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Probabilistic roadmap method for path-planning in radioactive environment of nuclear facilities

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ABSTRACT

In order to reduce the radiation exposure of the staff in radioactive environment of nuclear facilities, the probabilistic roadmap method is applied to optimize the walking path, which is on the basis of the map model, collision detection technology and dose calculation method. The proposed method can make a route in a very short time. The advantages of the path-planning method are reflected in two simulation experiments. From the first experiment, you can see the necessity and significance of path-planning in radioactive environment. To be specific, the cumulative dose is reduced greatly. In the other experiment, the computing speed of the proposed method is striking. Compared with the traditional A* algorithm, the reaction of this proposed method is almost instantaneous. Therefore, the proposed method has a good effect on path-planning in the radioactive environment of nuclear facilities.

1. Introduction

In the world energy pattern, nuclear energy is an integral part. And in the future, under the dual pressures of energy demand and environment protection, more countries are likely to develop nuclear energy. So, nuclear energy is promising. It can be foreseeable that nuclear energy will be further widely used in the near future. However, it remains challenging to solve the problems regarding radiation during the development of nuclear energy. For example, for those staff who are exposed to the radioactive environment, nuclear radiation is a potential risk. According to statistics, during the overhauling of nuclear power plants, Chinese workers receive about 80 percent of the total annual dose(Wan, 2012). According to the principle of ALARA (as low as reasonably achievable), it is necessary to design a route navigation scheme for workers in radiation environment of nuclear facilities to ensure that they receive the minimum radiation dose before or during their work. What's more, a reasonable route should be proposed quickly enough by means of the path-planning method in an emergency, so that the existing problems can be safely addressed. Hence, it is meaningful to optimize the walking route in radioactive environment of nuclear facilities.

The development of path-planning in radioactive environment has attracted much attention. A localized navigation algorithm based on a well-designed and distributed wireless sensory infrastructure was put forward by Khasawneh et al., which was tested under the "Radiation Evasion" and the "Nearest Exit" criterion (Khasawneh et al., 2013a; b). Combining particle swarm optimization algorithm and multi-objective decision method, Liu et al. addressed the walking-path in radioactive environment (Liu et al., 2014). And Wang and Cai also researched the problem further (Wang and Cai, 2018). As for the single objective problem, Liu et al. established the road network and improved the A* algorithm (Liu et al., 2015). In addition, their further work focused on the multiple radiation areas (Liu et al., 2016) and dynamic radioactive environments (Li et al., 2016). With the development of virtual reality technology, virtual simulation is playing an increasingly important role in the work of nuclear plants. For instance, Mól et al. simulated a real nuclear power plant and assessed radiation dose rate by means of a platform adapted from a low cost game engine (Mól et al., 2009a,b). What's more, Chao et al. devoted to a sampling-based method (SBM) for planning minimum dose path for workers in nuclear facilities (Chao et al., 2017). After their further study, Chao et al. proposed the Grid-based RRT* algorithm. In their paper, the principle of the rapidly exploring random tree star (RRT*) is combined with the grid searching strategy (Chao et al., 2018).

In this paper, in order to search an optimized free path quickly for occupational workers in the radioactive environment of nuclear facilities, some research about the probabilistic roadmap method used to optimize the walking path in radioactive environment is done. Probabilistic roadmap method performs well in robot motion planning (Kavraki et al., 1996, 1998; Kala, 2014a; Aarno et al., 2004), which is

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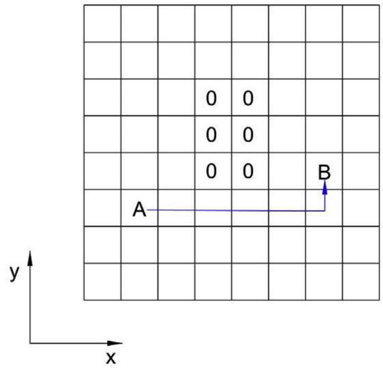

Fig. 1. The model of a hypothetical map.

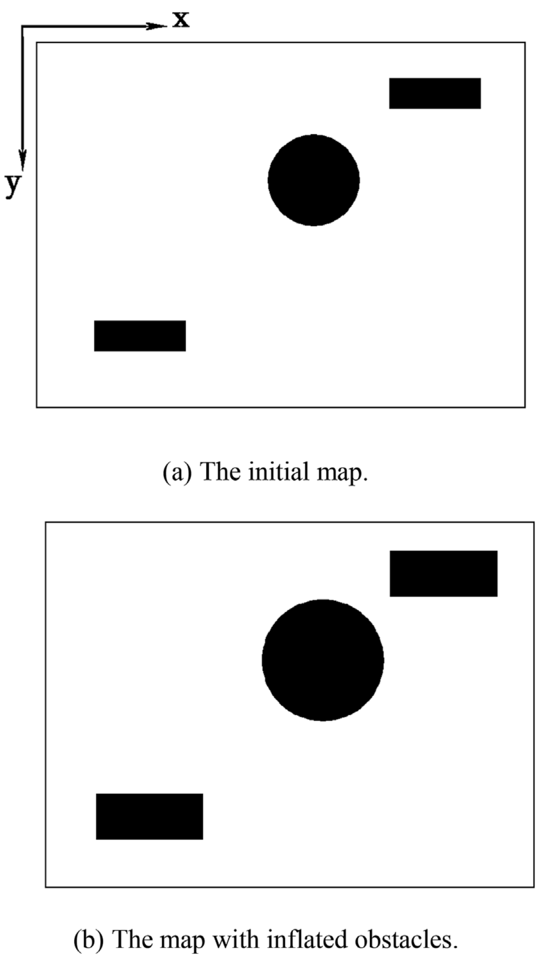

Fig. 2. Description of the volume inflation of the obstacles. (a) The initial map. (b) The map with inflated obstacles.

used to determine a path between the robot's starting configuration to the goal configuration. In the case where the path does not need to be optimal, it can also search for a shorter path quickly. In addition, the computational cost of probabilistic roadmap method is small. Therefore, this method can better meet the needs. A* algorithm (Hart et al., 1968, 1972; Kala, 2014b) is also applied during the experiments. As a heuristic algorithm, A* algorithm is widely used in the field of path-planning (Persson and Sharf, 2014; Cui and Shi, 2011) and it tends to find the shortest path. While searching for all possible solutions, it will prioritize the better solution to reduce path costs, that's why it is popular in many cases. What's more, the related mathematical models are proposed and applied in the context of radiation. The effectiveness of

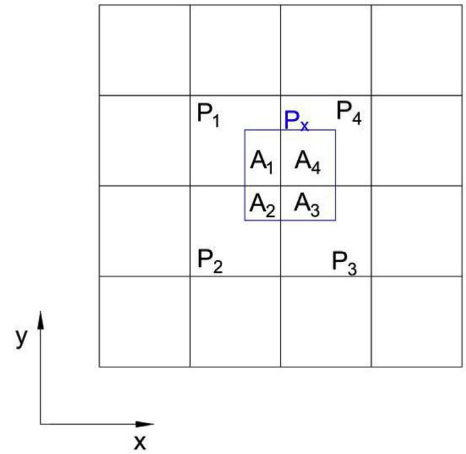

Fig. 3. An illustration of the interpolation method.

the proposed method is experimentally supported.

The rest of paper is structured as follows: Section 2 introduces the fundamental algorithms; Section 3 concentrates on the path-planning method; Section 4 discusses and analyzes the results of two simulation experiments; Section 5 concludes the paper.

2. Fundamental algorithms

2.1. Probabilistic roadmap algorithm

Probabilistic roadmap (PRM) algorithm is proposed by Kavraki et al. (1996). This algorithm proceeds in two phases, namely the learning phase and the query phase. During the learning phase, an undirected graph $R = (N, E)$ called the roadmap is constructed in a probabilistic way. By definition, N is a set of nodes, which are chosen appropriately in the free configuration space (C-space). The configuration space refers to the space of arrangements of points. The nodes in N are connected to the neighbouring nodes using local planning method and any feasible paths are put into E. It should be noted that the nodes and the edges must be collision-free. In complex cases, there is an expansion step intended to improve the connectivity of the roadmap. Due to the randomness of the nodes, the planned route is not fixed.

In the query phase, the start node S and the goal node G are input. Next, connect S and G to some two nodes $\widetilde{S}$ and $\widetilde{G}$. Then, search the sequence of edges from $\widetilde{S}$ to $\widetilde{G}$ in E. Finally, the optimized feasible path connecting S to G is presented. Notably, when search the sequence of edges in E, some other algorithms are to be used. In this paper, A* algorithm is chosen to implement this function.

2.2. A* algorithm

A* algorithm is proposed by Hart et al. (1968), which is an extension of Dijkstra's algorithm. It is widely used in computer games. The evaluation function $f(n)$ consists of two parts.

$$f(n) = g(n) + h(n) \tag{1}$$

where, $f(n)$ is the cost from the start node S to the goal node G; $g(n)$ is the actual cost of the path from the start node S to the current node n; $h(n)$ is the estimated cost from the current node n to the goal node G. Furthermore, there are an Open list and a Closed list in A* algorithm. The initial Closed list is empty and the initial Open list only includes the start node S. In order to search for the optimal node connected to the current node n, the neighbors of the current node n are added to the Open list. The initial current node is the start node S. Then, search the Open list for the node with the minimum f-value and take it as the new current node n'. Next, switch the searched node n' to the Closed list.