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Search for Radioactive Sources in Obstacle Areas

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Abstract:

This article considers computer-aided search for missing radioactive sources in obstacle areas. In this paper, we design a heuristic algorithm to track the maximum radiation dose to locate the radiation source according to the distribution characteristics of the radiation field with obstacles. And by optimizing the search model, the model has strong practicability and adaptability. Simulation experiments prove that the above algorithm can search for radioactive sources in a relatively short time.

Keywords:*Nuclearradioactivesource,Radiationfielddistribution,Search,Algorithm.*

I. INTRODUCTION

The search for out-of-control radioactive sources is mostly limited to personnel engaged in nuclear technology. With the help of radiation detectors, the search is inefficient in special circumstances. Long-term exposure to high-radiation environments has become a bottleneck that restricts the development of radioactive source search technology. Scholars at home and abroad are actively trying to explore new search methods to locate the radioactive source.

In the traditional radioactive source search, scholars at home and abroad use vehicle borne large crystal sodium iodide detector to search suspicious areas, and use portable detector carried by people to search large areas on foot in places where traffic is inconvenient [1,2]. In this search mode, people need to search in the high radiation environment for a long time.

Some scholars also try to use mathematical methods to study the location of radioactive sources, which goes beyond the limitation that nuclear professionals can only study and find radioactive sources. The generalized maximum likelihood rule is used to estimate the number and location of radioactive sources, and the parameters and the number of sources in the Bayesian framework are estimated by Monte Carlo integration[3,4]. The source location

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problem described by PDE[5]. Based on the G-M counter of multiple radiation sources, the location of radiation sources is carried out [6]. Bayesian method is used to improve the information source location of MLM [7]. There is also a positioning model based on the inverse ratio of dose rate and the square of distance [8].

However, there are also many scholars who are committed to the application of robots in radioactive search [9-12]. There is also a combination of mobile robots and Compton Camera to locate radiation sources[13], but the cost of robot technology development and application is high, and the core technology of robot search is still algorithm, so a good algorithm is the key to improve the robot search performance.

In the rapid development of nuclear technology, computer-aided artificial intelligence random search meets the needs of safety and low-cost development, and the research foundation of computer-aided artificial intelligence is extensive. Therefore, many scholars have designed algorithms to simulate the search of radioactive sources on the computer [14-19].

In 1995, Wacholder E, Elias E, Merlis Y.[20]uses artificial neural networks to locate radioactive sources. In 2005, Presler O[21] and others developed a simple and practical algorithm to use two detectors to measure the emission of gamma rays from a huge sample, so that the ratio of the detector's counting rate can be used to locate the position of the point source of the bulk volume. In 2019, in order to solve the problem of expensive instrumentation and complicated positioning process in locating radioactive sources, Ming Sheng W [22] proposed self-adaptive M-H sampling algorithm for locating the radioactive sources is. Firstly, the dose of different measurement points in the radiation field was obtained by a portable personal dosimeter. Then, based on the spatial decay law of the source, a Bayesian inference model for estimating the position of the point source was established, and the posterior distribution of the source parameters was obtained. Finally, the posterior distribution was sampled by the M-H algorithm, which adaptively adjusts the initial value and the proposed function variance to realize the localization of the point source in the indoor environment. The experiments were carried out with Eu-152.The simulations show that the algorithm can locate source with a small error, and the method is feasible and effective. In 2015, Min Zhang [18] designed a heuristic search algorithm for line scanning, which can quickly search unknown sources in a short time. In this article, the author uses a small amount of grid data and a simulated human search design algorithm and focuses on the search of radiation sources in complex terrain.

II. SEARCH FOR THE RADIATION SOURCE IN THE OBSTACLE AREA

Let's assume that choose a rectangular area as the search area. Evenly divide the length of the rectangleinto n cells $x_1, x_2, \cdots, x_{n-1}$, and the the width of the rectangle into m cells $y_1, y_2, \cdots y_{m-1}$, and obtain a rectangular grid in the area, and record the radiation dose at the grid node as$f_{i,j}, i = 0,1,2, \cdots, n, j = 0,1,2, \cdots m$.

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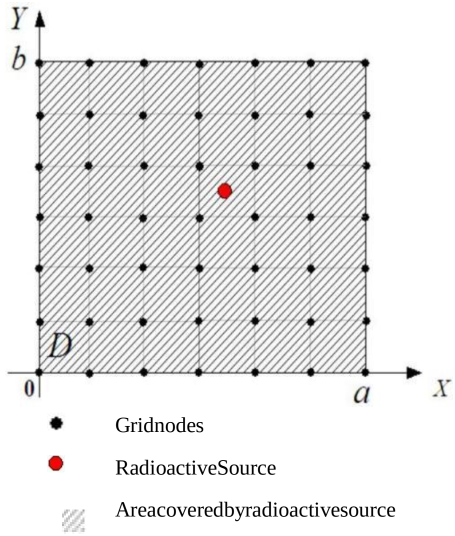

Fig1:Meshing of the search area

2.1 Judgment of the RadioactiveSource

The logic of searching the point with the largest dose value in the grid is used to locate the radiation source. However, in practice, sometimes the maximum point is not the real radiation source point due to objective factors, such as data misreading. Therefore, when searching the maximum point, it is necessary to determine whether the point is a radiation source point. So we need design the algorithm to judge the radiation source.

As the inverse ratio of the dose at any point to the square of the distance from the radiation source [23], so the tangent slope of the radiation dose curve increases gradually with the increase of (or direction) value in the interval excluding the point where the radiation source is located in the axial (or direction) and the tangent slope does not exist at the point where the radiation source is located.

The specific operation process of partial derivative threshold construction is to find out all maximum points $\mathrm{f}(\mathrm{x_i}, \mathrm{y_i}), \mathrm{i} = 1,2, \ldots, p$($p$ is the number of maximum points) in the search area. Then the partial derivative is obtained for each extreme point, that is, for each extreme point (x_i, y_i) in a very small change intervalΔx, the partial derivative is obtained in the X direction.

$$\frac{\partial \mathrm{f}(\mathrm{x_i}, \mathrm{y_i})}{\partial \mathrm{x}} = \frac{\mathrm{f}(\mathrm{x_i}+\Delta \mathrm{x}, \mathrm{y_i}) - \mathrm{f}(\mathrm{x_i}, \mathrm{y_i})}{\Delta \mathrm{x}}$$

If $\frac{\partial \mathrm{f x_i}, \mathrm{y_i})}{\partial \mathrm{x}} \leq t$, then (x_i, y_i) is not a radiation source. If$\frac{\partial \mathrm{f x_i}, \mathrm{y_i})}{\partial \mathrm{x}} > t$,then $(x_i, y_i)$is a radiation source,where t is an adjustable parameter,$1 \leq t < +\infty$. The actual t generally takes 5, 10, etc. See Partial Derivative Threshold Algorithm 2.1 for details.

Algorithm 2.1Partial Derivative Threshold Algorithm

Step1 Input the adjustable parameter$t$ and the maximum point to be determined.

Step2 Calculate the value $\frac{\partial f\, x_i, y_i)}{\partial x} = \frac{f(x_i+\Delta x, y_i) - f(x_i, y_i)}{\Delta x}$ for each maximum point (x_i, y_i).

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Step3 If $\frac{\partial f\, x_i\, ,y_i)}{\partial x} \le t$ then the point is not a radiation source else the point is a radiation source.

Here are some explanations for the algorithm of partial derivative threshold construction:

(1)For different types of radiation sources with different radiation equivalents, the selection of control parameters t is different, and the use of thresholds should be based on the actual situation to estimate the type of radiation source and dose selection.

(2)When calculating the partial derivative of the radiation dose function, because there is no exact analytical expression of the radiation dose function in the radiation field, the partial derivative of X can be transformed into the difference function of the radiation dose between the unit grid nodes, and it can also approximate the tangent slope in the X direction.

(3)The idea of partial derivative threshold construction can also be used with search algorithm as a judgment condition to prevent entering the pseudo region of multiple point radiation field to improve the search efficiency.

2.2 Search for Radioactive Sources with Obstacles

The search for radioactive sources in flat and unobstructed areas has been studied in detail. The actual radioactive source search is usually in urban or mountainous areas, often covered by high-rise buildings and staggered. In order to be able to search for nuclear radiation or hills under complex terrain effectively, the search for obstacle areas needs to be discussed.

For the search of radioactive sources with at obstructed areas, this article considers point sources with fixed radioactive sources and the same radioactive material. The radioactive source can be located on the grid node or inside the grid. If the grid is inside, the grid can be further subdivided to make the radioactive source point on the grid node. Sometimes in order to simplify the search problem and highlight the nature of the search algorithm, it may be better to set the radiation source point on the grid node.

2.2.1 Tracking Radiation Extreme Direction Search

In the search area of the radiation field, due to the reflection effect of the obstacle, the obstacle is deformed toward the radiation source surface, thereby forming a local radiation metering area. At the same time, due to the obstruction of the obstacle, the radioactive material weakens the radiation field when penetrating the obstacle, so that the local radiation measurement dose weakening area is formed away from the radiation source surface, thus breaking the original radiation measurement distribution law.

In the accessible search area D, it is noted that the distribution of the radiometric field in a small area centred on the radioactive source has the following characteristics:

(1)The radiometer field distribution in a small area centred on the radioactive source is symmetrical.

(2)The radiation measurement in the horizontal (vertical) direction has the same trend and opposite directions.

In the search area with obstacles, if there are obstacles next to the radioactive source, a small local neighbourhood that contains the radioactive source but does not contain the obstacle

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can always be found, so that the radiometric field in the neighbourhood still has the above characteristics. Therefore, using the characteristics of the radiometric distribution in the small area where the radioactive source is located, a radiometric direction method was designed to search for radioactive sources.

For each grid node (x, y), construct the horizontal index functions $F_1(i,j), F_2(i,j)$ and vertical index functions $F_3(i,j), F_4(i,j)$.

Definition 1 For any grid node $(x_i,y_j) \in D$ in the search area, if the function $F_1(i,j)$satisfies

$$F_1(i,j) = \begin{cases} \vec{i}, & f(x_{i+1},y_j) > f(x_i,y_j) \\ 0, & f(x_{i+1},y_j) \le f(x_i,y_j) \end{cases},$$

if the function $F_2(i,j)$satisfies

$$F_2(i,j) = \begin{cases} -\vec{i}, & f(x_{i+1},y_j) > f(x_i,y_j) \\ 0, & f(x_{i+1},y_j) \le f(x_i,y_j) \end{cases},$$

then $F_1(i,j), F_2(i,j)$ are called the positive and negative index functions of the point in the horizontal direction.

Definition 2 For any grid node $(x_i,y_j) \in D$in the search area, if the function $F_3(i,j)$satisfies

$$F_3(i,j) = \begin{cases} \vec{j}, & f(x_i,y_{j+1}) > f(x_i,y_j) \\ 0, & f(x_i,y_{j+1}) \le f(x_i,y_j) \end{cases},$$

if the function $F_4(i,j)$satisfies

$$F_4(i,j) = \begin{cases} -\vec{j}, & f(x_i,y_{j+1}) > f(x_i,y_j) \\ 0, & f(x_i,y_{j+1}) \le f(x_i,y_j) \end{cases},$$

then $F_3(i,j), F_4(i,j)$ are called the positive and negative index functions of the point in the horizontal direction(as shown in Fig 2).

For the search area D that has been defined and divided by a grid, two radiation measurement direction index functions, a horizontal direction index function and a vertical direction index function, are defined for each grid node in the area D. The direction index function can determine the direction of radiation measurement change in two directions at this point. The positive and negative doses of the direction index function correspond to the direction in which the radiation metering of the radiation source becomeslarger.

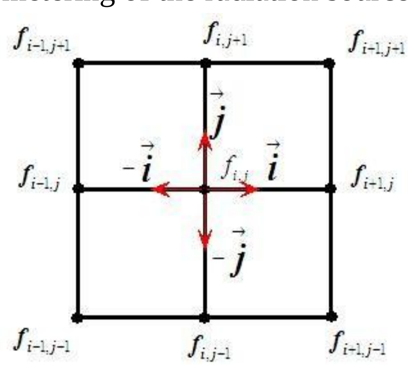

Fig2: Direction indicator function of data node of element grid

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Assume that the search area D of the obstacle is meshed, and the entire grid node sets $A = \{(x_i, y_j)|i = 0,1,,2 \ldots, n, j = 0,1,2, \ldots, m\}$in the sub-area within the search areaD$'$.

Definition 3 For any grid node $(x_i, y_j) \in D$ in the search sub regionD', if W satisfies the following relation

$$W = \sum_{(x,y)\in A}\left||F_1(x,y) + F_2(x,y)|\right| + \sum_{(x,y)\in A}\left||F_3(x,y) + F_4(x,y)|\right|.$$

then$W$ is called an index function of the radiometric change rate of the region D'.

In theory, if point (x, y) is a radioactive source, according to the principle of radiometric direction search, it is assumed that the radiometric horizontal index and the vertical index of a small area in the center of (x, y) should be 0, that is,

$$\sum_{(x,y)\in A} ||F_1(x,y) + F_2(x,y)|| = 0, and \sum_{(x,y)\in A} ||F_3(x,y) + F_4(x,y)|| = 0.$$

However, in fact, due to grid node data deviation and the location of the radiation source is not strictly located on the grid node, the radiation measurement direction index function of the radiation source point will not be equal to 0. Therefore, in actual operation, the search condition is to find regional radiation Measure the point with the smallest directional indicator function.

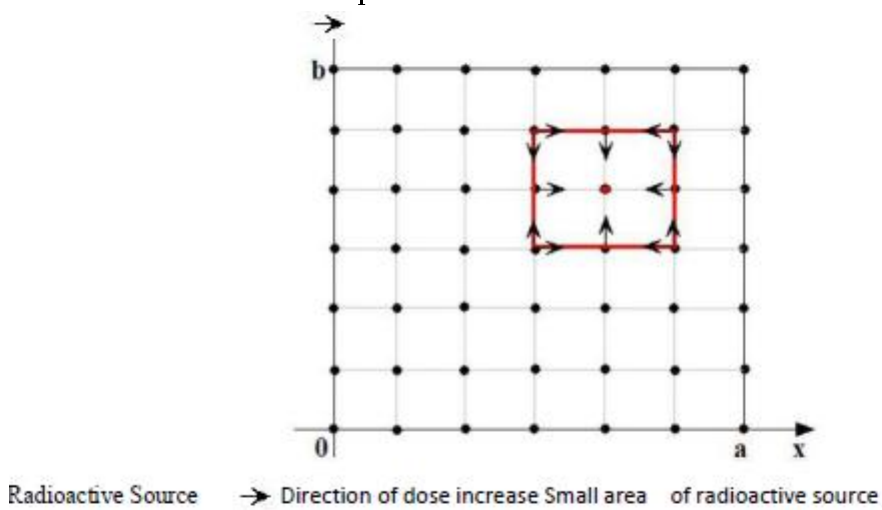

Fig3: Schematic diagram of radiation measurement changes in the area direction

The idea of tracking the radiometric maximal direction method is to find a small area with arbitrary points in the search area, and calculate the direction indicators and functions W of all nodes in the area. If W is smaller, the four directions in the area are more balanced, and the radiation source is only available. May be in the area. By calculating the weights of the small regions containing each grid node one by one, the regions of possible radioactive sources can be filtered out. Because radiometric distribution around the extreme points of the pseudo-region superimposed by the radioactive sources is also relatively symmetrical, the possible radioactive source points that are screened need to be combined with threshold judgment criteria to identify the pseudo-points and radioactive sources. For complex areas with obstacles, when nuclear radiation is shielded or blocked, the directional radiation metering search method is also

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applicable. See Radiation Metering Direction Search Algorithm 2.2 and Fig 3. fordetails.

Algorithm 2.2 Searching for the maximum direction of radiation dose Algorithm

Step1 Enter the threshold parameter M and the control parameter ε.

Step2 For any point $(x_i,y_j) \in D$, calculate the direction index function and function W of all nodes in the field grid area centered on $(x_i,y_j) \in D$.

Step3 If $W<\varepsilon$, output this point (x_i,y_j).

Step4 If the output point radiation measurement is greater than the threshold radiation measurement M, the point is output as a radiation source.

The following is a description of the search algorithm for tracking the maximum direction of radiometric measurement:

(1)In step 2 of the algorithm, the direction index function of each small area where each grid node is located can be calculated point by point in the grid for judgment. The radiometric direction search algorithm can be optimized and considered. After the maximum point is selected in the search, the direction index function dose W of the field grid where the maximum point is calculated is judged.

(2)The radiation measurement direction search algorithm needs to be implemented under a fine grid to ensure that the direction weight W of the small area where the radioactive source is located can be minimized, but too fine grid will increase the search time.

(3)If the radioactive source is at the grid node, the direction index function W of the area centered on it is close to zero. In fact, the radioactive source is not necessarily located exactly at the grid node, so the dose of W will not be small. Therefore, a smaller dose of s can be selected as the basis for judgment. When $W < \varepsilon$, it can be considered that there may be radiation. Source, but whether or not there must be a radioactive source, it needs to be determined in conjunction with the threshold judgment method.

(4)If the obstacles in the search area are small and exist in the area where the radiation source point is located, then the size of the small area containing the grid nodes should be appropriately increased. In a larger area, the area's radiation measurement direction The weight will also be small, so it will not affect the search results of the radioactive source; if the obstacle is large, especially the radioactive source is located next to the larger obstacle, the direction index weight of the area will increase a lot, this The determination of the weight of the radiometric direction will be invalid, so the radiometric direction search algorithm needs to be further improved.

2.2.2 Improved Algorithm of Tracking the Direction of Maximum Radiation Dose

When the radioactive source is next to a large obstacle in the search area or the radioactive source is on the edge of the search area, the radiometric direction search algorithm is used to obtain the radiometric direction weight of the area where the radioactive source is located. It will be discarded. At this time, the effect of the radiometric direction search algorithm is not

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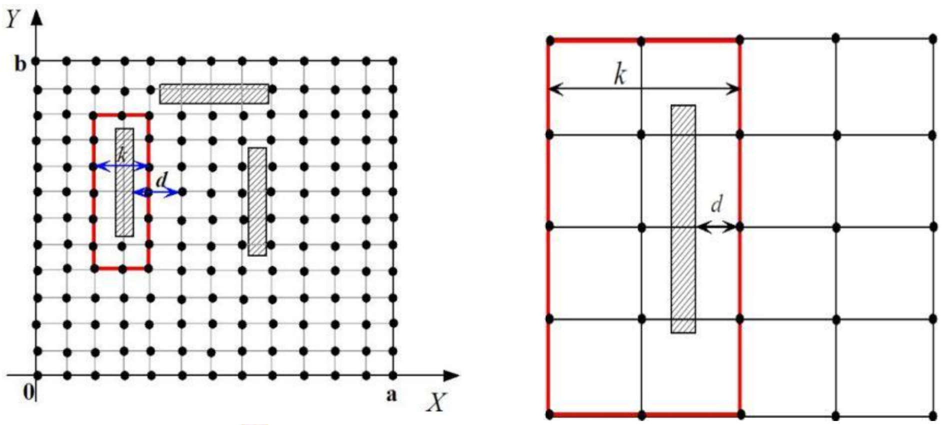
ideal. Therefore, the radiometric direction search algorithm needs to be improved, so that the radiometric direction search algorithm has strong adaptability.

Definition 4 For the obstacle area $Z_i, i = 1,2,\ldots,s$ in the search area D (is the numberofobstacles), for$\forall(x,y) \in D, \forall(x^{'},y^{'}) \in Z_i)$, it is called

$$d = min\{\sqrt{(x' - x)^2 + (y^{'} - y)^2}\}$$

And the shortest distance from point $(x,y)$to obstacle Z_i.

When the radioactive source is next to a large obstacle in the search area, it needs to be discussed separately.



Obstaclearea;*d* Nearest distance between obstacle andnode*K*Side length of area containingobstacles

Fig4: Schematic diagram of the relationship between the distancebetween obstacles and neighboring points and the length of thegrid

(1)If the distance d of the larger obstacle from the nearest grid node is greater than the grid lengthkofthedeterminedfieldgridarea,thatis,$d>k$,thegridnodethatmeetsthisconditionisnear the obstacle. Radiation measurement direction search algorithm. The radiation measurement weight of these grid nodes is relatively large. For these grid nodes with larger weights, combined with the judgment of the partial derivative threshold condition, it can be determined whether the point is a radioactive source. As shown in the left figure of Fig 2.4.

(2)If the distance d between the larger obstacle and the nearest grid node is less than or equal to the grid length k of the determined grid area, the instant $d \leq k$. The grid node that meets this condition is far from the obstacle. A small area containing the node and no obstacles can be found between the grid node and the obstacle. The radiometric direction search algorithm is used to determine the dose of the radiometric direction at this point. The grid node radiation measurement direction search algorithm is still used, as shown in the right figure of Fig4.

When the radioactive source in the search area is near the boundary of the search area, only half of the radiation field of the radioactive source remains in the search area, so the radiometric area of the radioactive source is asymmetric, so the directional radiometric weight is biased to one side. The grid's radiation measurement direction weight is large. For this type of point with a large weight, it is necessary to pick out and combine the partial derivative threshold theory to determine whether the point is a source point, as shown in Fig5.

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Through the grid nodes located next to the larger obstacles and the radiation source points on the boundary of the search area with larger weight points or grid nodes with less weight in the barrier-free area. In the end, the partial derivative threshold theory must be combined to determine whether the point is a sourcepoint.

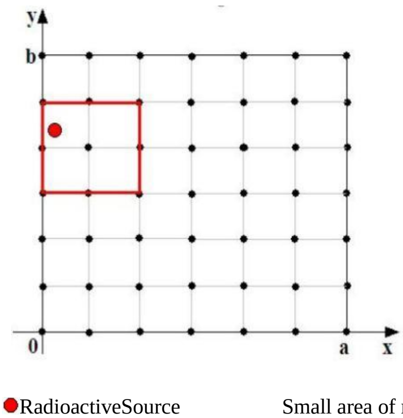

Fig5:Schematicdiagramoftheradioactivesourceattheboundaryoftheeacharea

The idea of the improved radiometric direction search algorithm is that when searching according to the radiometric direction search algorithm, the points with larger or smaller directional radiometric weights are likely to be radioactive source points. Therefore, for networks that meet these two conditions. The grid node combined with the partial derivative threshold theory is used to judge whether the point meets the characteristics of the radioactive source. If it meets, the point will be a radioactive source. The improved radiometric direction search algorithm 2.3 is given below.

Algorithm2.3 Improved radiometric direction search algorithm

Step1 Enter the threshold parameter k and the control parameter ε

Step2 For any point $(x_i, y_j) \in D$, calculate the direction index function and function W of all nodes in the field grid area centered on $(x_i, y_j) \in D$.

Step3 Judge the threshold W function;

Step3.1 If $W < \varepsilon$, output this point (x_i, y_j).

The partial derivative threshold algorithm is called on the point (x_i, y_j).
If (x_i, y_j) satisfies the partial derivative threshold condition, the point is output as aradioactive source.

Step3.2 If $W > k$, then output this point (x_i, y_j).

The partial derivative threshold algorithm is called on the point (x_i, y_j).
If (x_i, y_j) satisfies the partial derivative threshold condition, the point is output as a radioactive source.

Step4 If the output point radiation measurement is greater than the threshold radiation measurement M, the point is output as a radiation source

Here are some instructions for improving the radiometric direction search algorithm:

(1)The parameter s in step 1 of the algorithm is a threshold dose for determining whether

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there is a radioactive source at a grid node in an unobstructed area. Since there is no obstruction, the radiation metering distribution field centered on the radioactive source is symmetrical. The direction index function is generally close to zero, so s is generally verysmall.

(2)The parameter *k*is a threshold dose designed for the source point next to the obstacle or the source point on the boundary. When the directional function of all points in a small area is large and exceeds a preset threshold*k*, then the point is generally located next to the obstacle or the boundary of the search area.

(3)Step 3 in the algorithm adds the judgment of the radiation weight in the higher direction, whether it is a point with a large weight next to the obstacle, or a point with a large weight on the boundary of the search area and the dose is extremely small. Points need to be judged. Whether the source is a combination of partial derivative threshold theory and radiometric threshold theory is used tojudge.

III. SIMULATION

The search algorithm for tracking the maximum direction of radiometry uses 200 × 200 grid data, plus a circle of data 0 in the original grid data, to ensure that any point on the boundary has a field-shaped grid. The origin of the coordinate is at the plane (1,1).

In the radiation field, there is a radioactive source located at (1051,1051), and its radiometric value is 4×10^{12} units. Through the directional radiometric search algorithm, a point with a directional radiometric weight of 0 is found, that is, the source point is exactly at (1051, 1051), the radiation measurement value is 4×10^{12} units, and the experimental results meet the actual search requirements.

IV. CONCLUSION

In this paper, the heuristic algorithm is used to design the search algorithm for the radiation source in the obstacle area. The algorithm tracks the maximum direction of radiation measurement, and the simulation show that the algorithm can search for the radiation source in a short time. Therefore, the heuristic search algorithm is feasible and effective.

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