Mobile robot for radiation mapping in indoor environment

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Abstract. Radiation mapping is the process of measuring radiation intensity level at distributed sampling points in a predefined region of interest (ROI). This procedure is crucial in any radiological related emergency to locate contamination hotspot(s) or in routine inspections in any radiation facilities. When workers knowingly enter a high radiation zone to perform radiation mapping, they are exposed to the risk of radiation exposure. Mobile robot is a potential solution that could eliminate the health and safety risk and subsequently improve the measurement accuracy. This paper reports implementation of mobile robot for radiation mapping by using a commercial mobile robot platform, Turtlebot2 in conjunction with Robot Operating System (ROS). Mobile robot is capable to generate physical map of the targeted environment by using Simultaneous Localization and Mapping (SLAM). Simultaneously, Geiger Muller detector is utilized to perform radiation measurement. The radiation data is directly plotted on the physical map hence the radiation intensity distribution throughout the ROI could be assessed. Functionality of the radiation mapping robot is evaluated in real-world experiments and the results will be presented in the paper.

1. Introduction

Radiological emergency requires immediate and planned response to avoid significant damage on health, psychological, and financial consequences. The primary objective of emergency response are to regain control of the situation and mitigate the consequences in order to avoid or minimize the risk of deterministic and stochastic effects of radiation exposure to human being and the environment [1]. During any radiological related emergency, the process of radiation mapping is critical to measure radiation intensity distribution throughout the accident’s parameter. Radiation map will help to establish safety boundary, identify contaminated ‘hotspots’, localize the origin of radioactive source, as well as to estimate the dose rate distribution throughout the perimeter [2][3].

The role of robot is proved to be significant after Fukushima Daiichi nuclear accidents in 2011. Both inside and outside of accident site (buildings housing the nuclear reactors) are not accessible to human due to potential risk of high radiation exposure. Among the robots that were deployed are iRobot Packbot [4], Quince [5], and Talon [6]. These robots were utilized to perform damage assessment, radiological surveys, as well as some decontamination and clean-up tasks. However, robot missions after Fukushima Daiichi accidents revealed several shortcomings on the available robot technology targeted for emergency response. One of the most prominent issue is dependency on
teleoperation which requires good communication signal and highly skilled operators to control and maneuver the robots [5][7]. Due to this, some of the robots failed to be recovered and were lost during the mission.

Researches on autonomous mobile robot navigation are typically broken down into three important elements; mapping, localization, and path planning. In terms of mapping, Simultaneous Localization and Mapping (SLAM) has enables robot to create the map of unknown environments [8–10]. To localize the position of robot in the map, a number of methods existed [11][12]. Finally, path planning will tell the robot where to go and how to avoid obstacles along the way [13][14]. Given solutions to these three elements, a lot of current researches focus on utilizing mobile robot in wide range of applications such as in home and healthcare services, industrial, agriculture, and even in space exploration.

The aims of this research are to develop robotics platform for radiation mapping by integration of mobile robot and radiation detector. Next, we design an algorithm for coverage radiation mapping in indoor environment and validate both robot and algorithm in experiments and real-world application. Section 2 presents the robot setup and algorithm. Section 3 contains results and discussion from experimental evaluation. Finally, Section 4 will provide the conclusion and our plan for future works.

2. Research methodology

The research methodology to develop and implement autonomous mobile robot for radiation mapping is done in three stages. Initially, the platform is established by integrating mobile robot with radiation detector module. Next, we enable autonomous navigation for the mobile robot by utilizing ROS Navigation Stack. Lastly, we create the procedure of autonomous radiation mapping by mobile robot by using SLAM and in-house coverage radiation mapping algorithm. Each stage will be described in detail in the following sub-sections.

2.1. Integration of mobile robot and radiation detector module

Turtlebot2 (Turtlebot) is chosen as the mobile robot platform in this research. It is a commercial mobile robot platform that is widely used for research purposes due to its versatility. This robot consists of 2 differential drive wheels and equipped with navigation sensors such as on-board RGBD camera, wheels encoder, gyro sensors, wheel drop sensors, bump sensors and cliff sensors. Turtlebot is used in conjunction with Robot Operating System (ROS), an open source framework licensed under BSD. Simulation of robot navigation codes is done with ROS Gazebo whereas real time data visualization is done with ROS RViz.

Geiger Muller (GM) detector LND7121 is utilized as the radiation detector. The detector electronics module has been developed in our previous work [15]. This module consists of GM, high voltage supply of 500 Volts for detector, and signal processing unit that converts analog output of detector to digital signal (TTL pulse). A counter timer is implemented in microcontroller to count pulse generated by GM. The output of this module is gross count of radiation event represented in count per second (CPS) unit.

GM electronics module is connected to Turtlebot host computer via USB connection as shown in Figure 1. The module is installed on one of Turtlebot shelves. ROS package rosserial_arduino is utilized to implement ROS topics publisher. Radiation detector output data is published into Turtlebot ROS environments as /RadiationData topic at frequency of 1 Hertz.
2.2. **ROS navigation stack for autonomous navigation in physical environment**

ROS Navigation Stack is a set of ROS nodes and algorithms that computes how to move robot from its original position (current pose) to desired destination (goal pose). The navigation requires physical map of the environment typically referred as static map. Static map enables robot to localize its current pose in the map and execute navigation commands to the goal pose. In addition, the static map is also useful to visualize the result of radiation mapping with respect to environment geometry.

Navigation planning and execution involves path planner and costmap. Planner generates path from current pose to goal pose while referring to costmap. On the other hand, costmap provides map with static and dynamic obstacles information along the path. Move_base is the primary component of ROS Navigation Stack. When move_base receives a new goal pose, global planner computes a complete path from current pose to goal pose based on static map. As move_base execute the path, local costmap re-calculate the path as needed based on real time sensors data. Visualization of each component in RViz as Turtlebot moves from current pose to goal pose is shown in Figure 2.

![Physical setup and block diagram of Turtlebot, GM, and host computer.](image)

**Figure 1.** Physical setup and block diagram of Turtlebot, GM, and host computer.

![RViz Visualization of global planner, local planner, global costmap and local costmap.](image)

**Figure 2.** RViz Visualization of global planner, local planner, global costmap and local costmap.
2.3. Procedures of Autonomous Radiation Mapping

The complete procedures of autonomous radiation mapping involve three sequential steps as shown in Figure 3. As shown in Figure 3, the steps are mapping of physical environment, autonomous radiation mapping by mobile robot, and data processing and analysis.

![Figure 3. Procedures of radiation mapping.](image)

2.3.1. Mapping of Physical Environment

In order to build the physical map, a popular method called SLAM has been adopted [8]. SLAM enables map creation from visual and odometry data as robot moves around the region of interest. ROS gmapping package is an implementation of a SLAM algorithm to create 2-dimensional occupancy grid maps. The map uses pixel values to classify unoccupied spaces, occupied spaces, and unexplored spaces. Figure 4 shows map created by Turtlebot with gmapping package. Pixel resolution in Figure 4 (right) is 5 cm² whereas the map resolution is 512 pixels width and 480 pixels wide. Each pixel in the map could be translated into respective X-Y coordinates to define current pose and goal pose of the robot.

![Figure 4. Real world environment (left) and the resulting Occupancy Grid Map created by Turtlebot with gmapping package (right).](image)

2.3.2. Autonomous radiation mapping by mobile robot

Radiation mapping algorithm enable autonomous operation of the radiation mapping. Flowchart of the algorithm is shown in Figure 5. This algorithm requires occupancy map as the input. Occupancy map will be segmented into grids. To ensure coverage of the resulting radiation map, all unoccupied cells will be mapped by mobile robot. The sampling points are centroid of every unoccupied cell. Next, path that connect all the sampling points is generated for mobile robot navigation. During the scanning process, detector count data is accumulated for 3 seconds and recorded along with the X and Y coordinates of the sampling points. If any of the sampling points become unreachable during the mapping process, the action server goal will be pre-empted (cancelled) and robot will proceed to the next sampling point.
Figure 5. Flowchart of coverage radiation mapping algorithm.

2.3.3. Data processing and analysis
To generate the final radiation map, count data is plotted against the X-Y coordinates. The background counts are subtracted from the counts. At the moment, a simple python program is written to interpolate the discrete data and generate a continuous map. Location of the hotspot(s) are highlighted by map colour that represent the radiation intensity.

3. Result and discussion

3.1. Verification of the system
A series of experiments were conducted to verify the radiation map produce by the autonomous robot. These experiments were performed in a controlled environment where sealed radioactive sources are placed in known locations i.e. coordinates in the map. Then, robot is deployed into the environment to run radiation mapping autonomously. Resulting radiation map is analysed in terms of accuracy of the hotspot location with respect to actual position of the radioactive sources.

As shown in Figure 6, all three coordinates of the radioactive sources have been identified and visually highlighted by colour variations that represents the radiation intensity at the respective sampling points. X-pose and Y-pose in the map axis represent the cell X-Y coordinates respectively where the origin (0,0) is the start position in SLAM gmapping process (refer section 2.3.1). The results proved that combination between robot and coverage radiation mapping algorithm has manage to generate radiation map of the target location.
Figure 6. Resulting radiation map with discrete data (left) and interpolated data (right).

3.2. Radiation mapping at operational facilities

Finally, we investigate the potential application of autonomous radiation mapping for optimizing the safety of radiation worker. Radiation mapping were performed at two operational radiation related facilities. The first location is Alpha Spectrometry Counting Laboratory (Figure 7) that performs analysis of environmental samples such as soil, ground water, as well as flora and fauna. These samples are only associated with background or low level of radioactivity. On the other hand, the second location is Mobile Hotcell (Figure 8) that involves higher radioactivity sources stored in Long Term Source Storage (LTSS). Both selected locations are indoor with relatively smooth flooring surface.

Figure 7. Radiation mapping in Alpha Spectrometry Counting Laboratory (Location 1).
Figure 8. Radiation mapping in Mobile Hotcell (Location 2).

The results are shown in Figure 9 and 10. Both maps indicate elevated radiation level at expected areas where radioactive sources are stored in the respective locations. Based on Geiger Muller detector manufacturer datasheet, conversion factor of 0.010417 could be used to convert from CPM to microsievert per hour (µSv/hr). Highest dose rate at Location 1 is recorded at 1.5 µSv/hr whereas highest dose rate for Location 2 is 8.5 µSv/hr.

Figure 9. Radiation map for Alpha Spectrometry Counting Laboratory.
In terms of optimizing the safety of radiation worker, this map could be utilized to coordinate safe routes and duration during any activity related to the location. Thus, radiation exposure could be efficiently reduced and minimized in accordance to As Low As Reasonable Achievable (ALARA) practise.

4. Conclusion and recommendation
This paper concludes that a mobile robot for autonomous operation of radiation mapping has been successfully implemented by integration of Turtlebot, Geiger Muller detector, and coverage radiation mapping algorithm. This robot is targeted to enable coverage radiation mapping in indoor environment by using SLAM to generate the physical map of the location. Experimental evaluation proved that the radiation map produced by the robot has successfully highlighted the hotspots i.e. coordinate(s) of radioactive source in the physical map. Finally, applicability of the robot is investigated at two operational radiation related facilities. The resulting map could help radiation worker to coordinate their work and reduce the radiation exposure when working in the respective radiation facility. Thus, the robot is useful in terms of radiation safety for worker in two areas; automation of the process of mapping and planning the route or position during activity in radiation related facilities.

5. References
[1] IAEA 2015 Preparedness and Response for a nuclear or radiological emergency, no. GSR Pa. (Vienna, Austria: IAEA General Safety Requirements).
[2] Takahashi T, Nemoto Y, Nakano H, and Tsukiyama T 2014 Development of a new simulation software system to evaluate radiation doses and facilitate decontamination tasks in reactor buildings Prog. Nucl. Sci. Technol. 4 p 543–547.
[3] Minamoto G, Takeuchi E, and Tadokoro S 2014 Estimation of ground surface radiation sources from dose map measured by moving dosimeter and 3D map EEE/RSJ Int. Conf. on Intelligent Robots and Sys. p 1889–1895.
[4] Duckworth D, Shrewsbury B, and Murphy R 2013 Run the robot backward IEEE Int. Symp. Safety, Secur. Rescue Robot.
[5] K. Nagatani et al. 2011 Redesign of rescue mobile robot Quince IEEE Int. Symp. Safety, Secur. Rescue Robot p 13–18.
[6] Ohno K, Kawatsuma S, Okada T, Takeuchi E, Higashi K, and Tadokoro S 2011 Robotic control vehicle for measuring radiation in Fukushima Daiichi Nuclear Power Plant 9th IEEE Int. Symp. Safety, Secur. Rescue Robot p 38–43.
[7] Kawatsuma S, Fukushima M and Okada T 2012 Emergency response by robots to Fukushima-Daiichi accident: summary and lessons learned Ind. Robot An Int. J. 39(5) p 428–435.

[8] Cadena C. et al. 2016 Past, Present, and future of simultaneous localization and mapping: towards the robust-perception age IEEE Trans. Robot. 32(6) p 1309–1332.

[9] Mur-Artal R, Tardos J D and Tardós J D 2017 Orb-slam2: An open-source slam system for monocular, stereo, and rgb-d cameras IEEE Trans. Robot. 33(5) p 1255–1262.

[10] Grisetti G, Stachniss C and Burgard W 2014 Improved techniques for grid mapping with Rao-Blackwellized particle filters p 1–12.

[11] Silva Almeida J, Bezerra Marinho L, Mendes Souza J W, Assis E A and Reboucas Filho P P 2018 Localization System for autonomous mobile robots using machine learning methods and omnidirectional sonar IEEE Lat. Am. Trans. 16(2) p 368–374.

[12] Pedrosa E, Pereira A, and Lau N 2017 Efficient localization based on scan matching with a continuous likelihood field IEEE Int. Conf. on Auton. Robot Sys. and Competitions, ICARSC 2017 p 61–66.

[13] Bogaerts B, Sels S, Vanlanduit S, and Penne R A 2018 Gradient-based inspection path optimization approach IEEE Robot. Autom. Lett. 3(3) p 2646–2653.

[14] Thoa T, Copot C, Trung D and De Keyser R 2016 Heuristic approaches in robot path planning: A survey Rob. Auton. Syst. 86 p 13–28.

[15] Abd Rahman N. et al. 2016 Arduino based radiation survey meter Arduino based radiation survey meter AIP Conf. Proc. 1704 p 030012.

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