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A novel combination of Particle Swarm Optimization and Genetic Algorithm for Pareto optimal design of a five-degree of freedom vehicle vibration model

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ABSTRACT

In this paper, at first, a novel combination of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) is introduced. This hybrid algorithm uses the operators such as mutation, traditional or classical crossover, multiple-crossover, and PSO formula. The selection of these operators in each iteration for each particle or chromosome is based on a fuzzy probability. The performance of the proposed hybrid algorithm for solving both single and multi-objective optimization problems is challenged by using of some well-known benchmark problems. Obtained numerical results are compared with those of other optimization algorithms. At the end, the proposed multi-objective hybrid algorithm is used for the Pareto optimal design of a five-degree of freedom vehicle vibration model. The comparison of the obtained results with it in the literature demonstrates the superiority of this work.

1. Introduction

Vibration control of vehicles has attracted a great amount of research activities during the last decades. The vehicle motions are influenced by the harmful effects of vibration caused by engines and roads, which have a pivotal role in driver's comfort. Griffin et al. [1], Rakheja [2] and Barak [3] have shown that the interior vibration of a vehicle has a significant effect in comfort and road holding capability. In order to reduce this type of vibration, a suspension system could be installed between road excitation and the vehicle body. Bouazara [4] studied the influence of suspension system parameters on the vibration of the vehicle's model. Furthermore, Hrovat [5] used a three-dimensional vibration instead of the two-dimensional model to get more exact results. Crolla [6] applied a semi-active suspension model for improving the performance of the vehicle. Bouazara and Richard [7] presented their vibration model in three-dimensional space demonstrating that this model has a good estimation of the vehicle behavior. Moreover, Bouazara and Richard [8] studied three types of the suspension system (active, semi-active, and passive) for eight-degree of freedom vibration model. In that works, Bouazara combined all the performance criteria to an objective function, and he solved it as a single-objective optimization problem. For this purpose, he used weighting coefficients to adjust comfort and road holding capability criteria in a single-optimization design process. Gündogdu [9] presented an optimization for a four-degree of freedom quarter car seat and suspension system using Genetic Algorithms (GAs) to determine a set of parameters to achieve the best performance of the driver's seat. The desired objective was proposed as the minimization of a multi-objective function formed by the combination of not only suspension displacement and tire deflection but also the head acceleration and crest factor (CF), which is not practiced as usual by designers. Alkhatib et al. [10] applied GA to the optimization problem of a linear one-degree of freedom (1-DOF) vibration isolator mount, and the method was extended to the optimization of the linear quarter car suspension model. Nariman-zadeh et al. [11] introduced a new multi-objective uniform-diversity genetic algorithm (MUGA) with a diversity preserving mechanism for multi-objective optimization of a five-degree of freedom vehicle vibration model.

In fact, optimization is one of the problems, which has occupied the mind of a human being to itself from the past. The antiquity of optimization comes back to the year 300 B.C., when Euclid tried to find the minimum distance between a point and a line. Nowadays, it is no secret to anyone the wide application of optimization in

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different branches of science, engineering, industry and commerce. With the passing of time and the requirement to solve various optimization problems from the point of view of the number of objective functions, being constrained or unconstrained the problem and the time of solving the problem, optimization techniques have been undergone the change, too. In general, optimization algorithms are divided into two major categories, deterministic and stochastic [12]. Deterministic optimization algorithms use the strategy of successive search at the base of the derivative of the objective function. Hence, these techniques are proper for continuous, convex and differentiable objective functions. However, the most of the optimization problems are extremely non-linear, complex and non-differentiable. To optimize such problems, stochastic optimization methods play an important role. In recent decades, many researchers have returned their attention to stochastic methods such as evolutionary algorithms. GAs and Particle Swarm Optimization (PSO) that belong to the class of evolutionary algorithms are in the center of this attention.

On the other hand, evolutionary algorithms have some advantages and disadvantages in comparison with each other. Hence, it is impossible to be said that an especial algorithm can solve all optimization problems successfully. Thus, researchers use hybrid algorithms to solve the optimization problems. With these methods, two or some algorithms are combined to maintain the advantages of the used algorithms. Chen and Flan showed a better performance of a hybrid of GA and Simulated Annealing (SA) in comparison with pure GA or SA in solving optimization problems [13]. Furthermore, Elhaddad and Sallabi presented a hybrid of GA and SA algorithm to solve the Traveling Salesman Problem (TSP) [14]. Kaveh and Talatahari used a hybrid of PSO and Ant Colony Optimization (ACO) for design of frame structures [15].

In the present research, a new hybrid of PSO and GA operators is proposed. The used operators for the proposed algorithm consist of PSO formula, mutation and crossover from GA. The crossover operation consists of a classical crossover and a multiple-crossover. Selection of the PSO and GA operators in each iteration for each particle or chromosome is based on a novel fuzzy probability. The capability of this hybrid algorithm is evaluated in both classes of single and multi-objective problems. For reaching this aim, the proposed method is performed on some benchmark functions. The simulation results are presented and compared with the results of some other optimization algorithms applied to the same benchmark functions. The proposed multi-objective optimization algorithm makes use of the non-dominated sorting idea. Furthermore, two other mechanisms are added to the proposed algorithm so as to create a Pareto-optimal set having high convergence and uniform spread. The first mechanism uses a new leader selection technique based on the distribution density of solutions in the archive. The second mechanism presents a dynamic elimination technique to limit the number of non-dominated solutions.

Multiple-crossover GA was originally posed by Chen and Chang as a novel method [16]. They have used this algorithm for an especial case, to determine some parameters in a control problem. The crossover operator in the multiple-crossover GA uses three parent chromosomes unlike the classical crossover that uses only two chromosomes. In this work, the proposed hybrid algorithm uses both classical and multiple-crossover operators. It is mentionable that Elaoud et al. [17] have used the word of multiple-crossover GA for their proposed method, too. Their meaning of multiple-crossover is not the same as previously mentioned. Instead, they refer to the use of a dynamic selection scheme that can choose the best operators of crossover and mutation to be used at any given time in their GA.

Many researchers consider hybrid algorithms of PSO and GA. A complete list of hybrid algorithms is presented by Thangaraj et al. [18]. Refs. [19–23] show five works about the hybridization of PSO with GA that had presented in 2009 and 2010. Joeng et al. [19] presented a PSO/GA-hybrid algorithm and assayed its capability only by two multi-objective problems and compared their algorithm with a simple hybrid algorithm of PSO/GA, pure GA and pure PSO. Also, Valdez et al. proposed a hybrid algorithm of PSO and GA using fuzzy logic for decision making [20]. Firstly, they performed their proposed algorithm only for some single-objective benchmark problems. Secondly, they compared the proposed algorithm with pure GA and pure PSO, not any other algorithm. Bhuvaneswari et al. introduced a hybrid of GA and PSO for a case study and only compared the results with obtaining results from a traditional PSO [21]. Premalatha and Natarajan proposed discrete PSO with GA operators for document clustering and illustrated a graph comparing the results of the proposed algorithm and a simple PSO [22]. Abdel-Kader in [23] presented an algorithm combining GA, PSO and k-means for solving some clustering problems. Refs. [24,25] are two other works in the hybrid of PSO and GA that have been published in 2011. Ref. [24] proposed this hybrid algorithm using fuzzy logic. In this proposed method, fuzzy logic is used to combine the results of the PSO and GA. This method has been performed on some single-objective test functions for four different dimensions and has been compared with GA and PSO, separately. Ref. [25] also has tested its hybrid algorithm only for single-objective test functions.

In this paper, the proposed multi-objective hybrid algorithm is applied for multi-objective optimization of a five-degree of freedom vehicle vibration model. The conflicting objective functions that have been considered for minimization are set acceleration, forward tire velocity, rear tire velocity, relative displacement between sprung mass and forward tire, and relative displacement between sprung mass and forward tire. The design variables used in the optimization of vibration are seat damping coefficient, vehicle suspension damping coefficients, seat stiffness coefficient, vehicle suspension stiffness coefficients, and seat position in relation in relation to the center of mass. Various pairwise objectives are selected for two-objective optimization process. It is shown that a trade-off optimum design can be verified from those Pareto fronts obtained by the multi-objective optimization process. Furthermore, the superiority of time domain vibration performance of the proposed design points is shown in comparison with those given in the literature.

The rest of this paper is organized as follows. Section 2 gives a brief review on Genetic Algorithm and its operators. Section 3 presents the Particle Swarm Optimization algorithm. Section 4 describes the determination of probabilities for operators in details. In Section 5, single-objective and multi-objective optimization based on the proposed algorithm is illustrated. Furthermore, simulation results and comparison studies to verify the capability of the proposed method are shown in these sections. Moreover, this algorithm is implemented for multi-objective optimization of the vehicle vibration model in Section 6. Finally, Section 7 concludes the paper.

2. Genetic Algorithm (GA)

Genetic Algorithms belong to stochastic optimization methods and are used to solve search and optimization problems. John Holland introduced GA in 1975 with the inspiration of Darwin's theory about the survival of fittest [26]. One of the capabilities of stochastic algorithms is to work over a set of solutions instead of a single solution. Hence, GA produces a random set of solutions called initial population, at first. Each solution in a population is called a chromosome or an individual. The number of chromosomes in a population states the population size (N). This study uses a real-coded GA in which the solutions are applied as real values. A real-coded GA unlike the binary-coded GA does not have to spend a lot of time to