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A review of research on directional off-road path planning algorithms

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Abstract. Military orienteering can cultivate the skills of map reading, map use and military charting, and has gradually become a regular military training subject. A good track design plan is the basis for the smooth running of the competition. The current research on cross-country courses is mainly focused on single-track optimization, and there is very little research on multi-track planning, and design. However, in specific events, there are often multiple tracks running at the same time, and there are many restrictions, single track optimization design solutions are often not applicable. In this paper, we review multiple path planning algorithms and summarize the problems of these algorithms. On this basis, the advantages and disadvantages of static and dynamic path planning algorithms are analyzed, and future research trends and methods of path planning algorithms in orienteering are proposed.

Keywords: Orienteering, Path planning, Intelligent optimization, Genetic algorithm, Ant colony algorithm.

1. Introduction

According to certain competition rules in the field, orienteering is a kind of pointing tool, such as a compass and a map or topographic map. In the end, the player with the highest score wins. Orienteering route design is the process of planning the route of the orienteering competition by designing the starting point, checkpoint, and finish point on a suitable map or topographic map, so as to obtain as fair a route as possible. However, in the actual race, only the starting point and check candidate points are often known. When planning the route, it is necessary to determine the endpoint and the mandatory checkpoints by oneself, where the mandatory check points are the checkpoints that all courses pass through for the provision of water as well as medical supplies, etc. In real military combat, whether one knows the terrain and whether one can give full play to the terrain is one of the key factors affecting victory or defeat in combat.

Orienteering is of great significance in the training of military students, and this sport will not only test the physical ability and will of the participants, but will also examine map reading skills, direction recognition, etc. The orienteering competition requires a large space, usually choosing forests, parks, campuses, and mountains, which often contain some unknown geographical terrain, etc. Therefore, this will also exercise the ability of the participants to deal with unexpected situations.

The realization of multi-path orienteering competition path automation design is conducive to promoting the development of military orienteering sports and improving the comprehensive quality of the participants themselves. The current research on cross-country courses focuses on the optimal single path, which is not applicable to multi-path orienteering competitions. The design of multi-path orienteering courses pays more attention to the equilibrium between courses, rather than the shortest or optimal single path, according to which, the construction of a multi-path orienteering model framework is beneficial to reducing the path design cost and promoting the development of orienteering sports.

Therefore, the orienteering path planning algorithm is essentially a multi-constrained combination optimization algorithm, mainly including traditional path planning algorithm and intelligent optimization algorithm. In this paper, we first sort out the traditional path planning algorithms, then focus on the application of intelligent optimization algorithms to orienteering path planning, and finally compare and summarize the orienteering path planning algorithms.

2. Traditional path planning algorithm

2.1. Graph-based search method

Graph-based search method models the whole environment and then perform path search, which is more intuitive and easy to find the shortest path, and is suitable for path planning in global and continuous regions, including the Dijkstra algorithm, A* (A-Star) algorithm, and so on.

The core idea of Dijkstra's algorithm is greedy and breadth-first search, which spreads around the starting point and selects the next path point with the cost of the node to the starting point as the priority. A* algorithm is an improvement of Dijkstra's algorithm, which adds the heuristic search idea to Dijkstra's algorithm and considers not only the cost to the starting point but also the cost to the end point when selecting the next path point. It is easy to implement. However, the A* algorithm also has the problem of unsmooth planning paths, mainly due to the search field being too small and the path corner being too large, which can be improved by increasing the search field.

To address the problems of A* algorithm planning paths too close to obstacles and low path safety, Ge et al. proposed a mobile robot path planning safety A* algorithm. It adds a safety evaluation function to the heuristic function, so that the algorithm will consider the distance from obstacles when selecting the next path point [1].

2.2. Artificial potential field method Artificial potential field method (APF)

The artificial potential field method, a widely used algorithm in path planning algorithms, was first proposed by Khatib [2]. In the artificial potential field algorithm, the motion environment of the robot is considered as a virtual force field. The target point and the obstacle generate gravity and repulsive forces during the robot motion, and the combined force of the two, as the acceleration of the robot’s motion, controls the robot’s movement to the target point.

The concept of "potential field" in physics is introduced into the orienteering task scenario. The algorithm has good real-time performance and smooth path planning, which is suitable for local path planning. However, due to the complexity of the elements in the orienteering task scene and the number of points with zero combined force, APF is easy to fall into local optimum. An improvement idea is to set virtual obstacles or virtual target points to get rid of the local optimum. For the APF target point unreachability problem, it can be improved by setting the minimum attraction size and reducing the directional range of the repulsive force on the participant [3].

2.3. Sampling method

Since the graph-based search method and the artificial potential field, the method requires modeling of the environment, and in a multidimensional complex space, modeling can take a lot of time and computational cost. The sampling method does not need to model the whole environment space and reconstructs the environment with sampling points, which is relatively less computationally intensive. Take the RRT algorithm as an example, the RRT algorithm constructs a spatially populated tree by randomly picking points in space, using the trunk of the tree as the path. However, the RRT algorithm has large randomness and slow convergence. Guo combines the RRT algorithm with the artificial

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potential field method to help APF jump out of the local optimal solution by using the random sampling property of RRT. It also guides the random tree expansion by APF target gravity to reduce the randomness of the RRT algorithm and make the path finding more directional [4].

3. Intelligent optimization algorithm

Most intelligent optimization algorithms search for spatially optimal solutions by mimicking the foraging and rounding behavior of group organisms. The algorithms are capable of solving high-dimensional complex and multi-constrained optimization problems. Common algorithms include genetic algorithm (GA), ant colony algorithm (ACO), particle swarm algorithm (PSO), etc.

3.1. Genetic Algorithm

The Genetic Algorithms (GA) was proposed by Professor Holland in the 1970s and is often referred to as a traditional genetic algorithm or standard genetic algorithm. It stimulates and draws on the phenomenon of genetic inheritance, crossover, and mutation of genes in the evolution of organisms in nature. And through the algorithm design select, cross and mutate the individuals in the population, that are the three retained and inherited Individuals. Those rated as superior in terms of their adaptability, thus reflecting the mechanism of "survival of the fittest and elimination of the fittest" in the biological, and thus iterate and evolve until some convergence conditions are met.

Juidette et al. introduced the first generic genetic algorithm in fuzzy control and navigation systems in 2000 and obtained a planning path that was better than a random decision table [5]. Therefore, numerous researchers started to examine the application of genetic algorithms in path planning studies. Among them, Zhang et al. proposed a hybrid genetic algorithm with intelligent features by combining the advantages of TabuSearch and the genetic algorithm [6]. Yu et al. [7] proposed a path planning algorithm that satisfies the requirements of time, cost, and task allocation by using a combination of directed graph theory and genetic algorithm, thus realizing a new path planning problem. Compared with traditional graph-based algorithms, this algorithm has a simpler implementation method and higher efficiency. In the same period, Mahjoubi et al. [8] proposed a distributed path planning algorithm for static and dynamic obstacle environments based on the main computational steps of genetic algorithms, using the method of adding evolutionary operators and updating the representation environment at the Evolutionary Computation Conference. It further optimized the computational speed and robust performance of the path planning algorithm.

In order to solve the shortest path problem in graph theory, Li et al. [9] obtained an improved genetic algorithm applicable to optimal path planning by modifying the computational steps of encoding, crossover and variation, which has high academic value and reference significance. In the context of the rapid development of small handheld computing devices, Lin et al. [10] proposed a route guidance system based on a genetic algorithm, which achieves a high level of robustness, accuracy and computational efficiency. In the development of path planning algorithms with decision functions, Kumar et al. [11] introduced a global sampling function in the feasible solution space, and integrated the traditional Dijkstra algorithm and A* algorithm in the genetic algorithm.

3.2. Ant colony algorithm

In the 1990s, Colomi et al. first proposed the theory of ant colony systems to try to solve the classical travel quotient problem by observing the foraging behavior of ants, and obtained results of high quality [12]. During the foraging behavior of ant populations, each ant in the population leaves pheromones in its movement path to communicate information to the other ant populations. The shorter the movement path, the higher the pheromone concentration and the higher the probability of that path being selected by the ants, which forms a positive feedback mechanism for ants to find the shortest path.

Based on the general ant colony algorithm, many scholars have tried to introduce the ant colony algorithm in path planning research and made some worthy results.

Fan et al. [13] applied the reinforced ant colony algorithm to the path planning problem of mobile robots for the first time, and proposed an effective solution to the continuous function optimization

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problem containing constraints, and further promoted the improvement and solution of path planning algorithm under specific conditions. On the basis of considering the load of urban traffic, Hsiao et al. [14] proposed a shortest path planning algorithm based on ant colony optimization technique. The algorithm improves the performance while taking into account the performance and flexibility of the algorithm.

Zhu et al. [15] developed the nearest neighbor strategy and the objective guidance function based on the ant colony algorithm, which better solved the optimal path planning problem for robots in complex geographical environments.

Attiratanasunthro et al. [16] proved polynomial running time bounds for the ant colony optimization algorithm for the single objective shortest path problem on directed acyclic graphs and gave the first accurate evaluation of the performance and running efficiency of the ant colony algorithm from the algorithm theoretical point of view.

For the optimization of the dynamic path planning problem of mobile robots, Liu et al. [17] further improved the convergence speed of the ant colony algorithm by modifying the objective guidance function, and Shi et al. [18] conducted global simulation experiments on mobile robots in different environments by using the parameter adjustment methods of ant colony number, heuristic factor and pheromone volatile system, and obtained the comprehensive best-fit parameters. The object of the above work is mainly robots with mobile functions, but the results are still highly practical and portable for path planning algorithms of intelligent transportation.

In 2017, Zuo et al. [19] proposed an improved ant colony algorithm based on the algorithm steps and structure of the multi-objective optimal scheduling model, and then solved the task scheduling method of path planning problem in the cloud computing era.

The above is the development history and specific roles of traditional path planning algorithms and intelligent optimization algorithms in orienteering path planning, and scholars have made excellent contributions to this problem in recent decades.

4. Conclusion

This paper has studied and analyzed the research history and development of path planning algorithms based on traditional path algorithms and intelligent optimization algorithms from the research directions of real-time, parallelism, control system, and hybrid algorithms. Research on path planning using ant colony and the genetic algorithm has obtained rich results, but most of the results are achieved by modifying the details or parameters of the heuristic algorithm to optimize the effect of the algorithm, which is difficult to carry out in-depth research.

In the context of the popularization of many new technologies, such as Internet of Things and artificial intelligence, path planning research is facing more complex application environments and operating conditions. However, how to modify the heuristic algorithm to adapt to the exhibition of many new technologies is still one of the important topics in this field, and its research progress has important theoretical significance and application value for the modernization of the country.

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