the passive suspension. The root-mean-square value of the sprung mass acceleration of hybrid control with PSO is reduced by 29.1% compared with that of the passive suspension. It can be seen that the root-mean-square value of the sprung mass acceleration of hybrid control with COGA goes down more than hybrid control with PSO. The same is true for suspension dynamic deflection and tire dynamic load. It is obvious that the control effect of the hybrid control with COGA is better than the hybrid control with PSO.

TABLE II. THE OUTPUT RMS VALUES AND CONTROL EFFECT

control types	**Passive suspension**	**PSO-hybrid control**	**COGA-hybrid control**
SMA	0.6805	0.4827	0.4613
Effect(%)	-	29.1	32.2
SDD	0.009015	0.006115	0.004672
Effect(%)	-	32.1	48.2
DTL	462.6	405.8	386.9
Effect(%)	-	12.3	16.4

V. CONCLUDING REMARKS

A coefficient optimization method (COGA) is designed, based on a genetic algorithm, which is used to a hybrid control strategy of the semi-active suspension system. In this work, a genetic algorithm is serviced to optimize the sky-hook damping coefficient, the ground-hook damping coefficient, and the weighting coefficient of hybrid control. The simulation analysis of the suspension systems is carried out by MATLAB/SIMULINK software. Compared with the passive suspension system and the semi-active suspension hybrid control system with PSO, the root-mean-square value of sprung mass acceleration, suspension dynamic deflection, and tire dynamic load of the semi-active suspension hybrid control system with COGA has different degrees of reduction. The experimental results show that hybrid control with COGA has the best control effect, which can improve the vehicle riding comfort and handling stability, and prevent the adverse effects of body resonance on human organs effectively. It is proved that COGA can effectively improve the efficiency of hybrid control.

ACKNOWLEDGMENT

This work was supported by the Independent Innovation Research Fund Project of Wuhan University of Technology (NO. 2021-QC-B1-11).

REFERENCES

[1] Karnopp D. Design principles for vibration control system using semi-active damper[J]. Journal of Dynamic Systems, Measurement and Control, 1990. 112(3): 448-55.

[2] Val S.M, Noxak M, Sika Z, et al. Extended Ground-Hook-New Concept of Semi-Active Control of Truck’s Suspension[J]. Vehicle System Dynamics, 1997, 273(5-6): 289-303.

[3] Yang Jianwei, Li Jie, Jia Zhixuan, et al. Fuzzy-PID Country System Simulation of the Semi-active Vehicle Suspension. 2010. (1): 772-775.

[4] Zhiyong Yang et al. Sliding Mode Control for Vibration Comfort Improvement of a 7-DOF Nonlinear Active Vehicle Suspension Model[J]. Journal of Robotics and Mechatronics, 2019, 31(1): 95-103.

[5] H Pang, W Fu, K Liu. Stability analysis and fuzzy smith compensation control for semi-active suspension systems with time delay[J]. Journal of Intelligent & Fuzzy systems, 2015. 29(6): 2513-2525.

[6] Garg A, Arvind A, Gahvi B. Optimum Control for the Vehicle Semi-active Suspension System[C]. 2017: 421-430.

[7] Zhushun Ding, Feng Zhan, Yechen Qin, et al. Adaptive Neural Network Control for Semi-active Vehicle Suspensions[J]. Journal of Vibroengineering, 2017, 19(4): 2654-2669.

[8] Jalwadi, M.S. and Unaune, D. Performance analysis of Skyhook, groundhook and hybrid control strategies on semi-active suspension system. International Journal of Current Engineering and technology, Special Issue 3, 2014: 265-269.

[9] Ahmadian M, Pare C A. A Quarter-Car Experimental Analysis or Alternative Semiactive Control Methods[J]. Journal of Intelligent Material Systems and Structures, 2000, 11(80): 604-612.

[10] WU Wei-chun, CHEN Long, DING Ren-kai. Research on Hybrid Control Strategy of Active Suspension Based on Particle Swarm Algorithm [J]. Machinery Design & Manufacture, 2018(01): 29-31+35.

[11] Holland J H. Adaptation in Nature and Artificial Systems[J]. 2nd ed Cambridge: MIT press, 1992: 91-92.

[12] Holland J H. Genetic algorithms[J]. Scientific American, 1992, 267(1): 66-72.

[13] GUO Shanglai. Random control [M]. Tsinghua University Press, 1999: 97-117.