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Bacterial foraging optimization algorithm to improve a discrete-time neural second order sliding mode controller

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ABSTRACT

This paper deals with design parameter selection of a discrete-time neural second order sliding mode controller for unknown nonlinear systems, based on bacterial foraging optimization. First, a neural identifier is proposed in order to obtain a mathematical model for the unknown discrete-time nonlinear systems, then a novel second order sliding mode controller is proposed. Finally, both, the neural identifier and the controller are optimized using bacterial foraging algorithm. In order to illustrate the applicability of the proposed scheme, simulation results are included for a Van der Pol oscillator.

1. Introduction

To cope with various search problems in complex systems of real world, scientists have been inspired by nature for years, both as a model and as metaphor. Optimization is the core of many natural processes and the behavior of social groups of insects, birds and foraging strategy of microbial creatures. Natural selection tends to eliminate the species with poor feeding strategies to promote the spread of genes of the species with successful foraging behavior. Since a foraging of animal body, takes the necessary steps to maximize the energy used per unit of time spent foraging, taking into account all the limitations of their own physiology as detection and cognitive abilities, the environment, the search strategy of natural food, can lead to optimization and, essentially, this idea can be applied to optimization problems of the real world [3,5,6].

Recently, several swarm intelligence algorithms have been proposed, such as Ant Colony Optimization (ACO) [10], Particle Swarm Optimization (PSO) [2,16,20,32] Artificial bee colony (ABC) [14] and Bacterial Foraging Optimization (BFO) [26]. The BFO algorithm was first proposed in 2002 by Passino. It is inspired by the foraging behavior and chemotactic bacteria, especially *Escherichia coli* in our intestine (*E. coli*). By running smooth and tumbling, it can be moved to the escape area of nutrients and poison zone in the environment. Chemotaxis is more attractive behavior of bacteria, and it has been studied by many researchers [3,7,9].

The social behavior of the colony of *E. coli* is very interesting for engineering, due to their group response, since it allows them to get quickly and easily the best food supply with the lowest possible risk. These bacteria can communicate through chemical exchanges. The bacteria that have achieved a safe place to feed, communicate it to others who come to such place, while more food exists, the signal is stronger. Similarly, if the bacteria are in a dangerous place, with agents that may threaten the colony, they warn others to stay away from that place. This behavior can be represented mathematically forage as a kind of swarm intelligence [3]. It has attracted significant attention from researchers, and has been used in several areas of control application such as design of multiple optimal power system stabilizers [8] and optimization of active power filters for load compensation [24]. It has been

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shown that BFO is able to find the optimum value and avoid being trapped in the local optima. In the optimization process, besides its ability to locate the optimum value, the convergence speed of BFO is also considered [30].

On the other hand, different approaches can be taken for real-time implementations of control systems using digital devices. One is to obtain a continuous-time system model and then, synthesize a continuous-time controller using well established methodologies, and then discretize it. Another way is to obtain a discrete-time system model directly by identification or by integration in time of a continuous-time model, and then synthesize a discrete-time controller, which can be implemented digitally [1]. Sliding mode control is principally characterized by its robustness with respect to the system's modeling uncertainties and external disturbances. However, the application of this kind of control law is confronted to a serious problem: chattering. Owing to the many advantages of the digital control strategy, the discretization of the sliding mode control (SMC) has become an interesting research field. Unfortunately, the chattering phenomenon is more obvious in this case, because the sampling rate is smaller [22,23]. In this way, many approaches have been suggested in order to solve this problem. In the eighties, a new control technique, called high order sliding mode control, have been investigated. Its main idea is to reduce to zero, not only the sliding function, but also its high order derivatives [23]. This approach allows to reduce the oscillations amplitude, besides, the outstanding sliding mode system's robustness remains intact [18].

However, although this kind of control is robust to external disturbances [23], it requires the previous knowledge of a nominal system model. To overcome this requirement in this work we propose the use of a neural identifier that provides a mathematical model for the system to be controlled. In this sense it is well-known that Artificial Neural Networks (ANN) exhibit interesting properties as: adaptability, learning capability, and ability to generalize. Due to these properties ANN have been established as an excellent methodology as exemplified by their applications to identification and control of nonlinear and complex systems [12]. However training ANN is a complex task of great importance in the supervised learning topic; particularly for real-life complex problems which require the integration of several of soft computing methodologies to really achieve the efficiency and accuracy needed in practice [4,6,17,20,21]. The best well-known training approach for recurrent neural networks (RNN) is the back propagation through time learning [28]. However, it is a first order gradient descent method and hence its learning speed could be very slow [28]. In past years the Extended Kalman Filter (EKF) based algorithms has been introduced to train neural networks, in order to improve the learning convergence [28]. Besides it has proven to be reliable and practical for many applications [28]. However, EKF training usually requires the heuristic selection of some design parameters which not always is an easy task [1,2].

Therefore, in this paper various nonlinear techniques are combined in order to develop a second order sliding mode controller for discrete-time unknown MIMO nonlinear systems which can include both, external and internal disturbances and does not require the previous knowledge of a nominal model; to achieve this goal it is necessary to combine high order sliding mode technique with neural identification and an on-line learning algorithm based on an extended Kalman filter. This controller requires a suitable selection of design parameters for control law as well as for learning algorithm, typically, such parameters are heuristically selected, however in this paper an approach based on BFO is proposed to do an automatic selection of such parameters, resulting in a significant improvement for the controller development. Combining the above mentioned nonlinear techniques with a bio-inspired optimization one.

The paper's main contribution can be described as follows: first a discrete-time second order sliding mode controller is developed for MIMO nonlinear systems; then the controller design is extended for MIMO unknown nonlinear systems, based on a neural identifier designed with a Recurrent High Order Neural Networks (RHONN), trained on-line with an EKF-based algorithm and finally the controller development is improved using a BFO approach by adapting control law and learning parameters instead of using a heuristic selection.

The remains of this paper is organized as follows: In Section 3 a discrete-time neural identifier is presented using the EKF learning algorithm and the BFO technique; in Section 4, the controller design is proposed; in order to show the effectiveness of the proposed scheme, Section 5 includes simulation results for a Van der Pol Oscillator, without the previous knowledge of the parameters, under the presence of unknown disturbances as parametric variations; finally some important conclusions are reported in Section 5.

2. Discrete-time neural identifier

The use of ANN is well known for pattern recognition and for modeling of static systems. The NN is trained to learn an input–output map. Theoretical works have proven that, even with just one hidden layer, NN can uniformly approximate any continuous function over a compact domain, provided that the NN has a sufficient number of synaptic connections.

For control tasks, extensions of the first order Hopfield model called Recurrent High Order Neural Networks (RHONN), which present more interactions among the neurons, are proposed in [27]. Additionally, the RHONN model is very flexible and allows to incorporate to the neural model a priory information about the system structure.

Consider a MIMO nonlinear system:

$$x(k+1) = F(x(k), u(k)) \tag{1}$$

where $x \in \Re^n$, $u \in \Re^m$, and $F \in \Re^n \times \Re^m \to \Re^n$ is a nonlinear function. And the following discrete-time recurrent high order neural network (RHONN):

$$x_i(k+1) = w_i^\top z_i(x(k), \varrho(k)), \quad i = 1, \ldots, n \tag{2}$$