Expert Systems with Applications 40 (2013) 3185–3195

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

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

Optimal design of type-2 and type-1 fuzzy tracking controllers for autonomous mobile robots under perturbed torques using a new chemical optimization paradigm

Patricia Melin, Leslie Astudillo, Oscar Castillo *, Fevrier Valdez, Mario Garcia

Tijuana Institute of Technology, Tijuana, Mexico

ARTICLE INFO

Keywords:
Type-2 fuzzy control
Chemical optimization
Robotics

ABSTRACT

This paper addresses the tracking problem for the dynamic model of a unicycle mobile robot. A novel optimization method inspired on the chemical reactions is applied to solve this motion problem by integrating a kinematic and a torque controller based on fuzzy logic theory. Computer simulations are presented confirming that this optimization paradigm is able to outperform other optimization techniques applied to this particular robot application.

1. Introduction

Optimization is an activity carried out in almost every aspect of our life, from planning the best route in our way back home from work to more sophisticated approximations at the stock market, or the parameter optimization for a wave solder process used in a printed circuit board assembly manufacturer optimization theory has gained importance over the last decades. From science to applied engineering (to name a few), there is always something to optimize and of course, more than one way to do it.

In a generic definition, we may say that optimization aims to find the "best" available solution among a set of potential solutions in a defined search space. For almost every problem exists a solution, not necessarily the best, but we can always find an approximation to the "ideal solution", and while in some cases or processes is still common to use our own experience to qualify a process, a part of the research community have dedicated a considerably amount of time and efforts to help find robust optimization methods for optima finding in a vast range of applications.

It has been stated the difficulty to solve different problems by applying the same methodology, and even the most robust optimization approaches may be outperformed by other optimization techniques depending on the problem to solve.

When the complexity and the dimension of the search space make a problem unsolvable by a deterministic algorithm, probabilistic algorithms deal with this problem by going through a diverse set of possible solutions or candidate solutions. Many metaheuristic algorithms can be considered probabilistic, while they apply probability tools to solve a problem, metaheuristic algorithms seek good solutions by mimicking natural processes or paradigms. Most of these novel optimization paradigms inspired by nature were conceived by merely observation of an existing process and their main characteristics were embodied as computational algorithms.

The importance of the optimization theory and its application has grown in the past few decades, from the well known genetic algorithm paradigm to PSO, ACO, Harmonic Search, DNA Computing, among others, they all were introduced with the expectation of improving the results obtained with the existing strategies.

There's no doubt that there could be some optimization strategies presented at some point that were left behind due their complexity and poor performance. Novel optimization paradigms should be able to perform well in comparison with another optimization techniques and must be "easily adaptable" to different kinds of problems.

Optimization based on chemical processes is a growing field that has been satisfactorily applied to several problems. In Shi and Chu (2010) A DNA based algorithm was to solve the small hitting set problem. A catalytic search algorithm was explored in Yamamoto (2010), where some physical laws such as mass and energy conservation were taken into account. In Meyer, Yamamoto, Banzhaf, and Tschudin (2010), the potential roles of energy in algorithmic chemistries were illustrated. An energy framework was introduced, which keeps the molecules within a reasonable length bounds, allowing the algorithm to behave thermodynamically and kinetically similar to real chemistry. A chemical reaction optimization was applied to the grid scheduling problem in Xu, Lam, and Li

* Corresponding author. Tel.: +52 6646236318.
E-mail addresses: ocastillo@hafsamx.org, ocastillo@tectijuana.mx (O. Castillo).

0957-4174/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2012.12.032

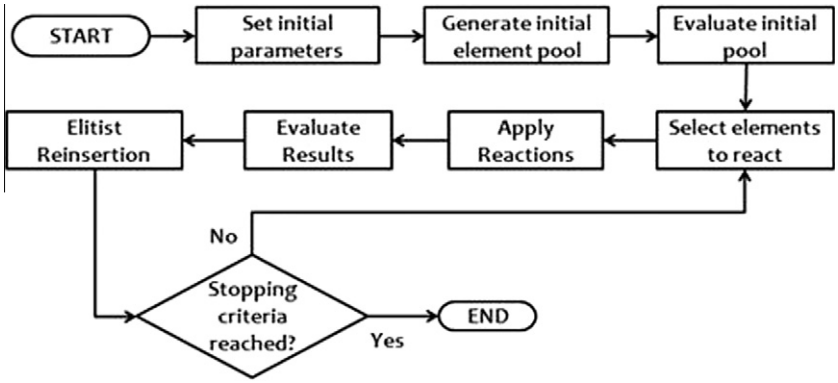

Fig. 1. General flowchart of the chemical reaction algorithm.

(2010), where molecules interact with each other aiming to reach the minimum state of free potential and kinetic energies. The main difference between these metaheuristics is the parameter representation, which can be explicit or implicit.

In this paper we introduce an optimization method inspired on the chemical reactions and its application for the optimization of the tracking controller for the dynamic model of the unicycle mobile robot.

The importance of applying this chemical optimization algorithm is that different methods have been applied to solve motion control problems. Kanayama, Kimura, Miyazaki, and Noguchi (1991) propose a stable tracking control method for a nonholonomic vehicle using a Lyapunov function. Lee, Lee, and Teng (1998) solved tracking control using backstepping and in Lee and Tai (2001) with saturation constraints. Furthermore, most reported designs rely on intelligent control approaches such as fuzzy logic control (Bentalba, El Hajjaji, & Rachid, 1997; Ishikawa, 1991; Lee, Leung, & Tam, 1999; Pawlowski, Dutkiewicz, Kozlowski, & Wroblewski, 2001; Tsai, Lin, & Lin, 2004; Ulyanov et al., 1998) and neural networks (Fierro & Lewis, 1998; Song & Sheen, 2000).

However the majority of the publications mentioned above, have concentrated on kinematic models of mobile robots, which are controlled by the velocity input, while less attention has been paid to the control problems of nonholonomic dynamic systems, where forces and torques are the true inputs: Bloch and Drakunov (1991) and Chwa (2004) used a sliding mode control to the tracking control problem. Fierro and Lewis (1995) propose a dynamical extension that makes possible the integration of kinematics and torque controller for a nonholonomic mobile robot. Fukao, Nakagawa, and Adachi (2000) introduced an adaptive tracking controller for the dynamic model of mobile robot with unknown parameters using backstepping methodology, which has been recognized as a tool for solving several control problems (Sahab & Moddabernia, 2011; Yu, Ma, Chen, Yu, & Pan, 2011). Motivated by this, a Mamdani fuzzy logic controller is introduced in order to drive the kinematic model to a desired trajectory in a finite-time, considering the torque as the real input, a chemical reaction optimization paradigm is applied and simulations are shown.

Further publications (Astudillo, Castillo, & Aguilar, 2007; Castillo, Martinez-Marroquin, Melin, & Soria, 2009; Martinez, Castillo, & Aguilar, 2009) have applied bio-inspired optimization techniques to find the parameters of the membership functions for the fuzzy tracking controller that solves the problem for the dynamic model of a unicycle mobile robot, using a fuzzy logic controller that provides the required torques to reach the desired velocity and trajectory inputs.

In this paper, the main contribution is the representation of the fuzzy controller in the chemical paradigm to search for the optimal parameters. Simulation results show that the proposed approach outperforms other nature inspired computing paradigms, such as genetic algorithms, particle swarm and ant colony optimization.

The rest of this paper is organized as follows. Section 2 illustrates the proposed methodology. Section 3 describes the problem formulation and control objective. Section 4 describes the proposed fuzzy logic controller of the robot. Section 5 shows some experimental results of the tracking controller and in Section 6 some conclusions and future work are presented.

2. The chemical optimization paradigm

The proposed chemical reaction algorithm is a metaheuristic strategy that performs a stochastic search for optimal solutions within a defined search space. In this optimization strategy, every solution is represented as an element (or compound), and the fitness or performance of the element is evaluated in accordance with the objective function. The general flowchart of the algorithm is shown in Fig. 1.

The main difference with other optimization techniques (Meyer et al., 2010; Shi & Chu, 2010; Xu et al., 2010; Yamamoto, 2010) is that no external parameters are taken into account to evaluate the results, while other algorithms introduce additional parameters (kinetic/potential energies, mass conservation, thermodynamic characteristics, etc.), this is a very straight forward methodology that takes the characteristics of the chemical reactions (synthesis, decomposition, substitution and double-substitution) to find for optimal solution.

This approach is a static population-based metaheuristic that applies an abstraction of the chemical reactions as intensifiers (substitution, double substitution reactions) and diversifying (synthesis, decomposition reactions) mechanisms. The elitist reinsertion strategy allows the permanence of the best elements and thus the average fitness of the entire element pool increases with each iteration. The algorithm may trigger only one reaction or all of them, depending on the nature of the problem to solve, in example; we may use only the decomposition reaction sub-routine to find the minimum value of a mathematical function.