Expert Systems with Applications 42 (2015) 5177–5191

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Path planning for mobile robots using Bacterial Potential Field for avoiding static and dynamic obstacles

Oscar Montiel *, Ulises Orozco-Rosas, Roberto Sepúlveda

Instituto Politécnico Nacional, CITEDI, Av. del Parque No. 1310, Mesa de Otay, 22510 Tijuana, B.C., Mexico

ARTICLE INFO

Article history:
Available online 27 February 2015

Keywords:
Path planning
Bacterial Potential Field
Bacterial Evolutionary Algorithms
Mobile robots
Collision avoidance

ABSTRACT

In this paper, optimal paths in environments with static and dynamic obstacles for a mobile robot (MR) are computed using a new method for path planning. The proposed method called Bacterial Potential Field (BPF) ensures a feasible, optimal and safe path. This novel proposal makes use of the Artificial Potential Field (APF) method with a Bacterial Evolutionary Algorithm (BEA) to obtain an enhanced flexible path planner method taking all the advantages of using the APF method, strongly reducing its disadvantages. Comparative experiments for sequential and parallel implementations of the BPF method against the classic APF method, as well as with the Pseudo-Bacterial Potential Field (PBPF) method, and with the Genetic Potential Field (GPF) method, all of them based on evolutionary computation to optimize the APF parameters, were achieved. A simulation platform that uses an MR realistic model was designed to test the path planning algorithms. In general terms, it was demonstrated that the BPF outperforms the APF, GPF, and the PBPF methods by reducing the computational time to find the optimal path at least by a factor of 1.59. These results have a positive impact in the ability of the BPF path planning method to satisfy local and global controllability in dynamic complex environments, avoiding collisions with objects that will interfere the navigation of the MR.

1. Introduction

The problem of autonomous navigation of a mobile robot (MR) consists in taking it from one position to another one without the assistance of a human operator, in particular, planning a reachable set of MR configurations to accomplish its mission. To solve this problem, it is necessary to have a methodology that allows guiding the MR to accomplish a set of navigation and operation goals, i.e., its mission. In general, this methodology deals with motion planning that includes two different but complementary tasks, path planning and trajectory planning. The first one consists in designing a dynamical system that can drive the MR from an initial position (state) to a target position (goal), whereas, trajectory planning focuses on determining how to move the MR along the solution given by the path planning algorithm in a way that the mechanical limitations of the MR are respected.

In this paper, we propose a new approach called Bacterial Potential Field (BPF) for path planning in MRs. The BPF proposal is based on Artificial Potential Field (APF) enhanced with a Bacterial Evolutionary Algorithm (BEA) to solve the limitations given by the original APF. At the present, this is the first implementation of a BPF algorithm for path planning for MRs.

The original APF method is a mathematical method widely used in autonomous navigation of MRs given that it provides an effective control on the movement (Kim, Heo, Wei, & Lee, 2011); some derivations of this method have been used for path planning (Chen, Di, Huang, Sasaki, & Fukuda, 2009a; Goerzen, Kong, & Mettler, 2010; He, Gao, & Nan, 2011; Kim et al., 2011; Weijun, Rui, & Chongchong, 2010). Nevertheless, it presents some limitations; the solutions were found to be subject to local minima (He et al., 2011), and far from the optimum in many cases, given that the planning was solely local and reactive (Chen, Lindsay, Robinson, & Abbass, 2009b). The path planning with the BPF proposal allows the MR to navigate in an autonomous form without being trapped in local minima, making the BPF proposal suitable to work in dynamic environments, which is very crucial in real-world applications. Some significant advantages of the BPF over the original APF method, as well as its derivatives with Evolutionary Artificial Potential Field (EAPF) are summarized in Table 1.

In Section 2, a bibliographic review of some important related work that embraces classical (including the APF), heuristic and meta-heuristic approaches of robot motion planning is provided. In Section 3, the main theoretical contributions of this work are stressed, as well as the pseudocode to implement the method is

* Corresponding author.
E-mail addresses: oross@ipn.mx (O. Montiel), uorozco@citedi.mx (U. Orozco-Rosas), rsepulvedac@ipn.mx (R. Sepúlveda).

http://dx.doi.org/10.1016/j.eswa.2015.02.033
0957-4174/

Table 1
Comparison between APF, EAPF and BPF, when they are used for the on-line global planning.

	APF	EAPF	BPF
Local planning	✓	✓	✓
Smooth path	✓	✓	✓
Global planning		✓	✓
Automatic gain search		✓	✓
Small time consumption			✓
Complex environments			✓
Adaptability to the environment			✓
Power of convergence			✓
Highly scalable			✓

given and explained. In Section 4, the conducted experiments for the BPF proposal are explained, analyzed and compared in performance with two EAPFs, in specific with a Genetic Potential Field (GPF) method based on a GA, and a second one EAPF called Pseudo-Bacterial Potential Field (PBPF) method based on a Pseudo-Bacterial Genetic Algorithm. Finally, in Section 5, conclusions and future work are provided.

2. Related work

The origins of robot motion planning can be tracked to the middle of the 1960s (Masehian & Sedighizaddeh, 2007). It has been dominated by classical approaches such as the Roadmap, Cell Decomposition, Mathematical Programming and APF. Representative proposals of Roadmaps approaches are the Visibility graph which is a collection of lines in the free space that connects the trait of an object to another; the Voronoi diagram of a collection of geometric objects is a partition of space into cells, each of which consists of the points closer to one particular object than any other (Eppstein, 1996); in the Subgoal Network, a list of reachable configurations from the start configuration is maintained. The Silhouette approach consists of generating the silhouette of the work cell and developing the Roadmap by connecting these silhouettes curves to each other (Bhattacharyya, Singla, & Dasgputa, 2007). The idea of Cell Decomposition algorithms is to decompose the *C*-space into a set of simple cells, and then compute the adjacency among cells. In the Mathematical Programming approach, the requirement of obstacle avoidance is represented by a set of inequalities on the configuration parameters; the idea is to minimize certain scalar quantities to find the optimal curve between the start and goal position (Siegwart, Nourbakhsh, & Scaramuzza, 2011). The APF concept was introduced by Khatib (1986). At the beginning, this method was used for obstacle avoidance in path planning for robot manipulators, through the time, it has been well adopted for MRs and groups of MRs, an example is presented in Barnes, Fields, and Valavanis (2009) where is proposed a swarm formation control with potential fields to control robot swarm formation, obstacle avoidance and swarm movement as a whole. In the APF, an MR is treated as a point representing in the configuration space a particle under the influence of an APF denoted by $U(q)$ whose local variations reflect the free space structure; the idea behind the APF method is to establish an attractive potential field force around the goal point, as well as to establish a repulsive potential field force around the obstacles. The two potential fields together (attractive + repulsive) form the total potential field called APF (Park & Lee, 2003).

In Masehian and Sedighizaddeh (2007) an amount of 1381 papers dating from 1973 to 2007 were surveyed, covering a sufficient depth of works in the robot motion planning field. In this work, a broad classification of heuristic techniques is presented, which facilitates its analysis and method's expectations. Broadly, the given classification is as follows: Probabilistic, heuristic and meta-heuristic approaches (Zhang, Chen, & Fei, 2006). In the former are the Probabilistic Roadmaps, Rapidly-exploring Random Trees, Level set and Linguistic Geometry. In the heuristic and meta-heuristic approaches are the Neural Networks, Genetic Algorithms (GAs) (Berger, Jabeur, Boukhtouta, Guitouni, & Ghanmi, 2010; Hocaoglu & Sanderson, 2001; Li, Ding, Cai, & Jiang, 2010), Simulated Annealing (Zhang, Collins, & Barbu, 2013), Ant Colony Optimization (Montiel, Sepúlveda, Castillo, & Melin, 2013), Particle Swarm Optimization, Stigmergy, Wavelets, Tabu Search and Fuzzy Logic. All the mentioned methods have their own strengths and drawbacks; they are deeply connected to one another, and in many applications, some of them were combined together to derive the desired robotic controller in the most effective and efficient manner.

In this paper, the BPF is proposed as a method for path planning for mobile robotics that ensures a feasible, optimal and safe path for the robot navigation. The BPF proposal uses concepts from the APF, mathematical programming, and meta-heuristic to solve efficiently a robot path planning problem, ensuring a reachable configuration set and controllability if it exists, outperforming current APF approaches. The APF is a reactive motion planning method with inherent well known difficulties to travel finding global optimal paths, because it cannot solve all local minima problems (Zhang, Chen, & Chen, 2012); hence, modern methods that overcome these challenges have been developed (Vadakkepat, Lee, & Xin, 2001). One of them is where the APF is blended with Evolutionary Algorithms (EA) obtaining a different potential field methodology named Evolutionary Artificial Potential Field (EAPF) Vadakkepat, Tan, and Wang (2000), here, the APF method is combined with GAs to derive optimal potential field functions (Vadakkepat et al., 2001). The variational planning approach uses the potential as a cost function, and it attempts to find a path to reach the goal point that minimizes this cost (Goerzen et al., 2010).

Furthermore from the GAs, Nawa, Hashiyama, Furuhashi, and Uchikawa (1997) proposed a novel kind of evolutionary algorithm called Pseudo-Bacterial Genetic Algorithm (PBGA) which was successfully applied to extract rules from a set of input and output data. This algorithm introduced a genetic operation called *bacterial mutation* that has demonstrated to be useful in environments with a weak relationship between the parameters of a system. It is a simple algorithm that presents a fast convergence and improvement in the solutions (Botzheim, Gál, & Kóczy, 2009, chap. 3; Botzheim et al., 2011), without detrimental in the landscape exploration. Furthermore, Nawa and Furuhashi (1999) proposed the Bacterial Evolutionary Algorithm (BEA) for fuzzy rule base extraction. This algorithm was based on PBGA supported by a new genetic operation called *gene transfer*, which establishes relationships among the individuals from the population; it can also be used for decreasing or increasing the number of the rules in a fuzzy rule base. Both the PBGA and the BEA are global search methods (Botzheim et al., 2009, Botzheim, Toda, & Kubota, 2010, cha 3). The convergence to the global optimal of the BEAs in comparison with the GAs is faster, which is important since the calculation process cost of combination is omitted (Fallah, Akbari, & Javan, 2010). The bacteriological approach is more an adaptive approach than an optimization approach as with GAs. It aims at mutating the initial population to adapt it to a particular environment. The adaptation is only based on small changes in the individuals. The individuals within the population are called bacteria and correspond to atomic units. Unlike the genetic model, the bacteria cannot be divided. The crossover operation cannot be used anymore. Bacteria can only be reproduced and altered to improve the population (Baudry, Fleurey, Jézéquel, & Traon, 2005).