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Path-planning research in radioactive environment based on particle swarm algorithm

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ABSTRACT

During the design, maintenance and decommissioning of nuclear facilities, nuclear radiation protection is an important part. In recent years, researchers have explored a lot of radiation protection approach, and some radiation protection approach have been applied in practice, such as visualization technique of radiation environment, path-planning method, robotics and etc., in these techniques the path-planning in radiation environment technology has become an important radiation protection measure. In this paper, we addressed a staff walking path-planning approach in radiation environment based on particle swarm algorithm and introduced some key technologies of path-planning in radiation environment. To obtain the optimal walking route to verify the operation of the proposed method, we carried out the simulation experiment in which dose and distance were as decision factors. The experiment results represented the probability and the effectiveness of path-planning in radiation environment based on particle swarm algorithm.

1. Introduction

It is the mission of engineers to design nuclear facilities and systems to be as safe as possible and to take necessary measures to preserve the safety and the health of personnel in nuclear power plant. However, no matter how sophisticated the designs, radiation exposure is unavoidable. According to statistics, the radiation dose that staff suffered during the daily activities of normal operation takes 20% of the total annual dose in Chinese nuclear power plant, and the radiation dose that staff suffered during the overhauling of nuclear power plant takes 80% of the total annual dose (Haixia Wan, 2012). As everyone knows, the basic ways of external irradiation protection are to reduce the time that personal stays in the radioactive room expand the distance between personal and radiation source, and take the shielding measures. So we can take the method of path-planning in radioactive environment as one of the measures of external irradiation protection. By path-planning we can control the time that personal stays in radiation environment and the distance between personal and radiation source, thereby to reduce the radiation exposure that personal suffered during work.

For the path-planning methods in radiation environment, domestic and foreign researchers have done a lot of research. For example, the Fugen Nuclear Power Station (NPS) in Japan was shut down permanently, Japanese developed Decommissioning Engineering Support System (DEXUS) to create a dismantling plan using state-of-the-art software such as 3-dimensional computer aided design (3D-CAD) and virtual reality (VR). In particular, an exposure dose evaluation system using VR has been developed and tested (Johnsen et al., 2004). The total system can be used to visualize radiation and evaluate the dose that personal suffered to optimize the walking route and the decommissioning plan.

Mól et al. used a game engine for virtual reality simulations in emergency situations (Mól et al., 2008). Game engine's open source code and existing functionalities are convenient for researchers and developers to simulate scenarios. The simulation platform collected dose rate data from radiation monitors installed in the real plant, then researchers assess dose for personnel (Mól et al., 2009). Further, Mól et al. used neural networks and virtual reality techniques for assessment of radiation dose exposition by nuclear plant's personnel, to optimize working tasks for minimisation of received dose (Mól et al., 2011).

South Korean developed simulation technology for prediction of radiation dose, which was developed by VRML and Java Applet. This simulation program can display radiation exposure levels in a virtual reality environment, represent high dose danger zones by

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graphically visualizing dose rates and predict the exposure dose of virtual workers (Kim and Park, 2004). This simulation program need specific dose calculation model to calculate the dose rate distribution, and then the workers should try and compare many paths to determine minimum radiation dose path.

American L.S. Pachter and M. Pachter considered the problem of navigating between points in the plane so as to minimize the exposure to radiation source. In order to resolve this problem, L.S. Pachter and M. Pachter introduced a weighted exposure and path length optimization problem and applied requires a variational approach (Pachter and Pachter, 2001). L.S. Pachter has demonstrated the feasibility of this method that barrier-free environment theory in point source radiation field. The method may determine a minimum dose path, but the length of the path maybe too long and curved path is difficult to realize in practice.

American M. Hage designed evolutionary software techniques based on sensor in radiation environments, and achieved the target which mobile vehicles avoid obstacle and reduce the continued radiation exploration (Hage and Couture, 1999). In the method, the genetic program was very complex and it need to be trained in known environments and then utilized in an unknown environment. The method was designed for the robot in radioactive environment, and not ensures the cumulative dose minimum on the optimized path, therefore maybe not suitable for walking path-planning of staff.

American Alzalloum (2009) addressed the least cost path problem for a radiological contaminated area and found optimal paths using Dijkstra's and Bellman–Ford algorithms, in these paths the total radiation exposure (cumulative dose) is minimum. In addressing this problem, Alzalloum took radioactive contamination area into vertices and edges, and respectively applied the point nuclear radiation model and Monte Carlo dose calculation model as the weights of each side of the edge. Dijkstra's and Bellman–Ford algorithms were modified and coded in Matlab, through simulation tests, and ultimately to find the optimize path which the total radiation exposure (cumulative dose) was the lowest. Alzalloum methods in the application process was too dependent on radiation field model, and ignored the actual environment of radioactive shielding, therefore, this method is only applicable to ideal radioactive environment, with some limitations.

Khasawneh et al. in the University of Jordan addressed a localized navigation algorithm for radiation evasion. A well-designed and wireless sensor networks infrastructure that is distributed in radioactive environment, through sensors measure the radioactivity level and using wireless communication technology transfer the information, finally the use of local navigation algorithm based on graph coloring theory for radioactive evasion (Khasawneh and Al-Shboul, 2010; Khasawneh et al., 2013a,b). Khasawneh et al. who have some practical ways, but in some radioactive environment, the algorithm would be stalled or cycled so that the optimal path can't be found, simultaneously, this method requires a lot of wireless sensors in practical applications, and it also increases the economic inputs.

The researches of path-planning in radioactive environment are seldom in China. Haixia Wan in North China Electric Power University, who developed rapid calculation program for dose rate distribution in visualization platform of radiation field based on Monte Carlo method (Haixia Wan, 2012). The program combined the virtual reality technology and radiation protection techniques, applied the computer to simulate dose rate distribution in complex radiation field environment, did virtual experiments operation, and calculated and displayed the data in real-time, eventually the computer terminals provide the radiation exposure situations obviously to the user. It is thus clear that the radiation field visualization is an effective means to reduce radiation dose for nuclear workers.

Currently, path-planning method in radioactive environment is mainly focused on searching the minimum total radiation exposure (cumulative dose) path. China has not yet a very perfect path-planning technology for radiation environment in practical engineering tasks. In some simulation experiments and practical applications, it is not easy to find that distance and cumulative dose do not have explicit mathematical relationships. Due to the requirements for tasks are different, the requirements for the path may also be different. For example: equipment maintenance, decommissioning of nuclear facilities, nuclear emergency and other engineering tasks in the nuclear power plant, which require not only the low radiation doses, but also little travel time or low cost.

Therefore, we proposed multi-objective path problem in radiation environment, and did research in this area using particle swarm algorithm and multi-objective decision-making techniques. On these bases, finally we addressed a multi-objective path-planning approach based on particle swarm algorithm in radiation environment, and did simulation experiments in a static radiation environment with dose and distance as two decision factors.

The rest of this paper is organized as follows: path-planning strategy, particle swarm algorithm and decision-making techniques are introduced in Section 2. The mathematical model of path problem in radiation environment and the implementation of the proposed method are described in Section 3. Section 4 describes the simulation experiment. Section 5 analyzes the results of simulation experiment. Finally, Section 6 presents the concluding remarks for this paper.

2. Path-planning method

The structure of path-planning method in radiation environment based on particle swarm algorithm is shown in Fig. 1. First, we get the geometry of radiation environment, distribution of dose rate and decision factors. Second, we set nodes in radiation environment, obtain weights of dose values between any two nodes, construct alternative road network. We transfer path-planning problem in radioactive environment into a variant TSP (traveling salesman problem), and then build the mathematical model of this problem. At last, we combine particle swarm optimization algorithm with multi-objective decision-making techniques to form the path-planning method in the radiation environment, and then implement the method by programming.

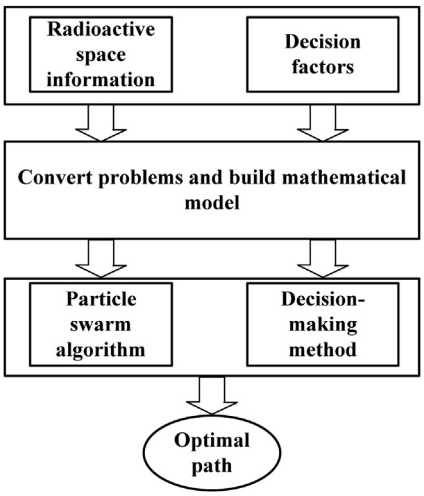

Fig. 1. The structure of multi-objective path-planning in radioactive environment based on PSO.