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Minimum dose method for walking-path planning of nuclear facilities

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ABSTRACT

A minimum dose method based on staff walking road network model was proposed for the walking-path planning in nuclear facilities. A virtual–reality simulation program was developed using C# programming language and Direct X engine. The simulation program was used in simulations dealing with virtual nuclear facilities. Simulation results indicated that the walking-path planning method was effective in providing safety for people walking in nuclear facilities.

1. Introduction

The working environment of nuclear power plant features high risk and high radiation, and so it is necessary to take measures to ensure the safety of staff working in a nuclear power plant. The effects of radiation cannot be readily detected relying on our senses, so the walking path relying on our senses may be not safe or efficient. But the path-planning method for nuclear facilities beforehand is very effective in the control of time and distance. Therefore, efficient path-planning programs and simulations are badly needed, to improve the processes involved and increasing safety for people.

Much work has been done recent years on the planning of walking-path in radiation environment. For example, Iguchi et al. (2004) developed a Decommissioning Engineering Support System (DEXUS) to create a dismantling plan such as 3-dimensional computer aided design (3D-CAD) and virtual reality (VR) technology, and the VR dose software can simulate the staff activities on related work scene, to visualize the radiation dose that staff suffered (Johnsen et al., 2004). But the VRdose software could be used to plan artificial path only.

South Korean (Kim and Park, 2004) developed simulation technology using VRML and Java Applet in 2004. To display radiation exposure levels in a virtual reality environment, represent high dose danger zones by graphically visualizing dose rates and predict the exposure dose of virtual workers.

American Alzalloum (2009) addressed the least cost path problem for a radiological contaminated area and found the minimum radiation exposure paths using Dijkstra and Bellman–Ford algorithms.

Khasawneh et al. (2013a,b) addressed a localized navigation algorithm for radiation evasion. A well-designed wireless sensor networks infrastructure is distributed in radiation environment.

Liu et al. (2014) in China proposed the multi-objective staff walking path problem in radiation environment, and then combined particle swarm optimization algorithm with multi-objective decision-making techniques to solve this problem.

Mól et al. (2008) used a game engine for virtual reality simulations in emergency situations. The simulation platform collects dose rate data from radiation monitors installed in a real plant, then researchers assess dose for personnel (Mól et al., 2009). Further, Mól et al. (2011) used neural networks and virtual reality techniques for assessment of radiation dose exposition by nuclear plant's personnel.

These methods are on theory without general mathematic, environment model and criterion. Related simulate program is scarce, and experimental data are difficult to obtain and compare to analyze. Therefore, a road network in radiation environment was established to find that distance and cumulative dose do not have explicit mathematical relationships, and then we can plan path based on it artificially. A staff walking path-planning method in static radiation environment for the minimum radiation exposure path problem in radiation environment was addressed.

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Finally, a path-planning virtual–real mixed simulation program in radiation environment was developed.

The rest of this paper is organized as follows: Section 2 briefly describes A* algorithm. Section 3 focuses on the implementation of the proposed method. Section 4 briefly introduces the simulation program. Section 5 describes the simulation experiments. Section 6 analyzes the results of simulation experiment. Section 7 presents the concluding remarks.

2. Techniques used for planning of walking-path

Dijkstra's algorithm was conceived by Dijkstra (1959), is a graph search algorithm that solves the single-source shortest path problem for a graph with non-negative edge path costs, producing a shortest path tree.

A* algorithm was firstly described by Peter Hart, Nils Nilsson and Bertram Raphael of Stanford Research Institute (Hart et al., 1968, 1972). It is an extension of Dijkstra's algorithm. A* is commonly used for the common pathfinding problem in applications such as games, but was originally designed as a general graph traversal algorithm.

The walking path could be searched using the following equation:

$$F(n) = G(n) + H(n) \tag{1}$$

where,

$F(n)$ is the cost between start node and destination.
$G(n)$ is the actual cost of optimal path between start node and node (n).
$H(n)$ is the estimated cost between node (n) and destination.
$G^*(n)$ is the cost of a path from start node to destination with minimum cost so far found by A*, $H^*(n)$ is any estimate of the cost of an optimal path from node (n) to a preferred goal node of node (n). If $G(n) \geqslant G^*(n)$ and $H(n) \geqslant H^*(n)$, A* algorithm can be used to find the least cost path.

A* algorithm needs Open list and Closed list. Open list is used to store unchecked nodes. Closed list is used to store checked nodes. A* algorithm works as detailed below:

(1) Add start node to Open list.
(2) Repeat the following steps:
  (a) Check for the lowest F cost node on Open list, which is referred to as the current node.
  (b) Switch it to Closed list.
  (c) For each of the nodes adjacent to this current node:
    - If it is not walkable or if it is on Closed list, ignore it. Otherwise do the following.
    - If it is not on Open list, add it to Open list. Make the current node the parent of this node. Record costs of F, G, and H for the node.
    - If it is on Open list, using G cost as the measure to check if this path is better. A lower G cost means this is a better path. If so, change the parent of the node to the current node, and recalculate the G and F scores of the node. If your open list is sorted by F score, resort the list to an account for the change.
  (d) Stop when you:
    - Add the target node to Closed list, and in this case the path has been found, or
    - The target node has not been found, and Open list is empty. In this case, there is no path.
(3) Save the path. Working backwards from the target node, go from each node to its parent node until you reach the start node.

3. Methods

Structure of path-planning methods for nuclear facilities is shown in Fig. 1. Preliminary data is obtained. And then Road network of nuclear facilities is built. Artificial and minimum dose path-planning methods are designed.

3.1. Road network

Road network has direct influence on the quality and efficiency of path-planning, is the basis of path-planning methods for nuclear facilities. Road networks include grid model, visibility graph model and free-space model. Different road networks lead to different planning results.

Visibility graph model needs visible points need be settled in the scene. The number and position of visible points are determined by staff on the site before walking-path planning. Visibility graph model was included in the path-planning method based on particle swarm algorithm for radioactive environment. The cumulative dose between visible points has larger errors in the calculation. Free-space model is not suitable for the assessment of cumulative dose exposured in nuclear radiation field. Thus, compared to two methods above, grid model has dose rate distribution data of scene and reduced calculation error of cumulative dose. Grid is proposed by Howden in 1968.

Each grid, representing one region in workplace, has eight neighboring grids: top, bottom, left, right, top left, bottom left, top right, bottom right. Considering the particularity of grid, movement of object is shown in Fig. 2(a).

The digital map contains workplace structure map and dose rate distribution map. Workplace structure map is a two-dimensional array with 0 and 1, as shown in Fig. 2(a). Obstacle is represented by 0, free space is represented by 1. Arbitrary shape obstacle and equipment is represented by some finite grids.

Dose rate distribution map is also represented by a two-dimension array, as shown in Fig. 2(c). Each grid contains one dose rate which is the average of all dose rates in one grid. If the dose rate at any position in one grid is equal to the average dose rate of this

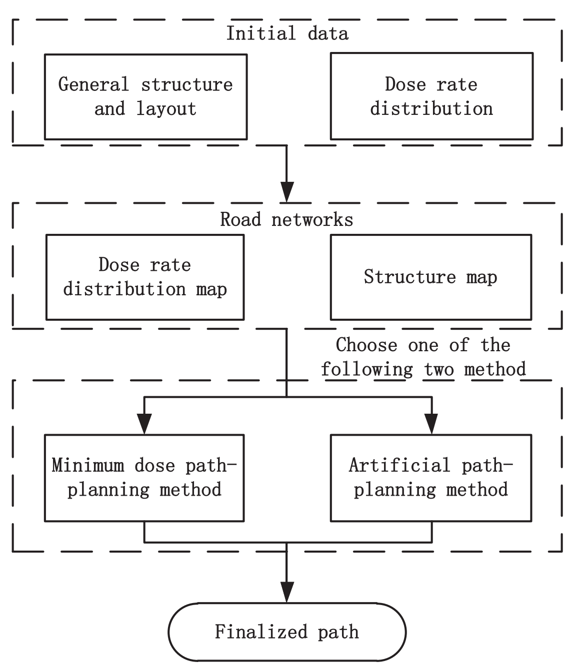

Fig. 1. Structure of path-planning methods for nuclear facilities.