Information Sciences 294 (2015) 203–215

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

New approach using ant colony optimization with ant set partition for fuzzy control design applied to the ball and beam system

Oscar Castillo *, Evelia Lizárraga, Jose Soria, Patricia Melin, Fevrier Valdez

Tijuana Institute of Technology, Tijuana, Mexico

ARTICLE INFO

Article history:
Received 20 May 2013
Received in revised form 10 September 2014
Accepted 24 September 2014
Available online 2 October 2014

Keywords:
Ant colony optimization
Fuzzy logic
Fuzzy control design

ABSTRACT

In this paper we describe the design of a fuzzy logic controller for the ball and beam system using a modified Ant Colony Optimization (ACO) method for optimizing the type of membership functions, the parameters of the membership functions and the fuzzy rules. This is achieved by applying a systematic and hierarchical optimization approach modifying the conventional ACO algorithm using an ant set partition strategy. The simulation results show that the proposed algorithm achieves better results than the classical ACO algorithm for the design of the fuzzy controller.

1. Introduction

Recently it has been shown that fuzzy logic controllers (FLC) provide a good alternative to conventional control systems [3,16,34]. However, a FLC must be designed specifically for a given system; that is, its parameters must be adjusted *ad hoc*. This adjustment is usually performed “manually” or by trial and error [21]. Since this usually takes a lot of time for an FLC designer, several bio-inspired and evolutionary techniques have been proposed for this purpose, such as: Genetic Algorithms (GAs) [2], Particle Swarm Optimization (PSO) [10] and Ant Colony Optimization (ACO) [9], among others; the latter approach being the one that is considered in this paper.

ACO algorithms have been successfully applied to versatile combinational optimization problems, namely vehicle routing [23], quadratic assignment problem (QAP) [32], job-shop scheduling [13], the TSP problem [31] and the ball and beam system [22]. The former being our case of study which is an important and classic laboratory model for teaching engineering and control systems in the research area. Because it is a simple and easy to understand system, it can be used to study many classic and modern design methods in control engineering as it has a very interesting property for the control engineer: it is unstable in open loop.

In this paper we describe the proposed methodology to design a fuzzy system using a new approach based on the ACO metaheuristic. The proposed algorithm modifies the classical ACO algorithm, i.e. a new modification of the algorithm has been proposed to improve the efficiency and accuracy. To explain this in more detail, the proposed algorithm is viewed as a series of steps that are performed hierarchically and sequentially, allowing a faster optimization and better results, compared with the classical ACO algorithm [1].

---

* Corresponding author.
E-mail address: ocastillo@tectijuana.mx (O. Castillo).

http://dx.doi.org/10.1016/j.ins.2014.09.040

The proposed algorithm performs the overall optimization by dividing the total number of ants, equivalently, among the five main ACO variants [26,29]: Ant System (AS), Elitist Ant System (EAS), Rank Based Ant System (ASRank), Man-Min Ant System (MMAS), Ant Colony System (ACS). To improve the performance of the proposed method a stagnation mechanism was added that would stop a particular variant that is not producing optimal results. This approach has been applied previously for the Traveling Salesman Problem (TSP) providing satisfactory results [19,24]. In other works, several ACO variants have been tried simultaneously [3,13], but not for designing fuzzy controllers and with the ant set partition strategy, which is the proposed contribution in this paper.

We performed several experiments applying the proposed method to the ball and beam problem, whose objective is to stabilize the balance of the ball using a fuzzy logic controller to determine the new position of the ball according the angle of the beam [22]. The proposed ACO algorithm optimizes the type of membership functions, parameters of the membership functions and fuzzy rules of the FLC.

In Naredo and Castillo [22] the same 5 variants of ACO were applied in an individual fashion to design fuzzy controllers for the ball and beam problem and at the end one of the variants was selected as the best one for this benchmark control problem. In particular the AS variant was determined to be the best one for this problem. In the present paper we are now considering the use of the 5 variants simultaneously to improve the performance with the ant set partition strategy and its application to the ball and beam benchmark problem.

Chang et al. [3] proposed an algorithm with the capability to update the pheromone, adaptive parameter tuning, and mechanism resetting. The proposed method is utilized to tune the parameters of the fuzzy controller for a real beam and ball system. The control of the ball and beam system is decoupled into two subsystems, the position control of ball and the balance control of beam. Two unique fuzzy control strategies are utilized to balance the beam and to keep the ball in the designated position. The proposed fuzzy ACO optimized control scheme contains a fuzzy beam-balance controller, a fuzzy ball-position controller, and the fuzzy ACO tuning mechanism.

Other related work is the one by Martinez et al. [20] in which both ACO and genetic algorithms (GAs) are compared for fuzzy controller design showing that ACO could outperform GAs in this kind of problems. However, the benchmark control problem is not the ball and beam and no direct comparison of results could be made with the work presented in this paper. We have to say that only the simple ACO was used in the work presented in [14] and no modification of the ACO was proposed.

This paper is organized as follows. Section 2 describes the basic concepts of ant colony optimization. Section 3 details the proposed approach of ant partition and the problem of graphic representation. Section 4 describes the Ball and Beam system and the fuzzy logic controller to stabilize the system. Section 5 shows the simulations results. Section 6 presents a statistical test for the proposed approach. In Section 7, a conclusion of this study is presented.

2. Basic concepts of ant colony optimization

Proposed as an ant colony analogy by Dorigo in 1990s [9], ACO is defined biologically speaking by ants who aim to find food visiting potential food places. To communicate, ants use stigmergy, which is a biological mechanism that can transmit information through the environment by using pheromones exuded by ants. Artificially speaking, each ant is a possible solution to a problem, where the set of possible solutions is represented as a graph [5–8].

In the ACO algorithm an ant k visits each node. To select the next node j, a stochastic probabilistic rule (1) is applied, which is determined by using information of the amount of pheromone τ_{ij} in node i, within a feasible neighborhood N_i^k,

$$p_{ij}^k(t) = \begin{cases} \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}]^\beta}{\sum_{l \in N_i^k} [\tau_{il}(t)]^\alpha [\eta_{il}]^\beta} & \text{if } j \in N_i^k \\ 0 & \text{otherwise} \end{cases}. \tag{1}$$

The heuristic information η_{ij} is provided by the Root Mean Squared Error (RMSE) given by:

$$RMSE = \sqrt{\frac{1}{N}\sum_{q=1}^{N}(u_q - \tilde{u}_q)^2}, \tag{2}$$

where $\hat{u}$ is the control signal, u the reference and N the number of observed points, and the parameters α and β are the relative weights of pheromone and heuristic information, respectively.

Once the path is constructed it will be evaluated to determine the cost of the path. Depending on the cost of the path is the amount of pheromone $\Delta\tau_{ij}$ that an ant will deposit on the node (3). The better the path, the larger the amount of pheromone that will be deposited by the ants and this is represented by:

$$\tau_{ij} = \rho\tau_{ij} + \Delta\tau_{ij}, \tag{3}$$

where ρ is a parameter that represents the evaporation coefficient, $0 < \rho < 1$.

The algorithm terminates when the path created by each ant has been evaluated.

The general steps of the basic ACO algorithm are the following [11,12]: