Mobile robot path planning using artificial bee colony and evolutionary programming

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ABSTRACT

In this paper, an evolutionary approach to solve the mobile robot path planning problem is proposed. The proposed approach combines the artificial bee colony algorithm as a local search procedure and the evolutionary programming algorithm to refine the feasible path found by a set of local procedures. The proposed method is compared to a classical probabilistic roadmap method (PRM) with respect to their planning performances on a set of benchmark problems and it exhibits a better performance. Criteria used to measure planning effectiveness include the path length, the smoothness of planned paths, the computation time and the success rate in planning. Experiments to demonstrate the statistical significance of the improvements achieved by the proposed method are also shown.

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1. Introduction

The path planning problem is a fundamental issue in mobile robotics because the need of having algorithms to convert high-level specifications of tasks from humans into low-level descriptions of how to move as stated by LaValle [1]. It can be formulated as follows: given a robot and the description of its working environment, the goal is to plan a trajectory for the robot that joins two specific positions using motion primitives from an available set, and that avoids collisions with the elements present in the robot scenario [2]. The planning algorithms try to provide of autonomy to robots to solve some problems without the intervention of human operators. According to LaValle [1], there are at least two good reasons to study planning algorithms. First, it is very interesting to get machines that can solve some tasks that are difficult to solve for humans, this involves modeling planning problems, designing efficient algorithms and developing robust implementations. Second, planning algorithms have been successfully used in various industries and academic disciplines like robotics, manufacturing, aerospace applications, etc.

A chronological review of the advances in the development of path planning algorithms is presented in [3]. There are some general classical methods as: the use of roadmaps, Cell Decomposition, Potential Fields, and Mathematical Programming. In order to improve these classical methods, probabilistic algorithms have been developed, including Probabilistic Roadmap Method (PRM) and Rapidly-exploring Random Trees (RRT). Further details on the implementation of the classical and probabilistic methods can be found in [4].

Meta-heuristic algorithms have also been used to solve the path planning problems. The main advantages of the meta-heuristic techniques are: (i) the possibility of inclusion of expert knowledge in the search procedure and, (ii) the potential of working with several candidate solutions simultaneously instead of only exploring a single alternative. In [3] we can observe the considerable increase in works that use heuristic and meta-heuristic techniques to solve the path planning problem. In particular, there are works that use Genetic Algorithms (GA), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) among others. Among these approaches, we can find an evolutionary approach for the path planning and navigation of a mobile robot [5]; a GA-based planner that generates free configurations and tries to connect those configurations with a start and a goal position [6]; an improved genetic algorithm to increase the exploration diversity of candidate solutions and reduce the possibility of being trapped in local minimums [7]; an improved genetic algorithm to generate free-collision paths [8], and a memetic algorithm to generate paths, using operators to evolve candidate solutions based on certain criteria [9]. Other meta-heuristics techniques are the swarm intelligence techniques; they

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are based on the collective behavior of some social species. Among these kind of approaches, we can find a planner that uses the ACO algorithm and nine motion directions of the robot within the grid representation of the map [10] and PSO-based planners for a mobile robot [11–13]. The Artificial Bee Colony (ABC) algorithm has also been used to solve planning problems as in the Mansury work [14].

A detailed review of the main features of the evolutionary approaches in the recent literature are presented below.

- With respect to the robot model, previous approaches [6,14,12,15] use a point model for the mobile robot.
- With respect to the meta-heuristic strategy, the approaches [6,14,12,15] use a single evolutionary technique (GA, PSO, and ABC).
- In regard of the individual encoding of the meta-heuristic techniques, the approaches [15,12] encode each individual as a collection of cells in a grid map generated by the discretization of the robot scenario. In [14], they encode the path using the parameters of two Ferguson splines, limiting with that the complexity of the path planning problems that can be solved, but being adequate for the Robo-soccer scenario used in their tests. Achour and Chaalal [6] propose to use a set of segments to encode the individual. These segments are evolved into a roadmap of segments that do not collide with the obstacles in the map until finding a free path connecting the start and the goal position.
- For the fitness function, Achour and Chaalal [6] favor both the minimal total length and the smoothness of the path, however the method is restricted to use only path segments generated by the GA during its evolution. The approaches [12,15] minimize the distance of the cell sequence but their methods are restricted to move the robot cell by cell.
- Test scenarios used to validate previous approaches are also of variable complexity. Goel and Singh [15] address the path planning problem in dynamic scenarios, but they present only one example and they use a discretized grid of the scenario. Mansury et al. [14] address the problem in a Robo-soccer scenario where there are only three obstacles. Li and Wang method [12] has been validated only in environments with sparse obstacles. Achour and Chaalal [6] consider a continuous representation of the scenario and present some problems including a small number of obstacles and corridors.

The main contribution of this paper is the development of new robust algorithm based on meta-heuristic approach to solve the path planning problem of a disk robot. The proposed planning system accomplishes its task in two steps. First, a feasible path planner using the ABC algorithm generates an initial path connecting the start position and the goal position of the robot and that path passes through intermediate configurations from a set of randomly chosen free configurations. Second, the initial path is optimized in a global way by using Evolutionary Programming (EP), that leads to short, smooth, and collision free paths. The proposed method was validated in a large set of path planning scenarios (benchmark maps). This test set includes most of the complex situations that a path planning algorithm can encounter in real world scenarios. The method is extensively validated against the classical PRM algorithm, as suggested by Masehian and Sedighizadeh [11]. Both planning systems are tested in the benchmark maps and compared with respect to measures such as: path length, path smoothness, search cost and planning success rate. We present quantitative and qualitative results of the comparative study.

The rest of this paper is organized as follows: Section 2 includes the formulation of the path planning problem in terms of our approach. Section 3 presents the feasible path planner using the ABC algorithm. Section 4 describes the EP in global path planning optimization. Section 5 presents a brief description of the PRM for
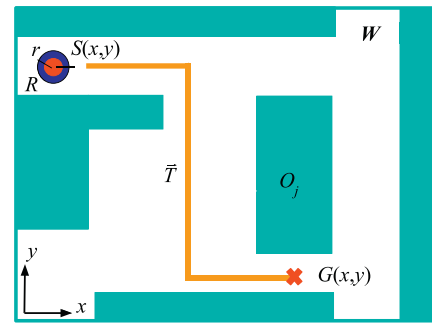

Fig. 1. Formulation of the path planning problem in terms of our approach. We use a circular model of the robot R with a radius r. The robot generates a path $\bar{T}$ from a start position $S(x, y)$ to a goal position $G(x, y)$ in the scenario W. The scenario has a set of static obstacles O_j, $(j = 1, \ldots, M)$.

the sake of completeness. Test and results are presented in Section 6 whilst our main conclusions and findings are presented in Section 7.

2. Problem formulation

A scenario W for the robot is considered as a 2D map, that includes a set of static obstacles O_j, $(j = 1, \ldots, M)$, and a mobile robot R with instantaneous position represented by its coordinate $C(x, y)$. We assume a circular model of the robot with a radius r (that is, a disk robot). The goal is then to find a sequence $\bar{T}$ of motion commands to let the robot move from a start position $S(x, y)$ to a target position $G(x, y)$. In our approach, $\bar{T}$ is composed of rotate and advance motion primitives. That is depicted in Fig. 1.

One of the main advantages of soft computing is the possibility of hybridization of different techniques. For the path planning problem, we have experimented on developing methods using a single evolutionary technique as ABC or EP. In our experiments, the use of a method exclusively based on ABC has shown difficulties to find paths that satisfy the optimization criteria. Nevertheless, this approach finds paths that are feasible but not optimal. We have also experimented with a path planner using only EP. This approach encounters problems to avoid collisions in the robot path but it is able to improve the path when it starts with a feasible one.

We present a meta-heuristic based planner to generate a trajectory composed of advance and rotate primitives. Firstly, we generate a feasible path free of collision by connecting free configurations from the start position to the goal position. The connections between the path segments are found by local search procedures guided by the ABC algorithm. Secondly, we optimize in a global way the initial path in terms of length and smoothness by using EP. The proposed fitness function favors the generation of paths with the following characteristics: shortness, collision freeness, and smoothness of the plan. The proposed method is hereafter referred as the ABC-EP planner. This method is inspired by the PRM planner, but our method replaces the step of building the visibility graph with a feasible path planner guided by the ABC algorithm.

3. Feasible path planner using the ABC algorithm

In this section we describe the ABC algorithm as an optimization tool, and then we describe our local search procedures guided by the ABC technique to generate an initial feasible path for the second part of the path planning system.

3.1. Artificial bee colony (ABC)

Among evolutionary approaches, the ABC algorithm has been found to perform better or at a same level than others like GA,