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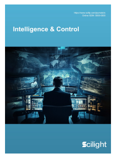

Article

A Low-Cost Robotic Platform for Radiation Mapping

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Abstract: A low-cost robotic platform for radiation mapping has been developed by integrating a commercial off-the-shelf (COTS) radiation detector with a repurposed smart vacuum robot. The equipped reliable dosimeter can effectively measure radiation levels while the smart vacuum provides mobility and operational capabilities, enabling autonomous navigation in areas with potentially harmful radiation, minimizing the risk to human health. The low cost and ease of use of this platform can greatly improve accessibility to robotics technology. Potential applications of this robotic platform extend across various sectors, including routine survey of radiation level at nuclear and medical facilities, and radiation mapping during emergency response.

Keywords: radiation mapping; robotics; dosimetry; environmental monitoring; emergency response; low-cost sensors

1. Introduction

Full awareness of the radiation levels in surrounding areas is critical in various fields, including environmental science, nuclear and medical industries, as well as emergency response. Challenges persist in effectively and accurately measuring radiation levels in dynamic environments. On one hand, traditional methods often rely on manual measurements, thus are time-consuming and prone to human error. On the other hand, automated robotic platforms involve specialized robots and advanced detector. Their high costs and complex operational requirements prevent them from widespread adoption, particularly in resource-constrained environments. This work aims to develop a low-cost robotic platform for radiation mapping based on COTS components, which can greatly enhance accessibility to robotics technologies, improving safety protocols, and ultimately contributing to better public health outcomes.

Recently, the demand for efficient and precise radiation detection in diverse settings, such as disaster zones, nuclear and medical facilities, has driven significant advancements in radiation mapping technologies. High-end specialized robots equipped with advanced Simultaneous Localization and Mapping (SLAM) systems are at the forefront of this development. These robots can navigate intricate environments while simultaneously mapping radiation levels, thereby providing real-time data crucial for decision-making in hazardous situations [1–8]. In addition to ground-based unmanned vehicles (UGVs), unmanned aerial vehicles (UAVs) have gained popularity in conducting radiation surveys. UAV-based platforms can access areas that are otherwise unreachable, enabling comprehensive surveys without endangering human operators [9–16]. Heterogeneous multi-robot approaches are being investigated to further improve coverage, enhance data accuracy, and increase efficiency [17–21]. Various detector technologies have been integrated onto robotic platforms to augment the capabilities of radiation mapping systems. For instance, timepix detectors have been successfully implemented on micro-UAVs, enabling high-resolution radiation detection with a compact form factor [22]. GM tubes and scintillation detectors have been utilized on ground-based platforms. They are effective for general surveys but may lack the resolution necessary for isotope identification [23,24]. Additionally, Compton cameras have emerged as a promising technology for directional imaging, assisting operators in source localization [25–27]. Despite the advancements in robotic radiation mapping platforms and detector integration, several gaps remain that hinder widespread adoption. A major challenge to the broader use of these platforms is their high cost, which makes them difficult for smaller laboratories and organizations to afford [28]. Another challenge is the complexity of setup and operation. Most current systems require specialized expertise and training, which limits their effectiveness in emergencies where fast deployment is critical [29,30].

In conclusion, recent work has advanced radiation mapping across UAVs, UGVs, and heterogeneous robotic platforms—including LiDAR-survey meter fusion [2], VTOL airborne gamma mapping [13], cost-efficient drone surveys [15], cooperative aerial-ground mission planning [19,20], modular UGVs for nuclear inspection [23], adaptive-sampling radiation mapping [3], and evolving deployment strategies in nuclear decommissioning [30]. In parallel, high-end mission-qualified systems—such as the UGV-CBRN disaster-response platform [31] and the DOE PCAMS RadPiper NDA robot [32]—demonstrate state-of-art performance but require specialized hardware and carry procurement and operation costs far beyond the reach of many universities or small organizations.

In contrast, the main goal of this work is to create an efficient and affordable automated radiation mapping platform that is easy to use and accessible across many applications. The system will be built entirely from COTS components to keep costs low and simplify deployment. By using consumer robotics, the platform is designed to automate radiation mapping tasks and reduce operator-dependent variability. It will be user-friendly and widely applicable, serving researchers, safety professionals, and regulatory bodies alike. Beyond technical improvements, this project emphasizes practical use: demonstrating how the system can support routine radiation monitoring in a variety of environments. By proving its effectiveness in real-world settings, the platform aims to advance safety and efficiency in radiation management, benefiting industries that work with radiation and strengthening protections for public health.

2. Materials and Methods

2.1. System Design and Architecture

The robot selected for our project is the Dreame L10s Ultra Robot Vacuum (see Figure 1). This decision was based on several key criteria:

1. Navigation: The Dreame L10s features advanced navigation capabilities, allowing for efficient mapping of various environments. Its intelligent obstacle avoidance and real-time mapping capabilities ensure thorough coverage of the designated areas.
2. Payload Capacity: The vacuum's design accommodates a sufficient payload capacity. After modifications, it has sufficient space and power to carry the radiation detector and the Raspberry Pi unit for data communication. It can also operate without frequent interruptions for charging or maintenance.
3. Cost: The Dreame L10s offers a competitive price point relative to its features and performance, making it an economical choice for our needs while still providing high-quality functionality.
4. Additionally, the Dreame L10s Ultra Robot Vacuum is supported by Valetudo (https://valetudo.cloud, accessed on 14 January 2026), which allows for a cloud-free and customizable operation.

This choice of platform aligns with the project's goal of creating an accessible and efficient radiation mapping solution, leveraging consumer robotics for enhanced operational capabilities.

Figure 1. The Dreame L10s Ultra smart vacuum used in this study.

The radiation detector selected for this work is the AccuRad from Mirion Technologies (see Figure 2). The AccuRad is a personal radiation detector designed to provide accurate radiation exposure measurements over a wide range. It utilizes a CsI(Tl) scintillation detector with temperature compensated SiPM, as well as a silicon diode for integrated dose and high and low dose rate measurements. The low dose rate range from the CsI detector is 1 µrem/h to 100 mrem/h (for Cs-137) with a minimum displayed value of 0.1 µrem/h. The high dose rate range from the silicon diode is 100 mrem/h to 1000 rem/h (for Cs-137). The dose rate linearity is ±10% from 10 µrem/h to 1000 rem/h. The dose linearity is ±10% from 10 µrem to 1000 rem.

Figure 2. The AccuRad personal radiation detector by Mirion Technologies.

The AccuRad includes built-in data logging, enabling users to track exposure over time for detailed analysis. Ruggedly built, the AccuRad performs reliably even in harsh conditions, making it suitable for medical, industrial, and research settings. These capabilities make the AccuRad a strong choice for monitoring radiation and supporting safety in environments where radiation exposure is a concern.

The Dreame L10s Ultra + AccuRad pairing was selected not to maximize performance relative to specialized nuclear robots, but because both units are widely available COTS products, enabling a low-cost, reproducible platform that requires no custom firmware, no external markers for navigation, and no bespoke calibration infrastructure.

Integrating the Dreame L10s robot with the AccuRad dosimeter involves several important considerations:

1. Real-time Data Broadcasting: The AccuRad will broadcast real-time dose measurements to a host PC. This capability is crucial for immediate analysis and response to any detected radiation levels, enhancing safety and operational efficiency.
2. Location Tagging: As the dosimeter collects data, it will simultaneously tag each measurement with its corresponding location. This feature allows for a comprehensive understanding of radiation exposure patterns, facilitating better decision-making and risk management.
3. Modifications for Seamless Integration: Ensuring that both devices can communicate effectively requires specific modifications to their software or hardware. This involves developing custom applications that allow for seamless data transfer and processing between the dosimeter, a Raspberry Pi unit, and the host PC.

In summary, the selection of the Dreame L10s vacuum and the AccuRad dosimeter is grounded in their respective capabilities and the critical integration considerations that will enhance the overall functionality of our system. By focusing on real-time data measurement and location tagging, we aim to create a robust solution that prioritizes safety and efficiency.

2.2. Integration Methodology

2.2.1. Mechanical Integration

The Dreame L10s Ultra was mechanically modified to create an internal payload bay suitable for radiation mapping. The stock cleaning hardware (roller, mop pads, and dust bin) was fully removed (Figure 3a), exposing the ~230 cm^3 main cavity. A Raspberry Pi 5 (CanaKit PRO kit) and the AccuRad detector were then mounted into this space using custom ABS 3D-printed bracketry. These brackets attach directly to existing internal screw bosses, enabling a fully reversible, non-destructive integration. A short USB lead connects the Raspberry Pi to the AccuRad and is routed along the original cable channel to retain chassis closure. This architecture yields a mechanically rigid, mass-balanced payload integration that preserves the robot's SLAM/navigation sensors while converting the consumer vacuum platform into a compact mobile radiation mapping system (Figure 3b).

(**a**) (**b**)

Figure 3. The mechanical integration of (**a**) the Dreame L10s Ultra smart vacuum, (**b**) an AccuRad detector and a Raspberry Pi.

2.2.2. Electronic Integration

The AccuRad detector connects with the Raspberry Pi unit through USB interface, which not only powers the device but also facilitates streamlined data communication. This Raspberry Pi draws power directly from the robot's main battery, which allows for continuous operation without interruption and eliminates the need for a separate power supply. In terms of data acquisition, the Raspberry Pi reads radiation dose rate measurements from the AccuRad via the USB connection. It then transmits this data, along with the current system time, to a host PC over a local WiFi network. This communication is accomplished using the MQTT protocol, which is well-suited for lightweight messaging and efficient data transmission. Simultaneously, the Dreame L10s Ultra robot also communicates with the host PC, sending its current location, time-stamped, using the same MQTT protocol. This dual-channel communication ensures that both the radiation data and the robot's location are logged and monitored effectively, contributing to a comprehensive data acquisition and logging system.

2.3. Software Development

2.3.1. Navigation and Path Planning

The Dreame L10s Ultra is equipped with advanced SLAM technology, utilizing LIDAR and other sensors for automatic obstacle avoidance. This allows it to create tailored mapping strategies and generate optimized paths based on the specific obstacles, types of flooring, and room configurations present in the designated area. For this work, we implemented two distinct mapping protocols: the first is automatic path planning, managed by the built-in firmware, ensuring effective mapping without user intervention; the second protocol allows for custom path planning via MQTT commands through Valetudo, enabling the user to program the robot's pathway and achieve more thorough and systematic coverage tailored to the mission and the environment.

2.3.2. Data Acquisition and Processing

To implement the system described, the first step involves setting up the AccuRad for real-time radiation measurement. This requires connecting the AccuRad device to a Raspberry Pi through USB. Subsequently, a Python script was written and executed on the Raspberry Pi to continuously read the radiation measurement data from the AccuRad. The next phase is to configure the Raspberry Pi for MQTT communication. This involves installing an MQTT broker on the Raspberry Pi, such as Mosquitto. An MQTT library, i.e., 'paho-mqtt' for Python, was utilized to publish the radiation data along with the current system time. The script included a function to read data from the AccuRad and publish it in a structured format, ensuring that the data is sent at a defined frequency. Following the setup of the Raspberry Pi, the Dreame L10s Ultra was configured for spatial data transmission. It is essential to ensure that the Dreame L10s Ultra is connected to the same local WiFi network as the Raspberry Pi. The device was set up to transmit the robot's current location coordinates, via MQTT, including a timestamp for synchronization with the radiation data. The next step involved setting up the host PC for data retrieval and logging. On the host PC, an MQTT client library was installed to subscribe to the radiation and spatial data topics. A logging mechanism was created to store the received data in a structured format, e.g., CSV. This ensured that the data can be easily accessed and analyzed later. To maintain data integrity, it is crucial to implement quality control and error detection mechanisms. This includes developing algorithms to check the integrity and quality of the logged data and implementing error detection methods, such as identifying outliers or missing timestamps. Once the data has been collected, a processing module on the host PC was created to correlate the radiation and spatial data based on their timestamps. Libraries such as Pandas were employed for data manipulation and correlation, allowing for a comprehensive analysis of the relationship between radiation levels and spatial data. Visualization plays a key role in interpreting the data. Utilizing visualization libraries like Matplotlib or Plotly, visual representations of the correlated data can be generated. This included maps and graphs that illustrate radiation levels in relation to spatial coordinates, providing valuable insights into the data. Finally, thorough testing and validation of the entire system is essential to ensure reliability. This involved verifying that data was logged correctly and that visualizations accurately represented the source distribution.

2.4. Experimental Methods

2.4.1. Experimental Design

This research was conducted within a laboratory environment measuring approximately 20 feet by 20 feet. At the center of the lab, two workstations were arranged for collaborative research endeavors. Encompassing these workstations were an array of critical laboratory apparatus, including a micro-CT machine, a fume hood and a few other workstations. Furthermore, several office chairs were distributed throughout the lab. Radiation sources employed in the study were situated in the northwest corner of the lab, including a collection of check sources (two 10 µCi Cs-137 sources). The base station of the L10s Ultra vacuum is positioned close to the southeast corner. For a visual depiction of the laboratory's configuration, please consult the accompanying image and the floor plan generated by the LIDAR of the Dreame L10s Ultra (see Figure 4).

Figure 4. The layout of the laboratory space and the floor map generated by the Dreame L10s Ultra.

2.4.2. Mapping Protocols

In this study, two distinct mapping protocols and procedures were implemented to evaluate the capabilities of the platform. The first protocol involved the utilization of the vacuum's automatic path planning feature. Initially, the device conducted a comprehensive scan of the room, generating an accurate floor map. This mapping process allowed the Dreame L10s Ultra to utilize its internal coverage-planning algorithm, which prioritizes (i) maximizing floor-area coverage, (ii) minimizing total path length, and (iii) minimizing dynamic re-routing resulting from obstacle avoidance events. The second protocol focused on generating a measurement grid of a predetermined spacing. This grid was designed to align with the floor map created during the initial scanning phase. Each measurement position within the grid was then verified against the generated floor map to eliminate any points that are not accessible to the robot. Following this validation, a script was executed on the host PC to navigate the vacuum along the designated paths. Mapping protocol 1 demonstrates the system's ability to perform a fully autonomous floor scan using the robot's native coverage path planning, whereas Protocol 2 enables controlled grid-based sampling to analyze spatial resolution vs. mapping time trade-offs.

During the experiments, the AccuRad transmits radiation data every second, along with the system clock time, over a local Wi-Fi network using the MQTT protocol. In the first mapping protocol, the Dreame L10s Ultra utilizes its automatic path planning feature and sends its location every 500 ms via the same Wi-Fi network using MQTT. In the second protocol, the vacuum remains stationary at each predefined measurement point for 10 s, broadcasting its location during this measurement period.

2.4.3. Data Processing

A host PC was used to retrieve the time-stamped radiation and spatial data transmitted by the Raspberry Pi and the L10s Ultra robot. The PC was connected to the same local Wi-Fi network and data transmission was achieved via the MQTT protocol. Following data retrieval, radiation measurements were synchronized with the corresponding spatial data based on the collected timestamps. This step was essential to ensure that each radiation reading was accurately matched to its specific location within the laboratory, thereby enabling a precise visualization of radiation levels. To ensure the integrity of the dataset, quality control measures were implemented to filter out erroneous or outlier data points. This involved a thorough examination of the dataset for missing timestamps, unrealistic radiation values, and inconsistencies in the spatial data. A Python script specifically for parsing the retrieved data. This script was crafted to read the data files, extract pertinent information, and prepare the dataset for subsequent visualization. Utilizing the matplotlib visualization library, radiation heat maps were constructed and overlaid onto the laboratory's floor plan. This map illustrates the radiation levels across various areas of the laboratory, identifying hotspots or areas of concern to enhance safety and operational efficiency.

3. Results

Key performance metrics used to evaluate the mapping results included the extent and thoroughness of mapping coverage, the accuracy of measurements, as well as the effectiveness of operations and the time needed to complete tasks. The results indicate that, in both mapping protocols, the automated radiation mapping platform achieved over 90% coverage of the designated area, significantly enhanced measurement efficiency compared to traditional manual methods while providing the same level of accuracy. In discussing accuracy, particularly in the context of using off-the-shelf dosimeters like AccuRad, it is essential to recognize that the accuracy of dose measurement is fundamentally constrained by the performance characteristics of the device itself. AccuRad, known for its reliability and precision, provides a robust platform for radiation mapping. However, the inherent limitations of any dosimeter, including factors such as calibration, sensitivity, and response time, can impact the overall accuracy of the measurements obtained. Spatial resolution refers to the smallest discernible detail within a mapped area, which is crucial for identifying localized radiation sources and understanding the distribution of radiation exposure. This is related to the frequency of data transmission in the first mapping protocol and the spacing of the measurement grid in the second mapping protocol. On the other hand, the AccuRad dosimeter, while effective, may have limitations in spatial resolution based on its design and its non-directional response.

3.1. Mapping Approach #1: Automatic Path Planning

An automatic path planning approach was first employed to generate laboratory radiation distribution maps. Our findings demonstrated that the integration of automatic path planning successfully automated hotspot detection, allowing for a more effective identification of areas requiring further investigation. The radiation heat map produced through this methodology provided a comprehensive overview of radiation levels, highlighting anomalous hotspots (see Figure 5). Comparative analysis with reference measurements confirmed the reliability of our mapping approach, demonstrating its potential application in various radiation monitoring scenarios.

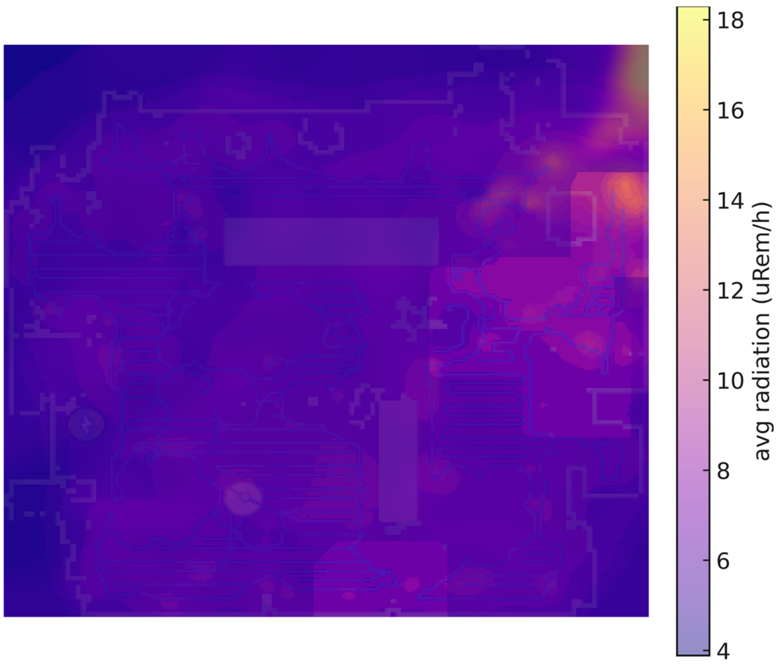

Figure 5. Radiation heat map generated using the automatic path planning approach.

3.2. Mapping Approach #2: Measurements over a Pre-Defined Grid

Firstly, a grid with pre-defined spacing was generated, which serves as the framework for measurements. This grid was then meticulously compared against the floor map produced by the Dreame L10s Ultra robotic vacuum. Coordinates that were inaccessible to the robot were then identified and eliminated. To facilitate the measurement process, a script was executed on the host PC, which directed the robot to perform radiation measurements at the valid coordinates across the grid. The data collected from these measurements were subsequently utilized to construct a comprehensive radiation heat map (see Figure 6). This mapping successfully highlighted the areas with elevated radiation levels, effectively identifying the hot spots within the surveyed environment. The integration of automated robotic technology with precise grid mapping proved to be an efficient method for radiation assessment, ensuring thorough coverage and accurate identification of potential hazards. This approach allowed the user to achieve the balance between spatial resolution and measurement time based on specific mission requirements.

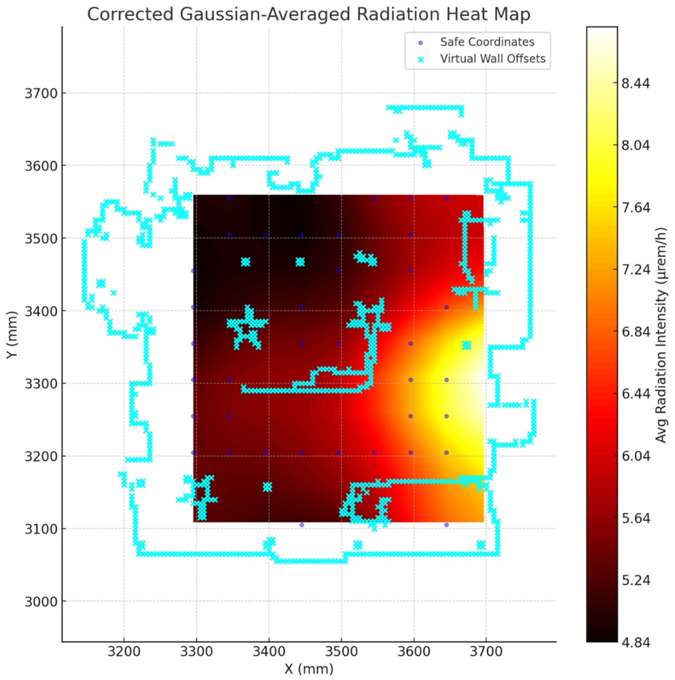

Figure 6. The validated measurement positions and the radiation heat map generated.

3.3. Cost-Benefit Analysis

The total cost of the system comprises of the following components:

- Dreame L10s Ultra: ~$500
- AccuRad dosimeter: ~$1600
- Raspberry Pi: ~$100

When evaluating alternatives to existing commercial solutions, it is crucial to assess not only the initial investment but also the ongoing operational expenses and long-term advantages. Established commercial systems typically command higher prices due to their sophisticated features, comprehensive support, and proven reliability. In contrast, the developed Dreame L10s Ultra and Raspberry Pi platform emerges as practical options for facilities aiming to strike a balance between cost and functionality. For instance, traditional monitoring systems utilized in nuclear facilities can cost anywhere from several thousand to tens of thousands of dollars, depending on their specifications. For example, Schwaiger et al. reported a high-end, field-deployable CBRN disaster-response unmanned ground vehicle (UGV-CBRN) that integrates autonomous radiation mapping with SLAM-based navigation [31]. Similarly, Jones et al. described the RadPiper PCAMS robot—a DOE-deployed in-pipe U-235 holdup nondestructive assay system incorporating a disc-collimated NaI detector and engineered for nuclear decommissioning field operations [32]. While significantly more capable, these systems are also substantially more expensive and, as a result, not realistically accessible to many small businesses, smaller laboratories, or academic users. The total bill of materials for our platform is approximately $1800–$2300 (intelligent vacuum robot, AccuRad PRD, Raspberry Pi, and 3D-printed mounts). Therefore, our system delivers approximately one order-of-magnitude cost reduction while retaining autonomous mapping functionality. This price point enables practical adoption by small research groups, university labs, training programs, and resource-constrained organizations that cannot procure specialized platforms.

The return on investment (ROI) for automated monitoring systems can be assessed by comparing the costs associated with manual surveys to those of automated solutions. Manual surveys typically incur significant labor costs, require considerable time, and may introduce inaccuracies that pose safety risks, particularly in sensitive environments like nuclear facilities. In contrast, automated monitoring systems such as the Dreame L10s Ultra and AccuRad not only reduce labor costs but also enhance the reliability of data collection. Thus, switching to an automated system could result in considerable savings. With operational and maintenance costs of the Dreame L10s Ultra estimated as negligible, the facility could potentially see a positive ROI within a short time period. Moreover, the implementation of routine monitoring at reduced costs strengthens safety protocols in nuclear power plants and facilities. Continuous monitoring enables quicker responses to potential hazards, thereby fostering a safer operational environment.

3.4. Main Contribution, System Limitations and Challenges

The primary contribution of this work is the demonstration that a consumer-grade smart vacuum robot—with minimal mechanical modification—can be repurposed into an autonomous radiation mapping platform. Unlike existing high-end nuclear-certified robots, which are purpose-built and costly, our solution leverages a COTS robotic platform while retaining its built-in SLAM, on-board localization, and autonomous path-planning functions. This enables a dramatically lower system cost and a significantly lower adoption barrier.

The deployment of smart vacuum robots in various environments presents several technical limitations that must be considered. One significant constraint is the accessibility of the device, particularly in navigating obstacles such as stairs and door frames. These physical barriers can impede the robot's ability to operate effectively across different levels of a structure, potentially limiting its operational range and efficiency. Additionally, the duration of a single run is constrained to approximately 1–2 h before the robot requires recharging. This limited operational time can affect the thoroughness and coverage of the mapping process, particularly in larger spaces. The effectiveness of the device is further influenced by the range of the Wi-Fi network, as connectivity issues can disrupt the robot's ability to receive updates, map its surroundings, and execute automatic path planning. Another critical technical limitation arises from the robot's constant movement during operation. This dynamic behavior introduces uncertainty in the radiation data collected, as the robot may not remain stationary while measuring environmental variables. Consequently, this movement can lead to uncertainties in the data, complicating the interpretation of results. Furthermore, there is a challenge in balancing resolution and mapping time. The grid size used for mapping directly impacts the detail of the data collected; however, finer resolutions typically require more time to process. This trade-off must be carefully managed to ensure that the mapping is both accurate and efficient. Lastly, the positioning of the detector or robot at ground level can significantly affect dose measurement results, particularly if the radiation source is elevated. Measurements taken from a lower vantage point may not accurately reflect the radiation levels present at higher elevations, leading to potential discrepancies in the data collected.

In summary, while smart vacuum robots offer innovative solutions for automated cleaning and environmental monitoring, their effectiveness is constrained by technical limitations related to accessibility, operational time, connectivity, movement-induced uncertainties, resolution versus mapping time, and the positioning of measurement devices. Addressing these limitations is essential for enhancing the reliability and accuracy of the data obtained during their operation.

4. Discussion

This research successfully demonstrates the feasibility of a low-cost automated robotic platform for radiation mapping through innovative integration of COTS components. The proposed system achieves significant cost reductions compared to commercial alternatives while maintaining acceptable performance standards for many practical applications.

Our approach addresses accessibility challenges faced by many potential users, including educational institutions, small research facilities, and organizations in developing regions. By providing an affordable, user-friendly solution, this system not only improves safety measures but also empowers a broader audience to engage in radiation monitoring activities. Beyond the laboratory demonstration, this platform concept could provide practical utility for routine screening in nuclear facilities, periodic radiation survey in medical centers, and rapid situational awareness mapping during emergency response, where a low-cost, autonomous, and easily deployable system may offer operational value.

Key contributions include:

- Demonstration of COTS component integration for specialized applications
- Significant cost reduction without major performance compromises
- Enhanced accessibility for resource-constrained organizations
- Validated performance across diverse operational scenarios

While the developed COTS-based platform enables autonomous indoor radiation mapping at significantly reduced cost, its achievable measurement precision is ultimately constrained by the accuracy and resolution of the integrated PRD. Therefore, the system is best positioned for routine area surveys, low-resolution contamination screening, and emergency response triage (e.g., rapid mapping of dose gradients). In contrast, medical radiation QA/clinical dosimetry tasks would require instrumentation with higher intrinsic precision, lower statistical uncertainty, and tighter calibration traceability than what is achievable with the cost-optimized PRD used here. As such, this platform is not proposed as a replacement for high-performance survey meters, but rather as an accessible complement for routine facility surveys and rapid situational awareness.

Future work on the low-cost automated robotic platform for radiation mapping will aim to enhance its capabilities and user experience through several key improvements. This includes increasing the platform's robustness and performance via field tests and integrating advanced sensors for more accurate radiation measurements. User interface enhancements are essential for accessibility, potentially through a mobile app featuring real-time data visualization and tutorials. Additionally, exploring other affordable COTS robotic platforms could improve maneuverability and operational efficiency, such as JetRacer Pro from Waveshare and MentorPi from Hiwonder. Expanding the platform's range and functionality by integrating long-range communication technologies and autonomous charging capabilities will further enhance its utility in monitoring scenarios. These advancements will ultimately contribute to improved safety protocols and more effective radiation exposure management.

Author Contributions

Conceptualization, H.Y.; methodology, H.Y.; software, H.Y., J.H. and W.Y.; validation, H.Y. and W.Y.; formal analysis, H.Y. and W.Y.; investigation, H.Y. and W.Y.; resources, H.Y.; data curation, H.Y. and W.Y.; writing—original draft preparation, H.Y.; writing—review and editing, H.Y.; visualization, H.Y.; supervision, H.Y.; project administration, H.Y.; funding acquisition, H.Y. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used Microsoft Copilot to improve grammar and clarity. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

References

1. White, S.R.; Megson-Smith, D.A.; Zhang, K.; et al. Radiation mapping and laser profiling using a robotic manipulator. *Front. Robot. AI* **2020**, *7*, 499056.
2. Ryu, B.H.; Park, P.W.; Yu, E.S.; et al. A Study on Real-time Radiation Map Generation System that Combines LIDAR and Survey Meter. In Proceedings of the Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Republic of Korea, 18–19 May 2023.
3. Adams, J.; Cintas, B.; Sung, N.; Abrahao, A.; et al. A Behavioral Robotics Approach to Radiation Mapping Using Adaptive Sampling. *Appl. Sci.* **2025**, *15*, 2076–3417.
4. Marques, L.; Vale, A.; Vaz, P. State-of-the-art mobile radiation detection systems for different scenarios. *Sensors* **2021**, *21*, 1051.
5. Mascarich, F.; Kulkarni, M.; De Petris, P.; et al. Autonomous mapping and spectroscopic analysis of distributed radiation fields using aerial robots. *Auton. Robot.* **2023**, *47*, 139–160.
6. Sato, Y.; Minemoto, K.; Nemoto, M.; et al. Automatic data acquisition for visualizing radioactive substances by combining a gamma-ray imager and an autonomous mobile robot. *J. Instrum.* **2021**, *16*, P01020.
7. Lee, M.S.; Hanczor, M.; Chu, J.; et al. 3-D volumetric gamma-ray imaging and source localization with a mobile robot. *arXiv* **2018**, arXiv:1802.06072.
8. Groves, K.; Hernandez, E.; West, A.; et al. Robotic exploration of an unknown nuclear environment using radiation informed autonomous navigation. *Robotics* **2021**, *10*, 78.
9. Martin, P.G.; Kwong, S.; Smith, N.T.; et al. 3D unmanned aerial vehicle radiation mapping for assessing contaminant distribution and mobility. *Int. J. Appl. Earth Obs. Geoinf.* **2016**, *52*, 12–19.
10. Connor, D.; Martin, P.G.; Scott, T.B. Airborne radiation mapping: Overview and application of current and future aerial systems. *Int. J. Remote Sens.* **2016**, *37*, 5953–5987.
11. Han, J.; Xu, Y.; Di, L.; et al. Low-cost multi-UAV technologies for contour mapping of nuclear radiation field. *J. Intell. Robot. Syst.* **2013**, *70*, 401–410.
12. Christie, G.; Shoemaker, A.; Kochersberger, K.; et al. Radiation search operations using scene understanding with autonomous UAV and UGV. *J. Field Robot.* **2017**, *34*, 1450–1468.
13. Woodbridge, E.; Connor, D.T.; Verbelen, Y.; et al. Airborne gamma-ray mapping using fixed-wing vertical take-off and landing (VTOL) uncrewed aerial vehicles. *Front. Robot. AI* **2023**, *10*, 1137763.
14. Kunze, C.; Preugschat, B.; Arndt, R.; et al. Development of a UAV-based gamma spectrometry system for natural radionuclides and field tests at central Asian Uranium legacy sites. *Remote Sens.* **2022**, *14*, 2147.
15. Katreiner, H.; Kovács, B.; Horváth, Á.; et al. Cost-effective drone survey of areas with elevated background radiation. *Drones* **2024**, *9*, 19.
16. Tancioni, P.; Berger, P.; Chandra, R.; et al. Experimental Characterization of a Lightweight Unmanned Aerial Radiation Detection System equipped with a "Flat Panel" gamma detector. Available online: https://resources.inmm.org/sites/default/files/2023-07/finalpaper_244_0512091715.pdf (accessed on 14 January 2026).
17. Lazna, T.; Gabrlik, P.; Jilek, T.; et al. Cooperation between an unmanned aerial vehicle and an unmanned ground vehicle in highly accurate localization of gamma radiation hotspots. *Int. J. Adv. Robot. Syst.* **2018**, *15*, 1729881417750787.
18. Gabrlik, P.; Lazna, T.; Jilek, T.; et al. An automated heterogeneous robotic system for radiation surveys: Design and field testing. *J. Field Robot.* **2021**, *38*, 657–683.
19. Chai, R.; Guo, Y.; Zuo, Z.; et al. Cooperative motion planning and control for aerial-ground autonomous systems: Methods and applications. *Prog. Aerosp. Sci.* **2024**, *146*, 101005.
20. Munasinghe, I.; Perera, A.; Deo, R.C. A comprehensive review of uav-ugv collaboration: Advancements and challenges. *J. Sens. Actuator Netw.* **2024**, *13*, 81.
21. Ding, Y.; Xin, B.; Chen, J. A review of recent advances in coordination between unmanned aerial and ground vehicles. *Unmanned Syst.* **2021**, *9*, 97–117.
22. Baca, T.; Jilek, M.; Manek, P.; et al. Timepix radiation detector for autonomous radiation localization and mapping by micro unmanned vehicles. In Proceedings of the 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Macau, China, 3–8 November 2019.
23. Villaverde, I.; Urquiza, A.; Outón, J.L. A Reconfigurable UGV for Modular and Flexible Inspection Tasks in Nuclear Sites. *Robotics* **2024**, *13*, 110.
24. Lazna, T. Optimizing the localization of gamma radiation point sources using a UGV. In Proceedings of the 2018 ELEKTRO, Mikulov, Czech Republic, 21–23 May 2018.
25. Durukan, H.M. Simulation of Radiation Source Localization through Circle Approach and 3-D Visualization of Unknown Environment Using UGV Equipped with 3-D Lidar Based on Rotational 2-D Lidar. Ph.D. Thesis, Texas A&M University, College Station, TX, USA, 28 June 2021.

26. Baca, T.; Stibinger, P.; Doubravova, D.; et al. Gamma radiation source localization for micro aerial vehicles with a miniature single-detector Compton event camera. In Proceedings of the 2021 International Conference on Unmanned Aircraft Systems (ICUAS), Athens, Greece, 15–18 June 2021.
27. Roser, J.; Hueso-González, F.; Ros, A.; et al. Compton cameras and their applications. In *Radiation Detection Systems*; CRC Press: Boca Raton, FL, USA, 2021; pp. 161–198.
28. Stolkin, R.; Molitor, N.; Berben, P.; et al. Status, barriers and cost-benefits of robotic and remote systems applications in nuclear decommissioning and radioactive waste management. no. NEA/RWM (2022). Available online: https://www.oecd-nea.org/jcms/pl_77051/status-barriers-and-cost-benefits-of-robotic-and-remote-systems-applications-in-nuclear-decommissioning-and-radioactive-waste-management?details=true (accessed on 14 January 2026).
29. Chiou, M.; Epsimos, G.T.; Nikolaou, G.; et al. Robot-assisted nuclear disaster response: Report and insights from a field exercise. In Proceedings of the 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Kyoto, Japan, 23–27 October 2022.
30. Lopez Pulgarin, E.J.; Hopper, D.; Montgomerie, J.; et al. From traditional robotic deployments towards assisted robotic deployments in nuclear decommissioning. *Front. Robot. AI* **2025**, *12*, 1432845.
31. Schwaiger, S.; Muster, L.; Novotny, G.; et al. UGV-CBRN: An Unmanned Ground Vehicle for Chemical, Biological, Radiological, and Nuclear Disaster Response. *arXiv* **2024**, arXiv:2406.14385.
32. Jones, H.; Maley, S.; Mousaei, M.; et al. A Robot for nondestructive assay of holdup deposits in gaseous diffusion piping. *arXiv* **2019**, arXiv:1901.10341.