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Optimization of tradeoff between ride and handling of vehicle via genetic algorithm

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Abstract. Optimal design of vehicles suspension system has significant effect on handling and ride comfort improvement, which are vital parameters in vehicle performance. In this paper, an optimization procedure for MacPherson suspension of vehicle based on lateral acceleration and velocity are proposed by using MATLAB and CARSIM software. Then, parameters of suspension system are optimized using Genetic Algorithm (GA) in a way that ride and handling properties of vehicle are amended. For comparison three optimization strategies un-optimized, modified (trial & error) and optimized are implemented into the proposed model during various driving maneuvers. The simulation results show the effectiveness of suspension system optimization on vehicle performance, which indicates that considerable improvements in the vehicle handling can be achieved whenever the vehicle is governed by optimized suspension.

Key words. Ride comfort, handling, lateral acceleration, lateral speed, genetic algorithm, CARSIM.

1. Introduction

Researchers in automotive industry and related field are searching a way to find an optimal condition for vehicle stability and comfort for passengers of vehicles. Due to this point that objectives in designing a suspension is in conflict with each other, so finding optimal condition without scarifying the other object is complicated. In [1] they investigated the effects of suspension parameter to sensitivity analysis and finding the importance weight of each parameter on vehicle performance. In addition, in [2] it was shown that lateral acceleration, yaw rate and lateral velocity (side slip angle) can significantly affects the vehicle stability and ride conditions. For improving the vehicle handling and stability properties, a yaw moment direct control

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[3] and active control steering [4] are presented, also, active [5] and semi active [6] control systems developed for increasing ride comfort.

This paper investigates the suspension system effects on handling and ride comfort of vehicles using CARSIM software in order to achieve improvements in stability and ride comfort through optimization of lateral acceleration and velocity with SA. Firstly, the Macpherson suspension is modeled, then a comprehensive vehicle model by concentrating on lateral dynamic is proposed in CARSIM, and then mechanism of suspension system is optimized by studying parameters and variables of suspension system in various vehicle movements.

2. Optimization of suspension method

2.1. Genetic algorithm

For the optimization procedure of suspension system of vehicle we used a GA. For this purpose in the next section the procedure of GA development is presented in detail

2.1.1. Description of the algorithm. GA is a competitive evolutionary method that repeats the processes of the mechanism of natural selection and biological evolution [5]. This algorithm is designed on the principle that most adaptable organisms have a better chance of survival [6]. A genetic algorithm to solve problems of optimization of supply chain networks have been used by various researchers [1–3]. A typical procedure of GA is illustrated in Fig. 1 [5].

Experience has shown that GA in the early stages of solving a problem can quickly produce better responses. But after improving response due to the diversification of parts of better responses in future generations due to reducing diversification, responses toward a locally optimal solution are turned, and in some cases, the possibility of more recovery is not possible. Mutation probability is an indicator that controls the Diversification of this algorithm. Two mutation probabilities are considered in this article. An algorithm with a low mutation probability rate starts to work and if in several successive diversifications (several consecutive generations), the best answer not to be improved mutation probability increases.

2.1.2. Natural selection. Selection aims to increase the quality of solutions by selecting better individuals to get copied in next generations. The most popular selection techniques are tournament selection, random selection, elitist selection, roulette wheel and so on. Tournament selection is one of the conventional methods in simulating natural selection in genetics algorithm, which is widely used [4].

In each generation of the GA, two parents are chosen from the population by the tournament selection function. Therefore, two individuals are selected from the population stochastically. The one with the better fitness cost is selected as the initial parent. The procedure is reproduced to get a next parent. Following choosing the parents, one offspring is performed by GA operators. To maintain the variety in the population, the offspring, which is not a duplication of any solution in

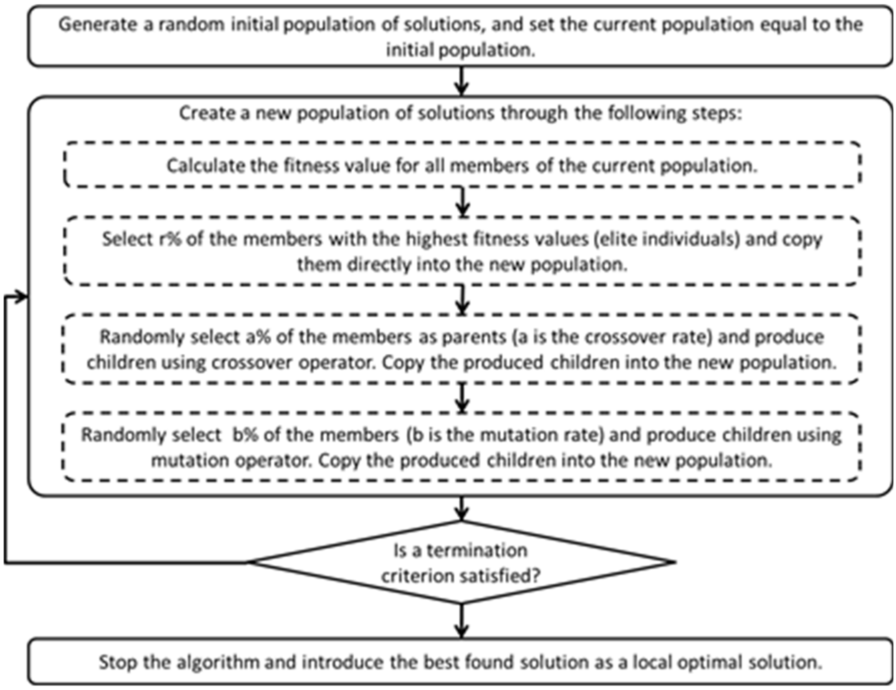

Fig. 1. The standard GA procedure

the population, replaces with the worst individual of the population. In this study, tournament selection is used as natural selection. In this method, to select each parent, two answers are selected from the population, and top option is selected as a parent.

2.1.3. GA operators.

1. Crossover operator

Crossover operator based on present responses generates new responses. In this action, some of the features of parents' chromosomes are transmitted to children. In this article, the two point operator is used for this purpose. Fig. 2 shows an example of this operator. In this operator, two random numbers are produced. The two random numbers divide each parent's chromosomes into three parts. The child of first and third part inherits chromosome of one of the parents. Middle chromosomes of parent based on rank in the middle part of the other parent are arranged and inherit to a child.

1. Crossover operator

Mutation operator is designed and used with the aim of improving Diversification in the genetic algorithm. In this paper, shift mutation operator is applied. Figure 3 depicts the operator.

Two different mutation probabilities are used to improve this algorithm performance. The problem is started with a mutation probability and answers based on

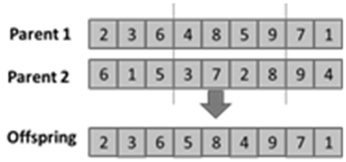

Fig. 2. A scheme of the twopoint crossover operator

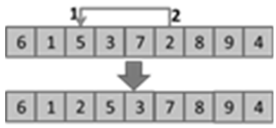

Fig. 3. A scheme of the shift mutation operator

GA improve. Then it is expected that the process of achieving better solutions is slow and algorithm tends to be converging. At this time aimed at the output of the algorithm from possible local optimum points and if the responses not improved within a specified number of generations, second mutation probability is applied. This action temporarily increases diversification and leads to the production of new responses. With the first improvement in the replies, the rate of first mutation probability is activated again. It causes that the algorithm while maintaining its convergence to have less chance of engaging in the local optimum points. Another important point is that by increasing mutation probability can lead to increase calculations and thus reduce the speed of the algorithm and reduce the quality of the final answer. Because in this algorithm, two mutation probabilities are intended, it can be reduced initial mutation probability as much as possible. It increases the speed of improving answers in early diversifications.

2.2. Optimization of Macpherson suspension by using GA

We use GA to minimize the objective function which includes ride and handling indexes (lateral speed and acceleration). This function is a real valued function of two variables and has many local minima and conflict objects making it difficult to optimize. In order to perform optimization using GA, objective function, variables and objective function constraints should be defined. Caster angle variations due to wheel oscillations can be optimized in a way that scrub is reduced and it is minimized at a specified height. For this purpose, lateral acceleration and velocity variation are expressed as objective function in GA. Figure 4 illustrates the GA performance in finding the tradeoff between ride and handling based on lateral acceleration variation. Also, the modeled vehicle is illustrated in Fig. 5 with suspension and steering systems.

In order to find the optimization results, SA with MATLAB linked to Carsim, and the results of optimization of suspension regarding two variables (based on lateral acceleration and lateral velocity as a variables) is presented in Fig. 3.

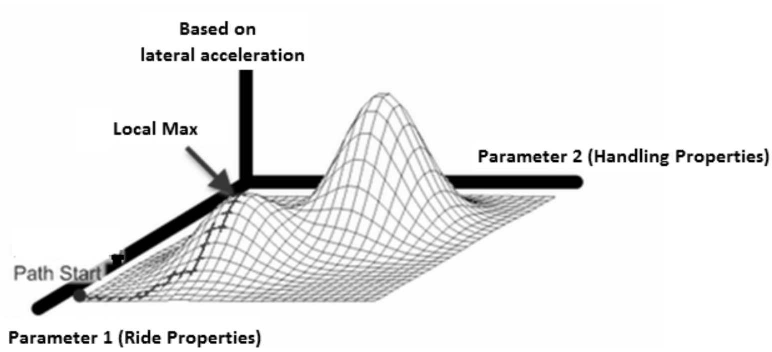

Fig. 4. SA procedure to enhance tradeoff between tow objectives

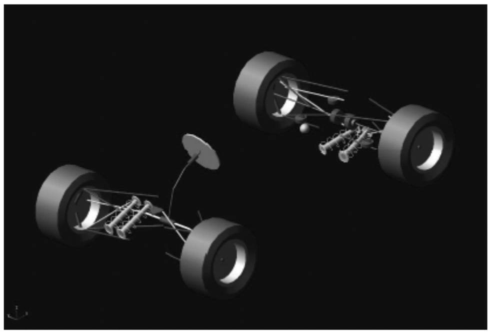

Fig. 5. Modeling of suspension system

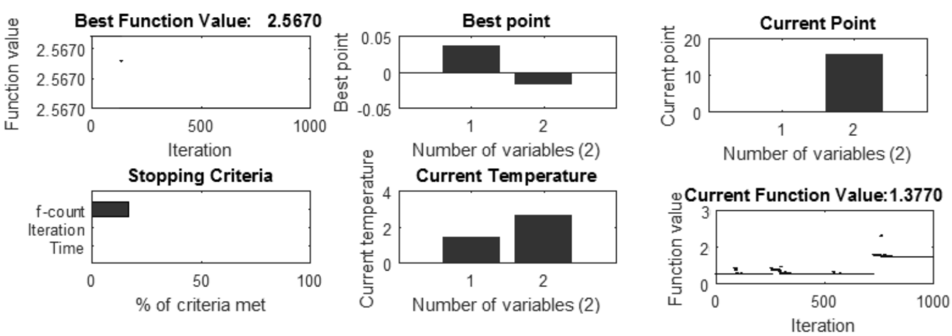

Fig. 6. Otimization results for combined function of ride and handling

3. Results and discussion

By modeling of whole of vehicle in CARSIM as shown in Fig. 2, simulation results with initial longitudinal speed of 30 m/s on a dry road during J-turn maneuver, lane-change, lateral deviation from objective path, acceleration, lateral and turning velocity are compared in Fig. 4 for system optimized with GA, system modified with trial and error method and unmodified suspension system.

It is clarified that the vehicle with unmodified suspension has considerable deviation over intended path. But, with improving suspension system and optimizing it by GA, objective path is traveled successfully with less deviation. By comparing path and vehicle position deviation in optimized suspension system with trial and error and GA methods, it can be observed that path follow is accurately conducted and optimized one GA can follow the path with mints lateral deviation.

As the results show, the optimized suspension system with GA represents the best response with respect to vehicle performance and follows the objective path with minimum deviation along with stability maintenance. The maximum speed and lateral deviation which should be minimized as vehicle stability variables are less than 1.4 m/s and 0.06 m, respectively. Also, maximum lateral acceleration is always lower than $6\,\mathrm{m/s^2}$ indicating suitable ride comfort and steering comfort of vehicle during intensive maneuvers.

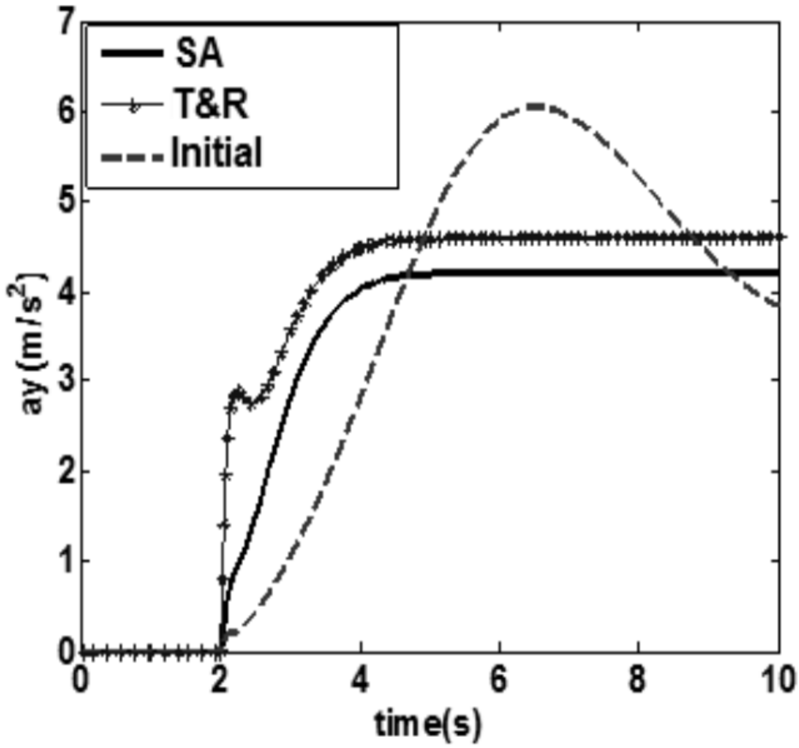

Fig. 7. J-turn maneuver: top left–path, top right–lateral deviation, bottom left–lateral velocity, bottom right–lateral acceleration

In addition, according to Fig. 4, two equivalent mechanisms with bump and roll inputs are modeled for optimized suspension system in order to sensitivity measurement of suspension parameters. The simulation results for state variables of vehicle such as turning speed, lateral speed and acceleration show that the optimized suspension system with GA obtains the best response regarding vehicle performance.

The maximum speed and lateral deviation which should be minimized as vehicle stability variables are less than 1 m/s and 0.08 m, respectively. Also, maximum lateral acceleration is always lower than 6 $\mathrm{m/s^2}$ indicating appropriate handling and steering comfort of vehicle during intensive maneuvers. However, lateral acceleration passes the threshold of 6 $\mathrm{m/s^2}$ in initial state that can be result in vehicle turnover.

4. Conclusion

In this paper, modeling of a double wishbone suspension system of an off-road vehicle is performed using CARSIM. Specifications of suspension system are optimized using GA aiming at minimizing camber angle variations. Moreover, sensitivity analysis and variations of parameters of suspension system resulted from bump and vehicle Roll inputs are presented for optimal case. In the next stage, simulation of vehicle motion during turning maneuver for vehicle parameters is conducted using comprehensive modeling of vehicle in CARSIM. The simulation results are compared in three stages for unmodified suspension system, modified suspension system with trial and error method and optimized suspension system with GA. The simulation results indicate that the suspension system type and its variables optimization including lateral velocity and acceleration reduction have considerable impact on ride comfort and handling and prevention of vehicle turnover through rapid speed tracks.

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