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A PSO-based adaptive fuzzy PID-controllers

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A B S T R A C T

In this paper, a novel design method for determining the optimal fuzzy PID-controller parameters of active automobile suspension system using the particle swarm optimization (PSO) reinforcement evolutionary algorithm is presented. This paper demonstrated in detail how to help the PSO with Q-learning cooperation method to search efficiently the optimal fuzzy-PID controller parameters of a suspension system. The design of a fuzzy system can be formulated as a search problem in high-dimensional space where each point represents a rule set, membership functions, and the corresponding system's behavior. In order to avoid obtaining the local optimum solution, we adopted a pure PSO global exploration method to search fuzzy-PID parameter. Later this paper explored the improved the limitation between suspension and tire deflection in active automobile suspension system with nonlinearity, which needs to be solved ride comfort and road holding ability problems, and so on. These studies presented many ideas to solve these existing problems, but they need much evolution time to obtain the solution. Motivated by above discussions this paper propose a novel algorithm which can decrease the number of evolution generation, and can also evolve the fuzzy system for obtaining a better performance.

1. Introduction

The optimality criteria methods are based on the derivation of appropriate optimality criteria for specialized design. Iterative numerical algorithms are then developed to find the design that satisfies the optimality criteria. This paper utilization fuzzy rule-based models are suitable when information about the physical process is vague and data available is scarce. However, a common bottleneck encountered is that the derivation of fuzzy control rules is often time-consuming and difficult and relies to a great extent on so-called process experts. An automated way to design fuzzy systems might be preferable. Therefore, more attention has been paid to the problem of how to construct a suitable rule base for a given task. The principle of multi-object optimization is reaching a compromise among conflicting objectives, rather than finding a single, globally optimal solution. Evolutionary programming is parallel to global search techniques that share the concepts of evolution theory and natural genetics. No a prior knowledge of the dynamics is assumed and no derivative or environment information is necessary. These various algorithms are similar in their basic concepts of evolution and differ mainly in their approach to parameter representation.

Particle swarm optimization (PSO) is a swarm intelligence technique developed by Kennedy and Eberhart [1], which was an algorithm for swarm intelligence based on stochastic and population-based adaptive optimization inspired by social behavior of bird flocks and fish swarms. Although the original PSO is very simple with only a few parameters to adjust, it provides better performance in computing speed, computing accuracy, and memory size compared with other methods such as

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machine learning, neural network learning, and genetic computation. Needless to say, each parameter in PSO greatly affects the performance of PSO. However, how to determine appropriate values of parameters in PSO is yet to be found. How to determine appropriate values of parameters in PSO can be regarded as level optimization. Hence many researchers have paid much attention to this challenging problem [2–4]. Recently, different hybrid PSOs have been proposed to overcome the drawback of trapping in the local optima. For example, an effective hybrid optimization strategy by incorporating the jumping property of simulated annealing (SA) into PSO, namely PSOSA, is proposed for estimating parameters of nonlinear systems [5]. A new hybrid gradient descent PSO, which is integrated with gradient information to achieve faster convergence without getting trapped in the local minima, is proposed by Noel and Jannett [6]. Juang [7] proposed a hybrid PSO algorithm named HGAPSO, which incorporates a GA's evolutionary operations of elite strategy, where the upper-half of the best-performing individuals in a population are regarded as elites. Huang and Mohan [8] proposed attempts to resolve performance due to the dimensionality of the problem and the location of the global optimum with respect to the boundaries of the search space by proposing a simple hybrid "damping" boundary condition that combines the characteristics offered by the existing "absorbing" and "reflecting" boundaries. For GA's, the solution space is more likely to be explored in the early stage of the search by setting a larger mutating space, and it combines the global search ability of particle swarm optimization with a synchronous local search heuristic for directed local fine-tuning. A new particle updating strategy is proposed based upon the concept of fuzzy global-best to deal with the problem of premature convergence and diversity maintenance within the swarm [9].

This paper is concerned with the development of adaptive fuzzy PID-controllers using PSO reinforcement evolutionary algorithm for finding the final trade-off in multiobjective optimization. However, the high speed of convergence in PSO often implies a rapid loss of diversity during the optimization process, which inevitably leads to undesirable premature convergence. Thus, the challenge in designing PSO hybrid evolutionary algorithm is to deal with the premature convergence without compromising the convergence speed. In most existing applications, the fuzzy rules are generated by experts in the area, especially for control problems with only a few inputs. With an increasing number of variables, the possible number of rules for the system increases exponentially, which makes it difficult for experts to define a complete rule set for good system performance. One disadvantage of designed fuzzy system is that the extracted rules are independent of the membership functions so there is no guarantee that the fuzzy system obtained will have sufficiently good performance, especially for a complex system problem with a large number of input variables. In many cases, however, the system's performance can be improved by further tuning the membership functions and selecting suitable fuzzification and defuzzification methods [10–13].

The vehicle is a complicated, nonlinear system with uncertainties of itself. And also operating conditions are changeable, e.g. the changes of road irregular excitation inputs with the variation of road surface roughness and of vehicle speed. So the control approaches for active suspensions based on the linear assumption of vehicle model have difficulties in practical application for good performance and robustness. Eski and Yıldırım [14] thought the main problem of vehicle vibration comes from road roughness. Therefore, they utilized a robust artificial neural network control system scheme for the control vibration of vehicle's suspension. In general, neural network-based robust control system is designed to control vibration of vehicle's suspensions for full suspension system. The control system consists of a robust controller, a neural controller, and a model neural network of vehicle's suspension system. In addition to neural network control scheme, Gulez and Guclu [15] proposed the dynamic behavior of a nonlinear eight degrees of freedom vehicle model having active suspensions and passenger seat controlled by a neural network controller is examined. A robust neural network structure is established by using principle design data from the Matlab diagrams of system functions. Cao et al. [16] proposed a novel scheme for the vehicle active suspension systems which integrates the Takagi–Sugeno fuzzy model, interval type-2 fuzzy reasoning, the Wu-Mendel uncertainty bound method, and selected optimization algorithms together to construct the switching routes between generated linear model control surfaces. However, for some practical systems including nonlinear elements, which cannot be expressed accurately in mathematics, the fuzzy logic control, has been proved to be one of the most efficient and systematic approaches to deal with such kinds of problems in that its control capability arises from emulating human logic instead of accurate mathematical model. Compared with conventional passive suspensions, active suspensions are very effective in improving vehicle ride comfort and handling stability. However, a key task for active suspension design is to determine a control law, which is capable of giving good system performance and better robustness. So we proposed adaptive fuzzy PID-controllers for automated way to design fuzzy systems which might be preferable of the active automobile suspension system controller. This paper deals with the design of fuzzy PID-controllers by using fixed triangular membership functions. The parameters of the considered controllers are then evaluated on the basis of PSO reinforcement evolutionary algorithm by using fitness functions associated with the system's performance indices – Integral of Absolute Error (IAE), Integral of Squared Error (ISE). The paper is organized as follows. Section 2 describes the hybridization of PSO and Q-learning concepts. Section 3 describes the methodology behind the design of the fuzzy PID-controller. Section 4 compares the application of the proposed method with other evolutionary algorithms. The conclusions are presented in Section 5.

2. The reinforcement evolutionary strategy

2.1. Adaptive particle swarm optimization

In the basic PSO technique proposed by Kennedy and Eberhart, a great number of particles move around in a multi-dimensional space, with each particle memorizing its position vector and velocity vector as well as the time at which it