Information Sciences 278 (2014) 357–379

Contents lists available at ScienceDirect

Information Sciences

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

Path planning for multiple mobile robots under double-warehouse

Yong Ma [a,b,c], Hongwei Wang [c,*], Yong Xie [c], Min Guo [c]

[a] School of Navigation, Wuhan University of Technology, Wuhan 430063, China
[b] Hubei Key Laboratory of Inland Shipping Technology, Wuhan, 430063, China
[c] Key Laboratory of Image Processing and Intelligent Control, Institute of Systems Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China

ARTICLE INFO

Article history:
Received 3 April 2013
Received in revised form 27 February 2014
Accepted 5 March 2014
Available online 24 March 2014

Keywords:
Multiple mobile robot
Path planning
Double-warehouse
Time-varying nonlinear programming problem
Con-Per-PSO
SA-PSO

ABSTRACT

This work investigates the conflict-free path planning problems for efficient guidance of multiple mobile robots under the dynamic double-warehouse environment, a challenging problem that appears recurrently in a wide range of applications such as the service robots moving in a multistory building. United with two symmetrical transfer elevators, double-warehouse consists of two parallel warehouses. Within each warehouse, the polynomial based paths are subject to constraints such as motion boundaries, kinematics constraints, obstacle-avoidance, limited resource of elevators and smoothness. We formulate the shortest path planning problems as one time-varying nonlinear programming problem (TNLPP) while restricted to the above constraints, and apply the multi-phase strategy to reduce their difficulty. We present the new variant algorithms of PSO named constriction factor and random perturb PSO (Con-Per-PSO) and the simulating annealing PSO (SA-PSO) to achieve the solution. Numerical simulations verify that, our approach can fulfill multiple mobile robots path planning problems under double-warehouse successfully.

1. Introduction

Double-warehouse consists of two perpendicularly distributed warehouses which are united with two elevators. The elevators are bilateral symmetrically emplaced on the double-warehouse. In each warehouse, there exist a certain number of mobile robots and obstacles static or moving. Similar to the grandiose parks and multistory buildings which are composed of several tiers of building, the classical double-warehouse can be represented by two tiers of the connected warehouse. Meanwhile, cars in the parks and the moving service robots can be treated as mobile robots. Because of the complicated multi-story environment, it is difficult for the automatic navigation of robots under double-warehouse. Therefrom, a particular challenge problem we are going to consider is planning effective paths for mobile robots that can conduct complex missions in a conflict-free manner under those double-warehouses.

Our focused problem evolves from the path planning problems for mobile robots limited to only a mono-plane environment. The latter problems are the vital part of robotics research and have been studied extensively [12,21,36]. The above two problems share much common ground, whereas the conspicuous difference is that the limited resource conflicts of elevators exist in our concentrated problem, when by using the elevators to transfer robots between the upper and lower warehouses.

* Corresponding author. Tel./fax: +86 27 87543130.
E-mail addresses: myongdl@aliyun.com (Y. Ma), hwwang@mail.hust.edu.cn (H. Wang), xyhust@163.com (Y. Xie), guomin_like@sina.com (M. Guo).

http://dx.doi.org/10.1016/j.ins.2014.03.058
0020-0255/

Contrast to the former path planning problems limited to mono-plane [2,29,31,43,48], the problems we concerned are not just the planned paths summation of the mobile robots in the two layers, but involve collision problems and conflict problems of the limited elevators resource.

In the context of planning environment, many excellent techniques have been developed for the path planning of mobile robots in mono-plane. In [5,33], they designed a centralized planner to plan paths for all the mobile robots. In our former work [21], we focused on the decoupling methods which sequentially divided the problems into one problem of path planning for each mobile robot with stationary obstacles and another of conflict resolution among the planned paths. However, little attention has been paid to the study of multiple mobile robots path planning problems under double-warehouse. Thus, there is a lack of available literatures which offer a generous problem solving guidance.

As a natural extension of our previous work in [21], to clarify the expression of our concerned problem, we propose the idea of multi-phase to simplify the modeling procession. In contrast with the goal function of [21,46] is minimizing path length of only one mobile robot, our goal function is minimizing the path length of all the mobile robots while explicitly take all the constraints into account. However, the safety constraints among mobile robots are not considered in [21]. In [19,36], quartic Bezier curves are adopted to represent the paths of mobile robots. Whereas approaches of [19,36] strictly restrict the paths to fourth-order Bezier curves and require the initial and final velocities of each mobile robot, which would be impractical for the realistic application. In [21,48], the parametrization method is proposed to formulate the path planning problem and the paths are achieved with the embedded functions of software, such as Matlab, Lingo. Owing to the error of those functions, the solutions can be remarkably improved with some efficient techniques.

Generous effectual techniques not only classical but heuristic are reviewed detailedly in [23]. From their research, it implies that the approaches used for mobile robots path planning evolved from the classical algorithms in the early stage before 1990 to the heuristics in the later stage after 1990. In the earliest stage, [9,11,16,28,32] have resolved the problem of path planning in dynamic environments. However, classical methods proved to be inefficient for multiple mobile robots path planning under the time-varying environment, which require considerably long time and huge storage memory. Consequently, heuristic methods are exploited to cope with those problems. Various algorithms are designed which range from the artificial potential field [18], fuzzy logic [24], stochastic processes [26] to neural networks [47], genetic algorithms (GA) [35], simulated annealing (SA), particle swarm optimization (PSO) [4,17,27,44], and their combinations [1]. PSO is one prevalent algorithm founded by Kennedy and Eberhart [17]. For the last decade, PSO has been extensively used in the field of single mobile robot path planning problems [27,34]. And in [22], we resolved the single mobile object path planning problem in four-dimension by using PSO. PSO is a swarm intelligence method inspired by the collective behavior of birds flock, which is famous for its concise mechanism, fine convergence, and a little computational time [38–40]. Thus, we proposed the PSO-based algorithms with improved techniques to solve the multiple mobile robots path planning problem under the double-warehouse.

As the fitness function for single mobile robot in the mono-plane cannot be directly used for multiple mobile robots in the double-warehouse, when using PSO, the foremost issue is how to determine the proper fitness function for our problem. The TNLPP is subject to path smoothness, safety criterion, and velocity and acceleration constraints, which can be classified as one single-object optimization problem with many nonlinear constraints. Recently, the interest in treating constrained single objective optimization problem as a multiobjective optimization problem is growing which can be found in generous works [3,37,41]. Within those algorithms, the constraints can be viewed as one or more of the objectives. However, as discussed in [10], owing to simply considering constraints as objectives or assigning the infeasible individuals a lower fitness than the feasible individuals might not introduce enough pressure to direct the search toward the region of the optimum, then the approach appears less robust than for constrained single objective algorithms. Consequently, we adopt PSO which excels in simplicity and is practicable to resolve the constrained single objective algorithm. To design the rational fitness function, a penalty function is adopted to transform the constrained TNLPP to general unconstrained TNLPP. The constraints are placed into the fitness function via the penalty parameter in such a way as to penalize any violation of the constraints. Then, a solution of the TNLPP can be attained with the enhanced PSO-based algorithms.

Some highlights of our paper are: (1) The path planning problem for multiple mobile robots under double-warehouse with resource conflict of elevators is proposed for the first time; (2) with exhaustive investigation, a novel model named time-varying nonlinear programming problem is elucidated; and (3) after the characteristics of the above model are analyzed scientifically, the improved PSO-based algorithms are devised to resolve our focused problem ideally, by using the ameliorated methods, the planned paths are smooth which satisfy the nonholnomic requirements of mobile robots, with the conflict-free paths that the mobile robots can execute their tasks freely without colliding with any other objects. Finally, numerical examples demonstrate the effectiveness of our developed approach.

The remainder of the paper is organized as follows. Section 2 describes the problem formulation. By using the idea of multi-phase, Section 3 sequentially models the problem from different criteria. Following that, Section 4 analyzes the model characteristics. Section 5 proposes one approach based on improved PSO to resolve the problem. Section 6 presents illustrative numerical examples for multiple mobile robots under double-warehouse using the proposed approach. Finally, Section 7 concludes this paper.