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Designing fuzzy rule base using Spider Monkey Optimization Algorithm in cooperative framework

Joydip Dhar [a,*], Surbhi Arora [b]

[a] *Department of Applied Sciences, ABV-Indian Institute of Technology & Management Gwalior, Morena Link Road, Gwalior, 474015, India*
[b] *ABV-Indian Institute of Technology & Management Gwalior, Morena Link Road, Gwalior, 474015, India*

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Abstract

The paper focusses on the implementation of cooperative Spider Monkey Optimization Algorithm (SMO) to design and optimize the fuzzy rule base. Spider Monkey Optimization Algorithm is a fission-fusion based Swarm Intelligence algorithm. Cooperative Spider Monkey Algorithm is an off-line algorithm used to optimize all the free parameters in a fuzzy rule base. The Spider Monkeys are divided into various groups the solution from each group represents a fuzzy rule. These groups work in a cooperative way to design the whole fuzzy rule base. Simulation on fuzzy rules of two nonlinear controllers is done with a parametric study to verify the performance of the algorithm. It is observed that the root mean square error (RMSE) is least in the case of SMO than the other evolutionary algorithms applied in the literature to solve the problem of fuzzy rule designs like Particle Swarm Optimization (PSO), Ant Colony Optimization algorithm (ACO) algorithms.

Keywords: Evolutionary algorithm; SMO; Fuzzy system

1. Introduction

In the past two decades, many bio-inspired algorithms like genetic algorithms and Swarm Intelligence algorithms have been applied to optimize the fuzzy rule-based design [1–6]. Swarm Intelligence Algorithms such as Particle Swarm Intelligence Algorithms have proved themselves superior in optimizing the fuzzy rule base design. These algorithms draw inspiration from nature, i.e., they optimize the solutions by mimicking the behavior of animals such as birds, ants, etc. foraging for food.

Many advanced implementations of these algorithms have studied in the literature, one of them is swarm implementation that uses multiple swarms, optimizing different components of a solution vector and working in a cooperative framework to optimize the function. Different ideas to utilize these algorithms to solve the problem of fuzzy system design have been proposed in literature such as hierarchical cluster-based multispecies particle swarm optimization algorithm (HCMPSO) [1]. Again, cooperative continuous ant colony optimization algorithm (CCACO) [4], that uses ant colony optimization in continuous domain [5] and the other modifications of ACO [6], have proposed and analyzed by Refs. [7–9].

Recent years a Spider Monkey Optimization (SMO) algorithm in the cooperative framework is proposed [10]. It is a fission-fusion based algorithm that mimics the social behavior of spider monkeys as they forage for food [11]. The food searching of spider monkeys in groups is led by a female monkey. If the group leader is not able to find food for the group, it divides the group into multiple subgroups each lead by their own subgroup leader. These subgroups now forage independently for the food. Subgroups also communicate with each other to exchange information about food and territorial boundaries.

* Corresponding author.
E-mail address: jdhar.iiitmg@gmail.com (J. Dhar).
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Multiple groups of spider monkeys have been used to optimize the fuzzy rules with each group tuning a single fuzzy rule. Spider monkeys of all groups optimize a solution vector with respect to the free parameters of the fuzzy rule. All groups exchange the information of the local leader of the other groups to optimize their solution vector. The cooperative framework similar has been used in the literature to solve different problems [12–17].

Motivated from the SMO algorithm in cooperative framework [10], we develop an application of SMO in designing a fuzzy rule base. This paper is organized as follows: section 2 deals with the description of fuzzy systems to be optimized. Section 3 introduces spider monkey algorithm in a cooperative framework. The results and discussions on parametric settings through simulation are presented in section 4 and finally section 5 presents the conclusions.

2. Fuzzy control systems

The paper addresses the problem of accuracy-oriented fuzzy rule design. In Ref. [12] the researchers have described the mathematical model of the fuzzy system used in the problem, i.e., Tagaki-Sugeno-Kang (TSK) Fuzzy system. The rules in TSK fuzzy systems are:
Rule$_i$ *: If* $x_1(k)$ *is* A_{i1} *And .... And* $x_n(k)$ *is* A_{in}*, Then* $u(k)$ *is* $f_i(x_1, , x_n)$.
Where $x_i(k)$ are the input variables, k is the time step, A_{ij} are the fuzzy sets defined by a Gaussian function as:

$$M_{ij} = exp\left\{ -\left(\frac{x_j - m_{ij}}{b_{ij}}\right)^2 \right\}, \tag{1}$$

where m_{ij} and b_{ij} represent the center and width of the fuzzy set A_{ij}, respectively.

The function in consequent part is defined as, the zero-order TSK systems:

$$f_i(x_1, \ldots, x_n) = a_{i0}, \tag{2}$$

and for first-order TSK systems:

$$f_i(x_1, \ldots, x_n) = a_{i0} + \sum_{j=1}^{n} a_{ij} x_j. \tag{3}$$

The number of rules defined in the fuzzy rule base gives the number of groups of Spider monkeys needed to optimize the problem. A fuzzy system with r given rules, r groups of spider monkeys would be applied to optimize the rules with each group, adjusting the free parameters m_{ij}, b_{ij}, and a_{ij} of the rule.

The solution vector of each Spider monkey optimizing a zero-order TSK system can be represented as:

$$\overrightarrow{s} = [m_{i1}, b_{i1}, \ldots, m_{in}, b_{in}, a_{i0}] \varepsilon\, \Re^{2n+1},$$

and the solution vector of the spider monkey optimizing a first-order TSK system is represented as:

$$\overrightarrow{s} = [m_{i1}, b_{i1}, \ldots, m_{in}, b_{in}, a_{i0}, .., a_{in}] \varepsilon\, \Re^{2n+1}.$$

In the inference engine, the fuzzy AND operation are implemented by the algebraic product in fuzzy theory. Thus, given an input data set $\overrightarrow{x} = (x_1, x_2 \ldots, x_n)$, the firing strength $\phi_i(\overrightarrow{x})$ of rule i is calculated by

$$\phi_i(\overrightarrow{x}) = \prod_{j=1}^{n} M_{ij}(x_j) = exp\left\{ -\sum_{j=1}^{n} \left(\frac{x_j - m_{ij}}{b_{ij}}\right) \right\}.$$

If there are r rules in a fuzzy system, the output of the system that is calculated by the weighted average defuzzification method:

$$u = \frac{\sum_{i=1}^{r} \phi_i(\overrightarrow{x}) f_i}{\sum_{i=1}^{r} \phi_i(\overrightarrow{x})}.$$

The next section describes the phases of SMO algorithm and its implementation in the cooperative framework to design the fuzzy rule system.

3. Spider Monkey Optimization Algorithm in cooperative framework

The SMO is based on fission-fusion characteristic of spider monkeys while they forage for their food. This study would map the two algorithms by applying SMO on the problem of accuracy-oriented fuzzy rule design that has already been solved using a modified version of ACO (CCACO) and do a parametric study on it. The study would further deal with modifications of SMO, i.e., steady state update of local and global leader, refinement in local leader decision phase and re-initialization of monkeys in each iteration to improve the accuracy of the optimizing algorithm.

3.1. Spider Monkey Optimization Algorithm

The spider monkey algorithm has been proved equally competitive in solving the problems of numerical optimization by the researchers [10,11]. The spider monkeys forage for food following a fission-fusion based social structure. The foraging behavior can be divided into four steps [10]:

1. The monkeys forage for food in a group of 40–50 members lead by a group leader (female monkey).
2. If the group leader is not able to find sufficient food for all the group members, she divides the group into subgroups consisting of 3–8 monkeys to reduce the competition. These groups now search for food independently.
3. Each subgroup is lead by a female monkey who is a local group leader. She is responsible for taking all the decisions for that subgroup.
4. Subgroups communicate with each other to exchange the information about availability of food and territorial boundaries.

In SMO algorithm, a group of spider monkeys is used to optimize the given function. Each spider monkey has its solution vector according to the fuzzy system designed as stated