Path Planning for Identification of Radiation Source Using Mobile Robot with Directional Gamma-ray Detector

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Introduction

Tsunami caused meltdown and explosion, and radioactive materials have been leaked out.

March 2011

Unit 1

Unit 3

Unit 4

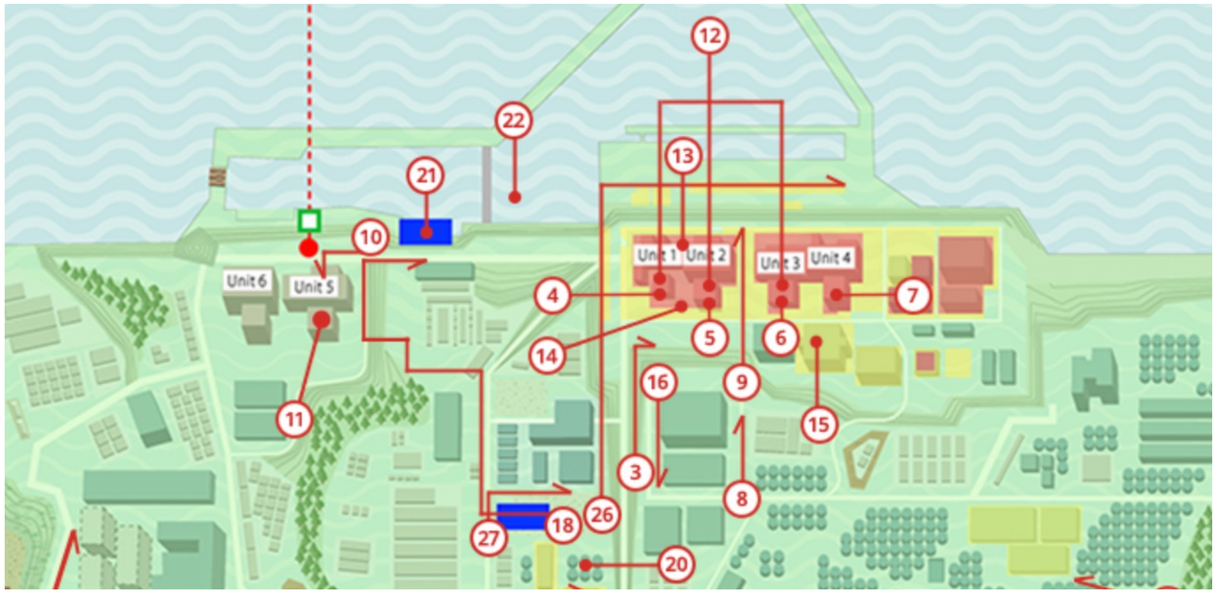
[TEPCO]

Green Zone Regular Uniform Area

Yellow Zone Protective Clothing and a Full or Half-Face Mask Area

Red Zone Protective Clothing and a Full-Face Mask Area

[TEPCO]



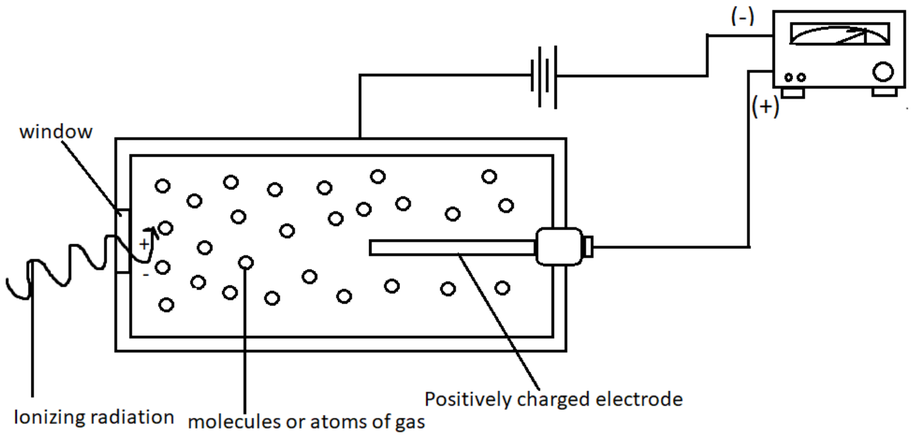
It is expected to use mobile robots for exploration

Gamma-ray detector

Gamma rays have the strongest penetrating power to pass through objects among radiations.

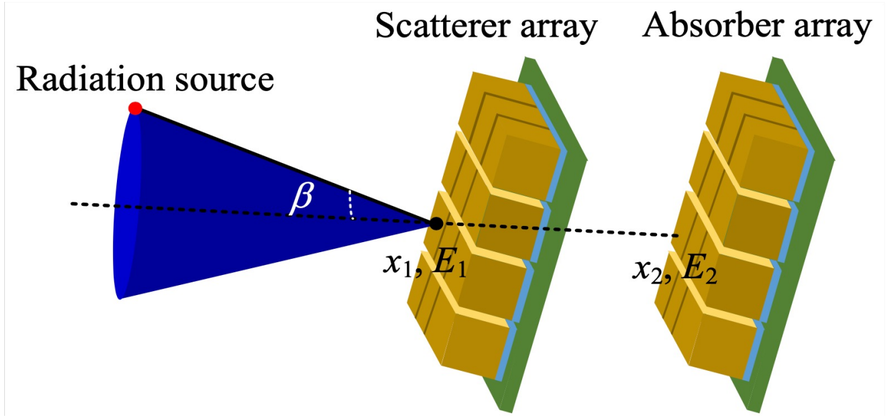
There are two types of gamma-ray detectors.

Non-directional detector



- Number of incident gamma-ray events acquired
- ex) Geiger Muller counter

Directional detector

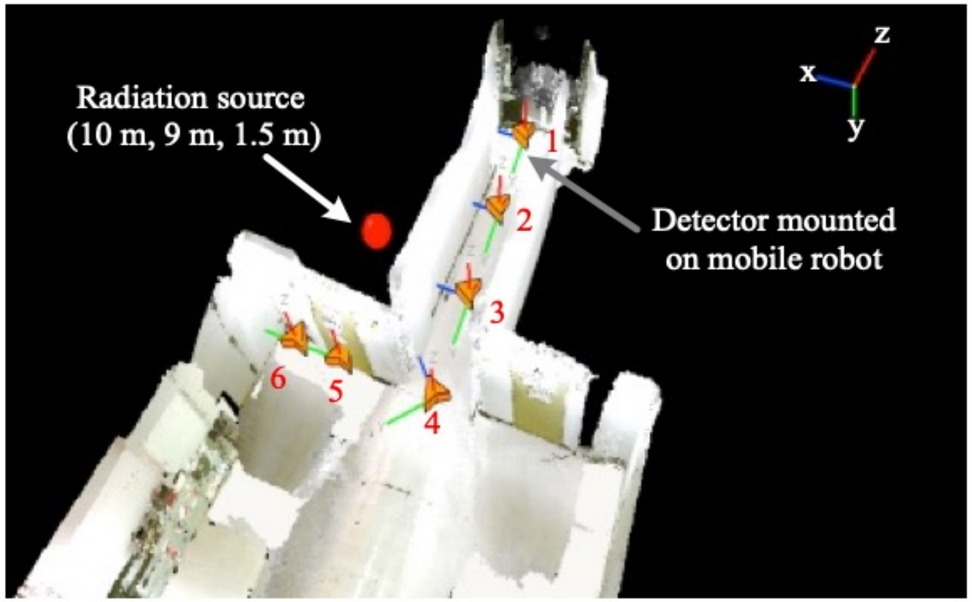


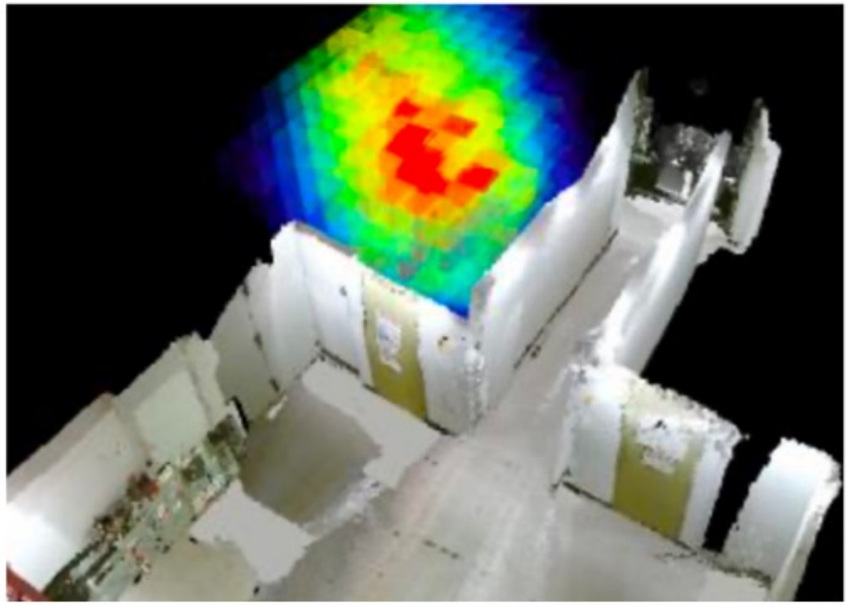
- Number and direction of incident gamma-ray events
- ex) Compton camera

Exploration Using Mobile Robot

Our research group have been working on the exploration using a mobile robot and the identification of radiation sources.

[Kim et al., 2018]





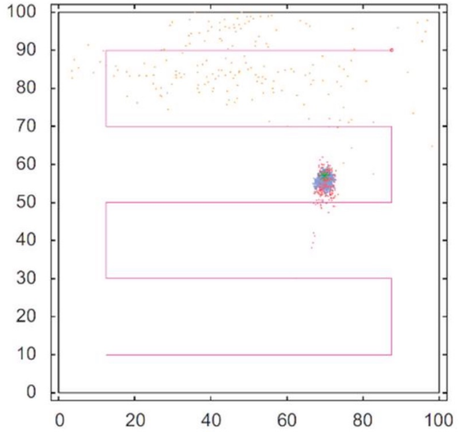
Path planning methods are required

Previous Studies

- Uniform search

  : determines paths to scan the whole area

  : shows **low efficiency**

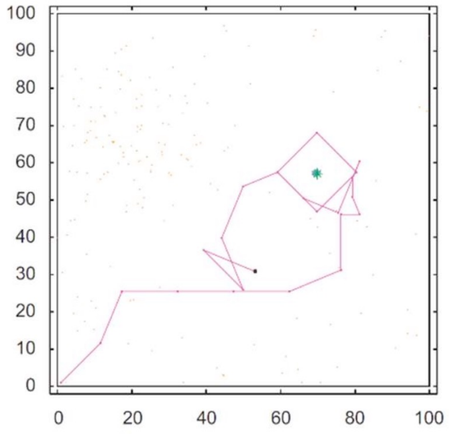


[Ristic et al., 2010]

- Information driven search [Ristic et al., 2010]

  : uses Renyi divergence as information gain

  : **uses non-directional detector**



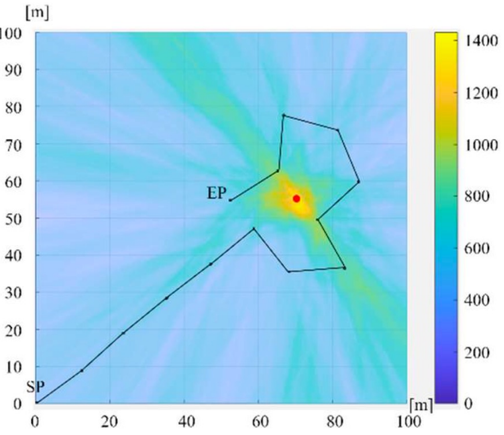
[Ristic et al., 2010]

- Path planning via principal component analysis (PCA) [Kishimoto et al., 2021]

  : assumes that the radiation intensity is known

  : **cannot be applied to mission when the radiation intensity is unknown**

[Kishimoto et al., 2021]



Objectives

To generate the exploration path

and identify a radiation source

even if the radiation intensity is unknown

Problem Definition

- Signle radiation source is located in the environment.
- There is no obstacle in the environment.
- One robot performs the exploration.
- The location and intensity of the source should be identified.
- The robot has the Compton camera which is one of the directional detectors.
- The robot can get the incident number and direction of gamma rays.
- Based on the data, the next measurement point is determined.

  The decision of the next measurement point is called as path planning in this study.

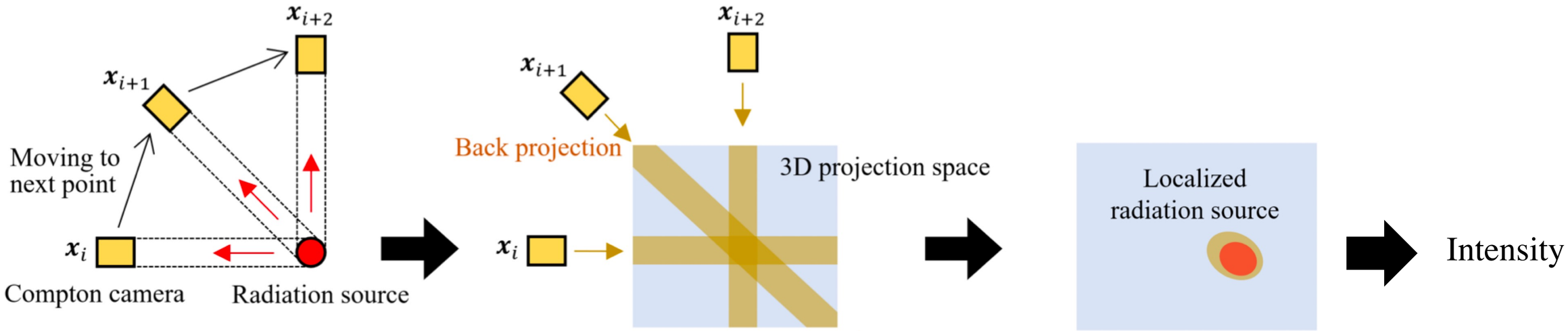
Proposed Method

The proposed method consists of three parts:

a) gamma-ray measurement : incident number, incident direction

b) path planning : next measurement point

c) identification of radiation source: location and intensity of the source

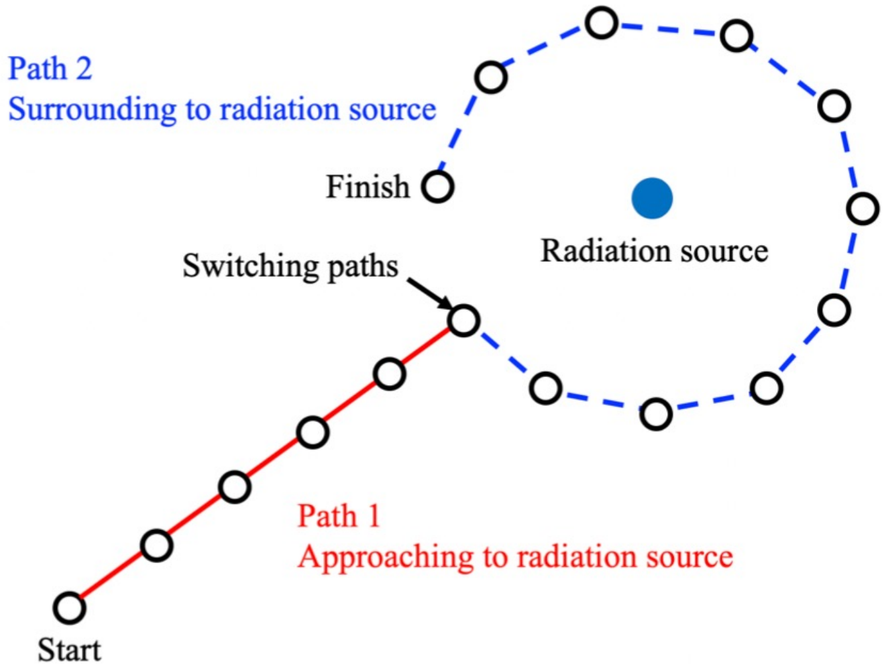


Approach

Our apporach is that

Path 1 moves toward the direction of incident gamma rays for efficienct measurement

Path 2 moves around the source for accurate identification



How to determine the point switching path 2?

How to grasp the distacne from the source?

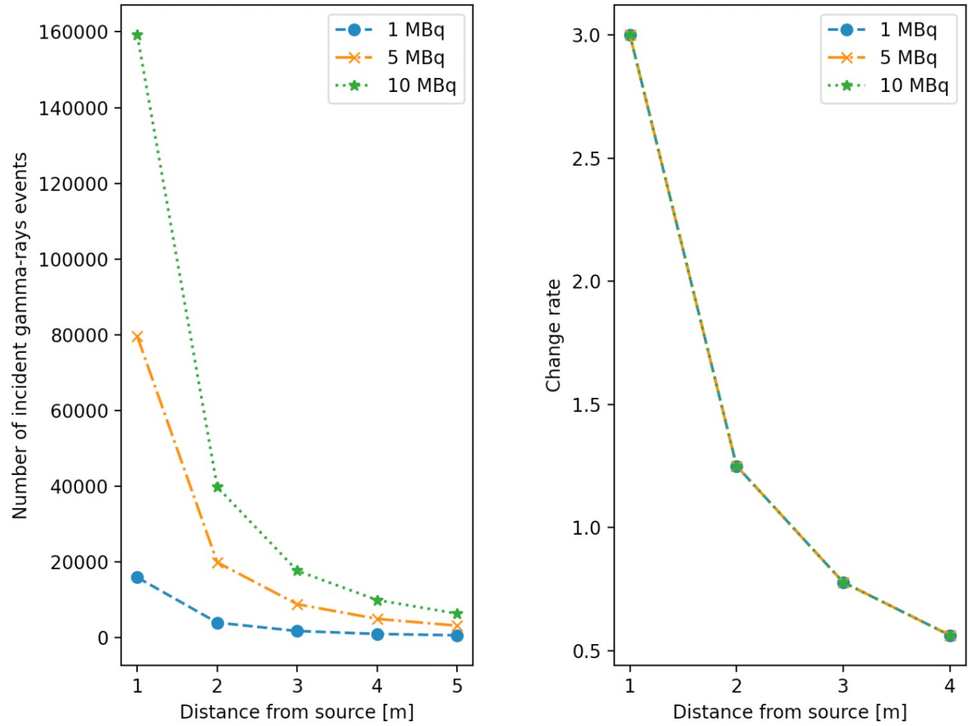
Novel Index Estimating Distance to Source

The number of incident gamma rays is represented as

$$n = \frac{IA}{4\pi r^2}.$$

The proposed method defines the change rate of the incident number

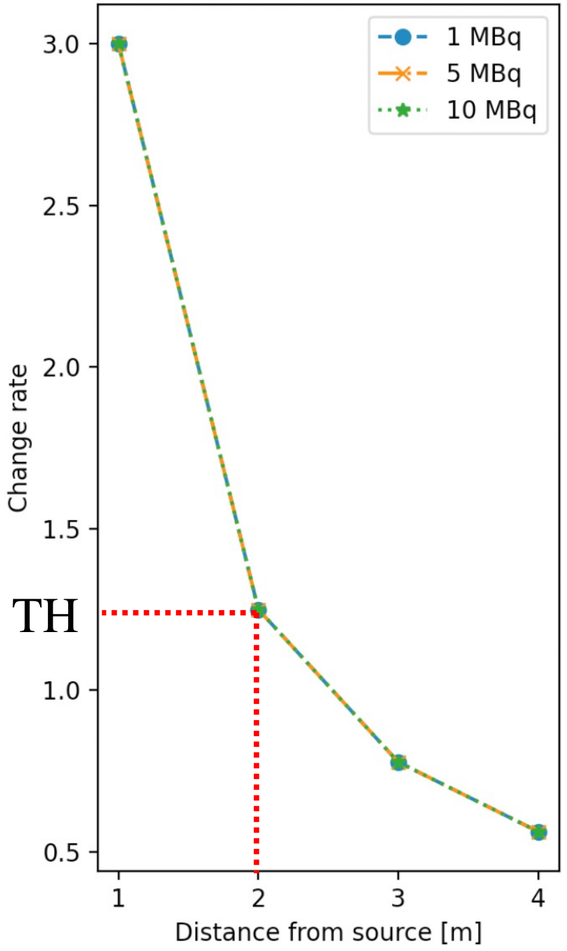
$$\dot{n}_i = \frac{n_i - n_{i-1}}{n_{i-1}} = \frac{r_{i-1}^2}{r_i^2} - 1 = \frac{(r_i + \Delta)^2}{r_i^2} - 1,$$



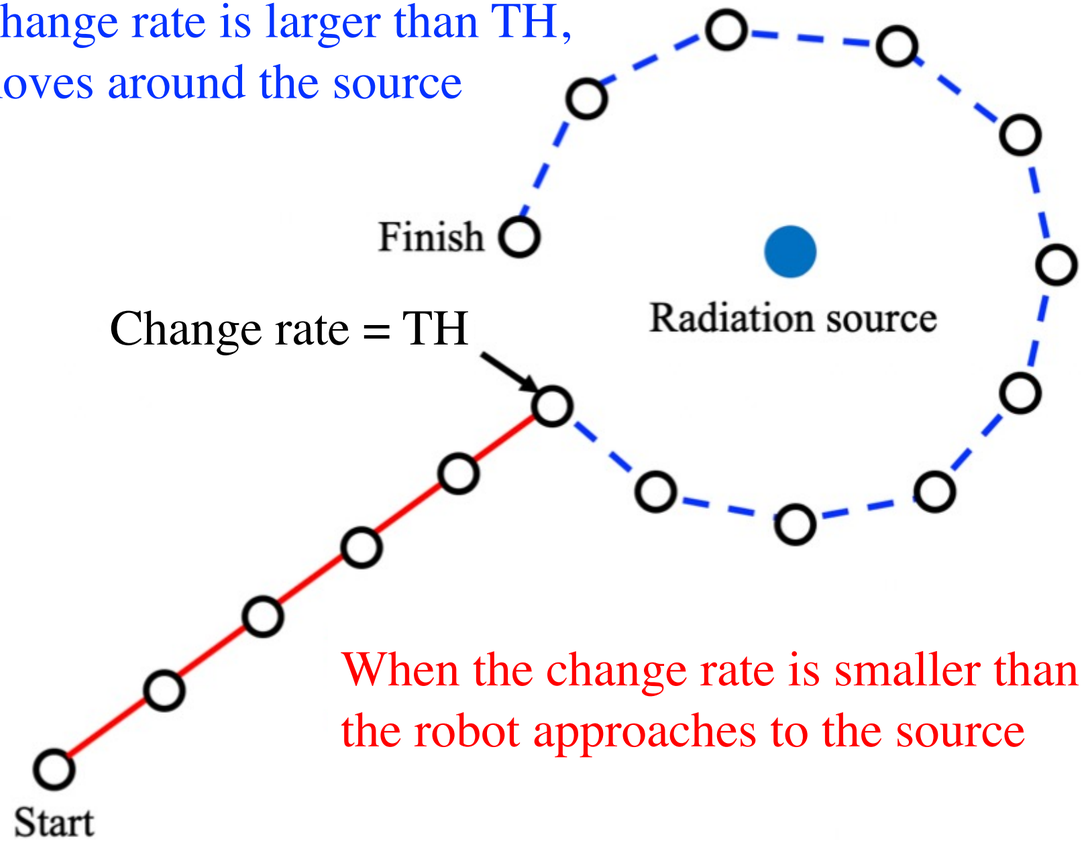
The change rate depends only on the distance from the source

Path Planning

For example,
we want the robot to be close from the source with 2 m.



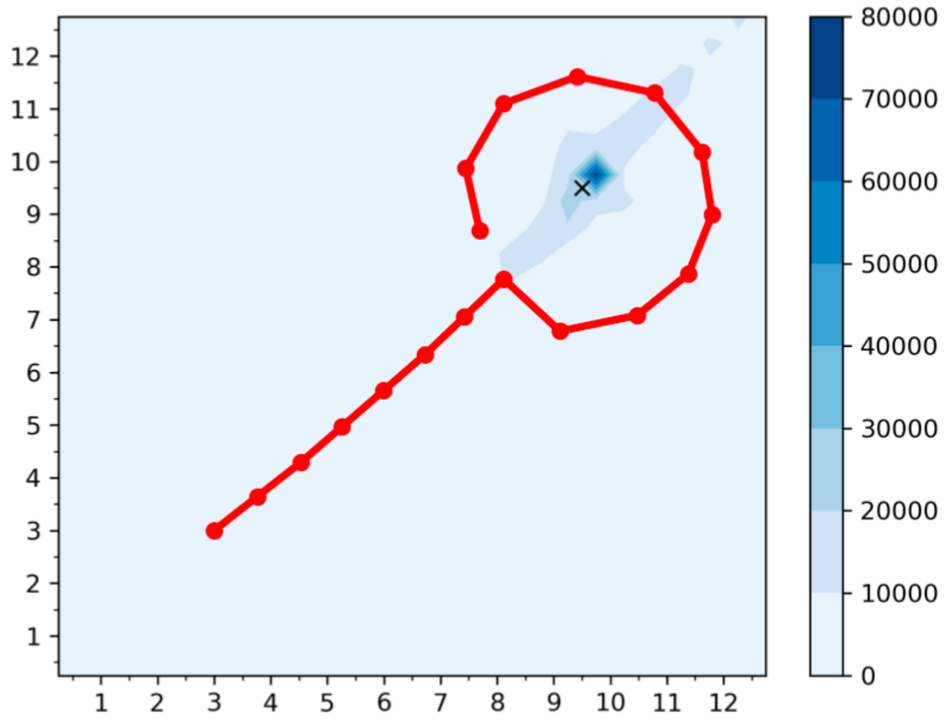
When the change rate is larger than TH,
the robot moves around the source



When the change rate is smaller than TH,
the robot approaches to the source

Evaluation

- A single source was located in an environment of 13 m x 13 m.
- The intensity of the source was 1 MBq.
- The measurement time at each point was 300 s, and the area of detector was 0.2 m^2.
- The size of each grid for the back projection was 0.5 m.



Localization error = (0.25 m, 0.25 m)

Estimated intensity = 0.97 MBq

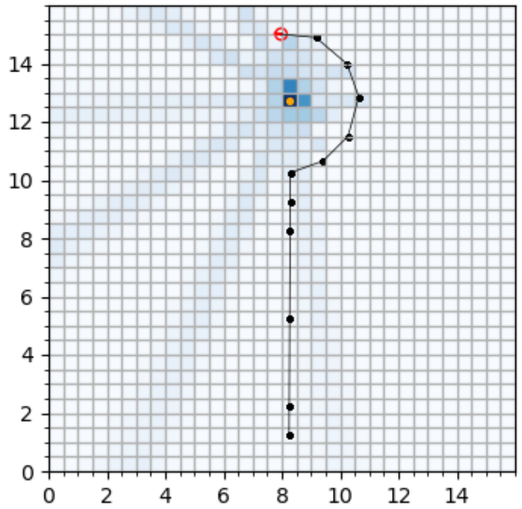
Conclusion

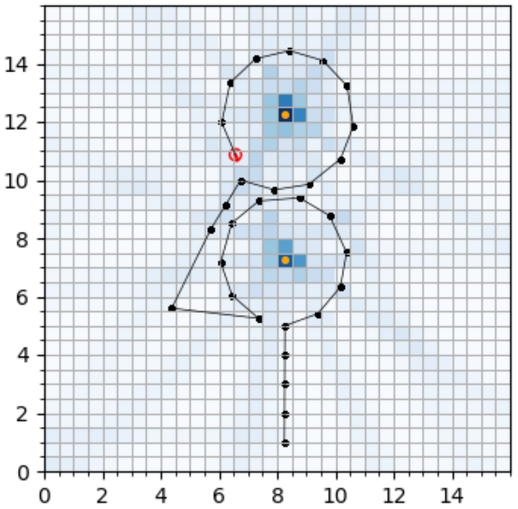
We proposed the novel index to grasp the distance from the source,

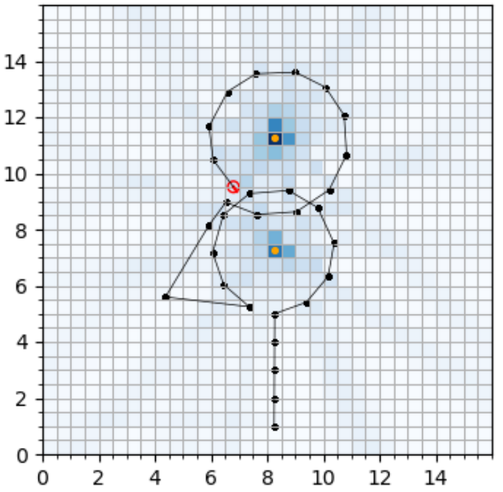
and it makes the exploration possible even if the intensity is unknown.

It was demonstrated that the proposed method successfully identifies the source.

Future works







Thank you for your attention

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