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Parameter identification of nonlinear dynamic systems using an improved particle swarm optimization

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ABSTRACT

Particle swarm optimization (PSO) is a stochastic population-based algorithm motivated by intelligent collective behavior of birds. Currently, PSO has been widely used in optimization problems. It also can be used to identify the unknown parameters in a nonlinear system, if a parameter identification problem can be transformed into an optimization problem. This paper is concerned with solving the parameter identification problem for nonlinear dynamic systems through a novel social emotional particle swarm optimization (SEPSO), which is combined with social emotional model. The feasibility of this approach is demonstrated through application to parameters identification of manipulator control system. The performance of the proposed SEPSO is compared with genetic algorithm (GA) and standard particle swarm optimization (SPSO) in terms of parameter accuracy. It is illustrated in simulations that the proposed SEPSO is more successful than SPSO and GA. Hence, the proposed algorithm can also be applied to many other parameter identification and optimization problem.

1. Introduction

Parameter identification is the foundation of state estimation, controller design, diagnosis and fault detection, etc [1]. Many traditional parameter identification methods have been proposed in the past, just like least square method, maximum likelihood method, etc. However, efficient and accurate identification for complex nonlinear systems is still a hard nut to crack. With the development of the optimization theory, some new intelligent algorithms have been rapidly developed and widely used, such as genetic algorithm, ant colony algorithm, particle swarm algorithm and so on. The intelligent algorithms have become a new method to solve the traditional system identification problems. Unlike traditional identification methods whose applications are limited by the system model structures, the intelligent algorithms do not have strict requirements on that. It has been demonstrated that the applications of intelligent algorithms can bring about better performance or improved designs. There are several researches on applications of intelligent algorithms to parameters identification and control system design, such as [2–6].

The parameters identification method of nonlinear dynamic system which proposed in this paper is based on the particle swarm optimization (PSO) algorithm. PSO algorithm is one powerful and widely used swarm intelligence technique 19, and it is easy to implement. 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. Hence, it has received much more attention to solve optimization problems. In addition, parameter identification for nonlinear dynamic systems could be essentially formulated as a multi-dimensional optimization problem [7]. There have been numerous applications that apply PSO to parameter tuning or identification problems, such as [1,8,9]. It was shown that PSO is a feasible approach for parameter identification of nonlinear systems.

Motivated by the aforementioned researches, the objective of this paper is to present a novel algorithm based on particle swarm optimization for parameter identification of nonlinear dynamic systems. In the proposed algorithm, a social emotion particle swarm optimization (SEPSO), which is combined with the social emotion model, is introduced to achieve better solution accuracy and faster speed of convergence.

To evaluate its performance, the proposed approach is applied to identify four parameters of manipulator control system. This implementation will help the details and understanding of the proposed approach. It is illustrated in simulations the proposed SEPSO is more successful than genetic algorithm (GA) and standard particle swarm optimization (SPSO) in terms of parameter accuracy. Hence, the proposed approach is a promising particle swarm optimization algorithm for system parameters. In addition, it can also be applied to many other identification and optimization problems.

The remainder of this paper is organized as follows. Section 2 provides a brief introduction to the background of PSO and parameter identification based on it. In Section 3, the SEPSO is introduced which is combined with the social emotion model. Section 4 describes the details of parameter identification for manipulator system. Section 5 shows simulation results. Final conclusions are drawn in Section 6.

2. Background

2.1. Particle swarm optimization

Particle swarm optimization (PSO) is a biologically inspired evolutionary computation algorithm, which was first introduced by Kenndy and Eberhart. It is a population based on stochastic optimization technique inspired by the Boid model. The Boid Model was introduced by Reynolds in 1987, which was inspired by the aggregate motion of a flock of birds. In this model, the behavior of each individual was closely related to the best position of itself and the global best position. Moreover, the behaviors followed the three principles: Collision Avoidance, Velocity Matching and Flock Centering. Every bird of the swarm, in the initial state, flied to random position in all directions. As time goes on, these random birds formed a community by self-organization, and then the community formed a large population slowly, finally all birds tended to be consistent [10].

In PSO, the population is referred to as a swarm and an individual is called particle. Every particle in the population has two vectors: the position vector and the velocity vector, which represent respectively the potential solution of the problem and the direction in the search space. PSO remembers both the best position found by all particles and that by each particle in the search process. The particle moves in a multidimensional search space by updating velocity and position to achieve the global optimal solution. The velocity vector and the position vector of each particle can be updated iteration by iteration according to the following two formulas:

$$v_i(k+1) = \omega v_i(k) + c_1 r_1 (\boldsymbol{Pbest}_i - x_i(k)) + c_2 r_2 (\boldsymbol{Gbest} - x_i(k)) \tag{1}$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \tag{2}$$

where $v_i(k)$ and $x_i(k)$ are the velocity and position of particle i at iteration k; $\boldsymbol{Pbest}_i$ is the position with the best fitness value searched so far by particle i; $\boldsymbol{Gbest}$ is the global best position. $r_1, r_2 \in (0, 1)$ are random numbers between 0 and 1; c_1 and c_2 are positive constant parameters which called acceleration coefficients. ω represents the inertia weight.

From the updating rules and the flow chart, it can be seen that PSO algorithm make the swarm to achieve optimal by collaboration between the particles. Although the code of each particle is very simple, the behavior of the whole swarm is complicated. Therefore, the PSO algorithm is simple and easy to implement, and has a profound background of intelligence. It can be used for both scientific research and engineering application.

2.2. Particle swarm optimization based parameter identification

Fig. 1 illustrates the Block diagram of the PSO based identification approach. $u(t)$ is the input of the system for parameter identification. The real system and its simulated model have the same initial conditions and inputs. The inputs to a performance evaluator are the output of the simulated model $\hat{y}(t)$ and measurement $y(t)$ of real system. The evaluator calculates the fitness of the tentative solution according to an identification criterion. If the fitness do not satisfied the evaluation criterion, the PSO based identifier can update the parameters by updating the best positions of particles to achieve better solutions. Then the new parameters $\hat{p}$ will be used to update the systems simulated model for next iteration of optimization till the maximum number of iterations has been accomplished or the fitness satisfied the identification criterion [1].