Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Radiation Exploration Algorithm Using the Combination of Spatial and Radiation Data for Radiation Distribution

Woosung Cho [a], Minjae Lee [b], Janghee Lee [a], SongHyun Kim [b*]
[a] *Division of Advanced Nuclear Engineering, Pohang University of Science and Technology (POSTECH)*
San 31, Hyoja-dong, Nam-gu, Pohang, Gyungbuk, Republic of Korea, 37673
[b] *SIERRA BASE, 76, Techno saneop-ro, 29beon-gil, Nam-gu, Ulsan, Republic of Korea, 44776*
[*]Corresponding author E-mail: shkim@sierrabase.co.kr
E-mail: romaster93@postech.ac.kr

***Keywords: Radiation exploration, Path planning, SLAM, Radiation distribution**

1. Introduction

In radiation-related facilities, a variety of accidents such as incidents of loss, theft, leakage, and contamination of radioactive materials annually occur. When an incident occurs, it is crucial to conduct recovery and prompt response to minimize additional damage. For prompt response, it is necessary to determine the location of radioactive material and understand the surrounding radiation distribution [1].

Radiation exploration algorithm is the most effective way for collecting radiation information without human involvement. It generates the optimal path to measure the radiation distribution, which provides the information for estimation of radioactive material location. [2-4]. However, the exploration algorithm to consider only radiation measurement data may result in problems to overlook sections and not cover all areas within the limited mission time.

Therefore, the approach to combine the two pathfinding strategies for spatial and radiation measurement data is proposed in this study. The use of spatial data enables the perception of the surrounding elements in uncertain environments and the simultaneous optimization of the overall exploration path. Radiation measurement data collected in real-time allows the creation of path for estimating distribution.

This paper is organized into four sections. Section 2.1 describes radiation-related path planning, Section 2.2 describes the combination method of geometric-based path planning and radiation data-based path planning, Section 3 shows the comparison of the proposed method and previous method, and Section 4 summaries future work.

2. Method

2.1 Path Planning based on Radiation Data

The location of radioactive material can be determined from accurate distribution data. Although radiation measurement data is collected in every spot of the exploration area for accurate radiation distribution, it is impossible to explore every spot due to some limitations. The entire radiation distribution can be obtained by using the regression methods and the partial measurement data.

The performance of radiation distribution prediction depends on the changes between adjacent value in partial measurement data.

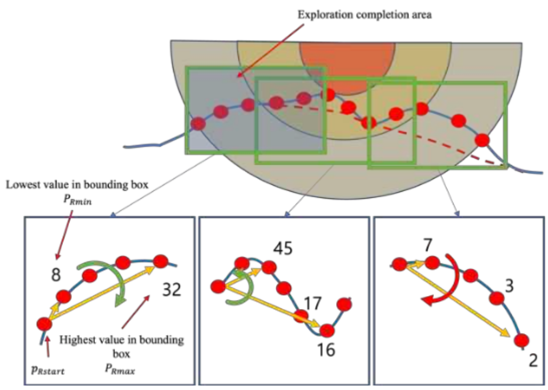

Fig. 1. Radiation-based path planning

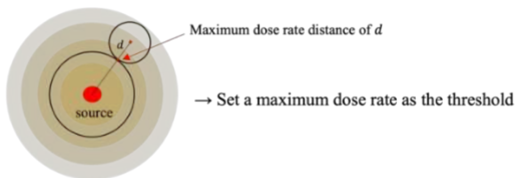

Fig. 2. Radiation threshold setting method

Exploration involves collecting radiation data in real-time, and radiation data is updated in the form of a queue. Stored radiation data and positions are denoted as R and P_r, respectively. Stored radiation data in the queue is vectorized based on maximum, minimum, and initial values. Fig. 1 describes the ways of real-time radiation data collection during operation and the determination of exploration direction based on the collected radiation data. The direction is determined by calculating the angle changes of each radiation vector using the following Eq. (1).

$$(1)\ RT = \arccos\frac{(P_{Rmax}-P_{Rstart})\cdot(P_{Rmin}-P_{Rstart})}{|(P_{Rmax}-P_{Rstart})||(P_{Rmin}-P_{Rstart})|}$$

However, it is difficult to predict radiation distribution in a multi-source environment, where the complex distribution is formed. Therefore, the presence of multiple sources is preferentially determined by using Eq. (2) for selecting areas where additional exploration is required. The maximum change is estimated by using the measurement data and distance as shown in Fig. 2. If a radiation variation is over the threshold, the area is considered a non-single source environment and re-explored with new paths different from the previous path. Fig. 3 shows variations in measured radiation for both single and multi-source environments.

$$(2)\ I(r) = \frac{P_r}{4\pi r^2}$$

where I is the intensity and r is the distance from radioactive source

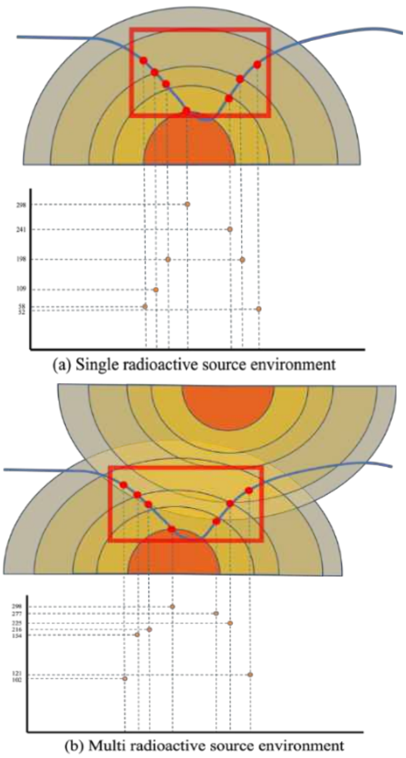

Fig. 3. (a) represents the distribution in a single-source environment, where following the blue path reveals an increase and then decrease in the red box's radiation. In (b), which is a multi-source environment, moving along the same path as (a) results in varying radiation changes in the red box due to different sources.

2.2 Radiation Exploration Method with GBP2

To efficiently explore uncertain areas, it is necessary to determine state of area such as explorable, exploration-complete and data-collectable area. Spatial data-based path planning such as NBVP, GBP2, MBP, AEP, FUEL, and TARE is a highly suitable method for exploring uncertain areas [5]. The proposed method in this study was developed by combining radiation-based exploration algorithm and the GBP2 algorithm, which can be minimized unexplored areas and is not sensitive to exploration environment.

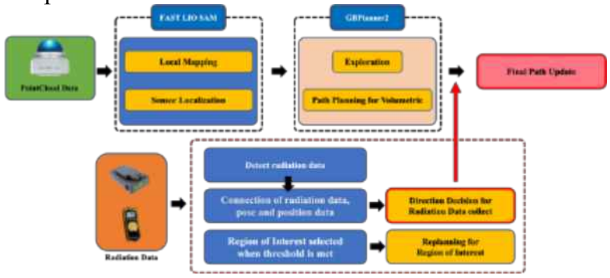

Fig. 4. System overview of radiation-spatial exploration

An overview of the algorithm considering both spatial data and radiation data is shown in Fig. 4. In geometric-based direction determination, the safe area, which a lot of volumetric information can be collected, is selected from real-time point-cloud data. The current position, target point and sensor range are defined as Ps, Pt and D, respectively. The boundary of the path is determined by using Eq (3). If Eq. (3) is satisfied, the movement direction is determined by Eq. (4).

$$(3)\ |P_s - P_t| \leq D$$

$$(4)\ GT = \arccos\frac{(P_t - P_s)\cdot(P_{s+1} - P_s)}{|P_t - P_s||(P_{s+1} - P_s)|}$$

Final path is determined through the radiation-based direction RT and the geometric-based direction GT. For the creation of safe and efficient exploration paths, weighting factor, donated as W_G, is applied to GT and RT. W_G is proportional to the radiation changes and inversely proportional to the ratio of geometric safety space to unsafe space. This prevents the robot from exploring inaccessible areas. Finally, the radiation vector and the spatial based vector are calculated as depicted in Eq. (6).

$$(5)\ W_G = \frac{\text{Radiation of chages}}{\text{Geometric of }\dfrac{\text{Safety space}}{\text{Unsafety space}}}$$

$$(6)\ T_{local} = W_G * GT + \frac{1}{W_G} * RT$$

3. Experiment Environment and Result

In this paper, we constructed a simulated exploration environment with radiation sources and radiation detectors. It is assumed that radiation data is collected in real-time, and the radiation distribution is generated by the source without shielding effect. An Unmanned Ground Vehicle (UGV), which lidar sensor and radiation detector is installed, was used for validating the developed algorithm. Radiation-related facility with an area of $14{,}400\text{m}^2$ was selected as exploration environment and five radioactive material was placed as summarized in Table I.

The results of the proposed and previous method are summarized in Table II. The developed algorithm could complete exploration with the time of $380s$ and the total traveling distance of $120m$. The traveling distance and exploration time in the previous method were $148m$ and $674s$, respectively. The radiation distributions and the paths were generated as shown in Fig. 5. it is confirmed that proposed method could reduce the exploration time by 43% and traveling distance by 18%. These results stem from the combination of spatial-based path planning, preventing the occurrence of local minima in multi-source environments or specific segments such as corner, dead end. However, persistent localization errors result in distorted radiation map and incorrect radiation distribution occurred when the radiation source was obstructed.

TABLE I: Location and value of sources

Source number	Source x, y location (m)	Source value (Sv/h)
#1	-15, -15	100.0
#2	-15, -14	200.0
#3	-15, -13	300.0
#4	-5, -15	400.0
#5	-5, -7	500.0

TABLE II: Compare the result

Method	Accuracy (%)	Time (s)	Exploration Distance (m)
Proposed	88	380	120m
Previous	74	674	148m

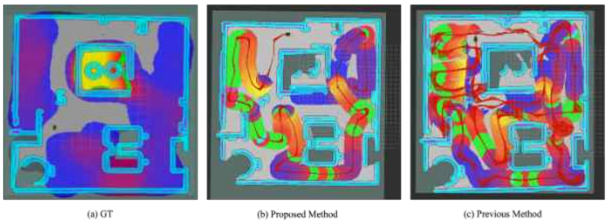

Fig. 5. Simulation data comparison: (a): Ground Truth. (b): Exploration results data considering both geometric and radiation factor. (c): Exploration results data considering only radiation factor.

4. Conclusion

In this study, the exploration algorithm with combining radiation-based and spatial-based techniques was developed for reducing the exploration time and the traveling distance. For validating the developed algorithm, the virtual environment was constructed and simple tests was carried out. Our method can reduce the exploration time by $254s$ and the exploration distance by $28m$. These results impose that the construction of accurate radiation map can be achieved even in situations with limited battery and exploration time constraints.

However, the current mapping process encounters difficulties with the accumulated error in radiation measurement, which results from error of localization. Moreover, it is impossible to consider the shielding effect for constructing the radiation distribution.

Position correction through loop closing method will be introduced for overcome the problem related to the accumulated error in the future. Furthermore, the method, which predicts the radiation distribution considering shielding effect, will be developed.

Acknowledgements

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT of Korea (MSIT) (RS-2022-00143654) and supported by the Technology development Program (S3325355) funded by the Ministry of SMEs and Startups (MSS, Korea) and supported by the Institute of Civil Military Technology Cooperation funded by the Defense Acquisition Program Administration and Ministry of Trade, Industry and Energy of Korean government under grant No. UD10044TU, RS-2024-00423589, and RS-2024-00422721.

REFERENCES

[1] Security of Radioactive Sources, IAEA, VIENNA, INTERNATIONAL ATOMIC ENERGY AGENCY, 2003
[2] Lazna, T., Fisera, O., Kares, J. & Zalud, L. "Localization of ionising radiation sources via an autonomous robotic system," Radiat. Prot. Dosim. 186, 249–256, 2019.
[3] Nouri Rahmat Abadi, B., et al., "CARMA II: a ground vehicle for autonomous surveying of alpha, beta and gamma radiation," Front Robot AI 10, 47, 2023.
[4] Mascarich, F.; Kulkarni, M.; De Petris, P.; Wilson, T.; Alexis, K. Autonomous mapping and spectroscopic analysis of distributed radiation fields using aerial robots. Auton. Robots, 47, 139–160, 2022.
[5] Dang, T., Mascarich, F., Khattak, S., Papachristos, C., & Alexis, K, "Graph- based path planning for autonomous robotic exploration in subterranean environments," Conference on Intelligent Robots and Systems, 3105–3112, IEEE, 2019.