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Comparative study of bio-inspired algorithms applied to the optimization of type-1 and type-2 fuzzy controllers for an autonomous mobile robot

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ABSTRACT

In this paper we describe the application of Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) on the optimization of the membership functions' parameters of a fuzzy logic controller (FLC) in order to find the optimal intelligent controller for an autonomous wheeled mobile robot. The results obtained by the simulations performed are statistically compared among them and the previous work results obtained with GAs in order to find which is the best optimization technique for this particular robotics problem.

1. Introduction

Nowadays, fuzzy logic is one of the most used methods of computational intelligence and with the best future; this is possible thanks to the efficiency and simplicity of fuzzy systems since they use linguistic terms similar to those that human beings use [18]. We consider in this paper not only type-1 fuzzy logic, but also type-2 fuzzy logic for controlling the autonomous robot [10,15]

The complexity in developing fuzzy systems can be found at the time of deciding which are the best parameters of the membership functions, the number of rules or even the best granularity that could give us the best solution for the problem that we want to solve [2].

A solution for the above mentioned problem is the application of bio-inspired algorithms for the optimization of fuzzy systems. Optimization algorithms can be a useful tool due to their capabilities of solving nonlinear problems, well-constrained or even NP-hard problems. Among the most used optimization methods we can find [7]: genetic algorithms (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), etc.

This paper describes the application of ACO and PSO as optimization methods for the parameters of the membership functions of the FLC in order to find the best possible intelligent controller for an autonomous wheeled mobile robot and making a statistical comparison of the techniques and with respect to previous results using genetic algorithms [11].

This paper is organized as follows: Section 2 shows the basic concepts of ACO and PSO and a description of S-ACO and gbest algorithms respectively, which is the technique that was applied for optimization. Section 3 presents the problem statement and the dynamic and kinematic model of the unicycle mobile robot. Section 4 shows the fuzzy logic controller proposed and in Section 5 the development of the optimization methods is described. In Section 6 the simulation results are shown. Section 7 describes the statistical results for the comparison of the optimization methods Finally, Section 8 shows the conclusions.

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2. S-ACO and gbest PSO algorithms

This section describes the theoretical basis of the algorithms applied in this research. The algorithms we used were the simplest versions of ACO and PSO, respectively.

2.1. S-ACO algorithm

ACO is a probabilistic technique that can be used for solving problems that can be reduced to finding good paths along graphs. This method is inspired on the behavior presented by ants in finding paths from the nest or colony to the food source [3].

The S-ACO is an algorithmic implementation that adapts the behavior of real ants to solutions of minimum cost path problems on graphs [12]. A number of artificial ants build solutions for a certain optimization problem and exchange information about the quality of these solutions making allusion to the communication system of real ants [4].

Let us define the graph $G = (V, E)$, where V is the set of nodes and E is the matrix of the links between nodes. G has $n_G = |V|$ nodes. Let us define L^K as the number of hops in the path built by the ant k from the origin node to the destiny node. Therefore, it is necessary to find:

$$Q = \{q_a, \ldots, q_f | q_1 \in C\}, \tag{1}$$

where Q is the set of nodes representing a continuous path with no obstacles; $q_a, \ldots, q_f$ are former nodes of the path and C is the set of possible configurations of the free space. If $x^k(t)$ denotes a Q solution in time t, $f(x^k(t))$ expresses the quality of the solution. The S-ACO algorithm is based on Eqs. (2)–(4):

$$p_{ij}^k(t) = \begin{cases} \frac{\tau_{ij}^k}{\sum_{j \in N_{ij}^k} \tau_{ij}^{\alpha}(t)} & \text{if } j \in N_i^k, \\ 0 & \text{if } j \notin N_i^k, \end{cases} \tag{2}$$

$$\tau_{ij}(t) \leftarrow (1 - \rho)\tau_{ij}(t), \tag{3}$$

$$\tau_{ij}(t+1) = \tau_{ij}(t) + \sum_{k=1}^{n_k} \tau_{ij}(t). \tag{4}$$

Eq. (2) represents the probability for an ant k located on a node i selects the next node denoted by j, where, N_i^k is the set of feasible nodes (in a neighborhood) connected to node i with respect to ant k, τ_{ij} is the total pheromone concentration of link ij, and α is a positive constant used as a gain for the pheromone influence.

Eq. (3) represents the evaporation pheromone update, where $\rho \in [0, 1]$ is the evaporation rate value of the pheromone trail. The evaporation is added to the algorithm in order to force the exploration of the ants, and avoid premature convergence to sub-optimal solutions [12]. For $\rho = 1$ the search becomes completely random [12].

Eq. (4) represents the concentration pheromone update, where $\Delta\tau_{ij}^k$ is the amount of pheromone that an ant k deposits in a link ij in a time t.

The general steps of S-ACO are the following:

1. Set a pheromone concentration τ_{ij} to each link (i,j).
2. Place a number $k = 1, 2, \ldots, n_k$ in the nest.
3. Iteratively build a path to the food source (destiny node), using Eq. (2) for every ant.
   - Remove cycles and compute each route weight $f(x^k(t))$. A cycle could be generated when there are no feasible candidates nodes, that is, for any i and any k, $N_i^k = \emptyset$; then the predecessor of that node is included as a former node of the path.
4. Apply evaporation using Eq. (3).
5. Update of the pheromone concentration using Eq. (4)
6. Finally, finish the algorithm in any of the three different ways:
   - When a maximum number of epochs has been reached.
   - When it has been found an acceptable solution, with $f(x_k(t)) < \varepsilon$.
   - When all ants follow the same path.

2.2. gbest PSO algorithm

PSO is a stochastic optimization technique based on population inspired in the social behavior of big masses of birds, fish or bees [6].

In PSO, the potential solutions (called particles), fly trough the space problem, where the less optimum particles fly to optimum particles, doing this iteratively until all the particles converge at the same point (solution). To achieve convergence, PSO applies two types of knowledge, personal experience or *cognitive component*, which is the experience that every particle