Design and Development of Robot for Surveillance and Critical Area Inspection

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Abstract: *This paper presents the design, development, and testing of a low-cost, modular robotic system for surveillance and radiation monitoring in nuclear power plants (NPPs). The robot integrates a Geiger-Müller radiation sensor, GSM-based emergency alerts, Bluetooth remote control, and a 3D-printed chassis optimized for hazardous environments. Experimental results demonstrate stable operation in simulated NPP zones, with a radiation detection response time of ≤30 seconds and a cost-effective production model (under ₹25,000). The system addresses gaps in outer-area NPP inspection and real-time radiation monitoring, offering scalability for future enhancements like autonomous navigation and AI-driven object detection.*

***Keywords** – Surveillance Robot, Nuclear Safety, Radiation Detection, Wireless Control, Low-Cost Robotics.*

1. INTRODUCTION

Nuclear power plants (NPPs) harness the energy released from nuclear fission reactions to generate electricity. In these plants, heavy atomic nuclei, typically uranium-235 or plutonium-239, are split into smaller fragments when struck by neutrons, releasing substantial heat energy. This heat is utilized to produce steam, which drives turbines connected to electricity generators.

Robots play a crucial role in national security by enhancing surveillance, reconnaissance, and tactical operations while reducing human risk. Their ability to operate in hazardous environments makes them essential for modern defense and security applications. With advancements in AI, automation, and sensor technology, robots will continue to play an integral role in national security. Nuclear power plants (NPPs) require rigorous inspection of high-radiation zones to ensure operational safety. Traditional methods rely on human workers, exposing them to significant risk.

Key Applications of Robots in NPPs:
1. Inspection & Monitoring: Robots equipped with cameras and sensors inspect reactors, pipelines, and steam generators, detecting leaks, cracks, or structural wear.
2. Maintenance & Repairs: Automated systems perform welding, decontamination, and component replacement in high-radiation zones.
3. Decontamination & Waste Handling: Robots clean contaminated surfaces, handle radioactive waste, and transport spent fuel safely.
4. Emergency Response: In case of accidents, robots assess radiation levels, contain leaks, and assist in rescue operations without risking human lives.
5. Surveillance & Security: Autonomous robots patrol NPP premises, preventing unauthorized access and detecting potential threats.

This project develops a robotic solution to:

- Monitor radiation levels in NPP exclusion zones.
- Transmit real-time alerts via GSM during emergencies.
- Enable remote wireless control via Bluetooth.

The robot's design emphasizes affordability (using Arduino Nano and modular sensors) and adaptability (3D-printed chassis with radiation-resistant PLA).

2. LITERATURE REVIEW

Recent advancements in robotic systems for nuclear inspection and surveillance highlight a strong focus on adaptability, mobility, and precision in hazardous environments. Various studies emphasize the development of robots tailored for critical applications such as nuclear decommissioning, infrastructure inspection, and emergency response.

- Multi-Functional Robotic Systems: Robots such as the KAEROT series have been designed with diverse functionalities suitable for various nuclear scenarios, showcasing adaptability in their deployment (Choi et al., 2019).
- Precision Handling and Sampling: The integration of robotic arms and track systems enhances the capability of robots to collect samples efficiently and traverse challenging terrains (Davies, 2022).
- Cost-Effective Ground Robots: Lightweight and economically viable robots like Vega have been introduced for ground-level nuclear tasks, emphasizing accessibility and operational efficiency (Bird et al., 2021).
- Self-Localization in Confined Spaces: Technologies enabling autonomous navigation and localization within tight and hazardous environments have been a pivotal area of development (Li et al., 2017).
- Contamination Detection: Advanced systems have been created that can be mounted on robots to detect α- and β-surface contamination, ensuring precise environmental monitoring (Wang & Sheng, 2024).
- Reinforced Control and Sensing Systems: Research has emphasized reinforcement of sensing and control technologies in nuclear robots to facilitate accurate path planning and monitoring in high-risk zones (Chang et al., 2021).
- Path Planning Techniques: Studies have evaluated the performance of different path planning algorithms to optimize the patrol routes of mobile robots within nuclear facilities (Liu et al., 2023).
- Emergency Response Capabilities: The demand for nuclear emergency response robots has been assessed, with key characteristics identified for effective intervention during crisis scenarios (Zhang et al., 2018).

No Proper security and inspection of outer area of nuclear power plants (NPP). There is no constant monitoring of the zones in NPP. Large sets of infrastructure need to be monitored or inspected. Inspection at critical areas is complex. Use of multiple sensors and electronics significantly increases the overall price of robots.

The objective is to Design and Develop a Low-cost Security and Critical radiation inspection Robot. To implement low-cost security alarm and alert indication in terms of security breach using GSM Module and LEDs. To implement a low-cost radiation monitoring using Geiger Muller Radiation Detector. Structural simulation of the robot using COMSOL.

3. METHODOLOGY

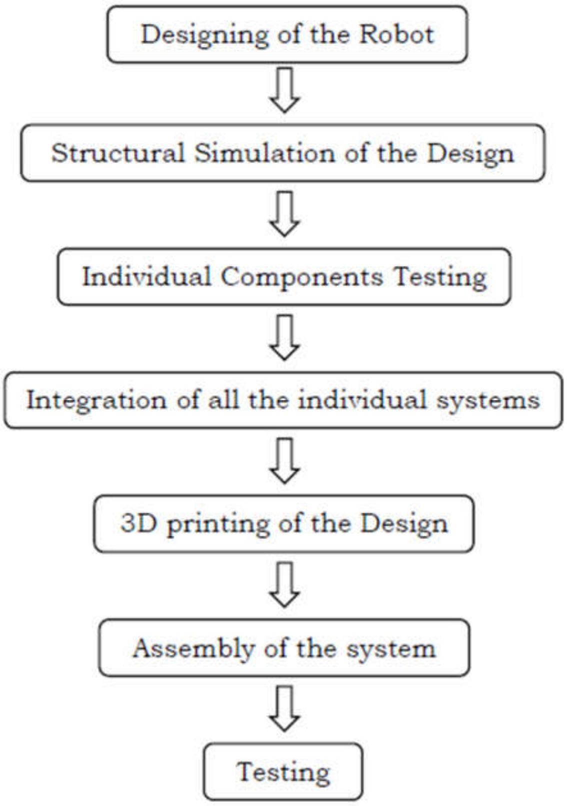


Figure 1. Methodology Flow Chart

4. EXPERIMENTAL WORK

The initial design of the main body of the robot had two slabs for placement of the components depending on their individual designs. Upon running structural simulations in FEA software, it was found out 6.9 MPa is the maximum stress and tensile strength of PLA is 40 MPa. Deformation of 1.8mm was existing during this simulation for the applied load due to lack of support. This deformation can be reduced / optimized by changing the design and adding support and ribs necessary.

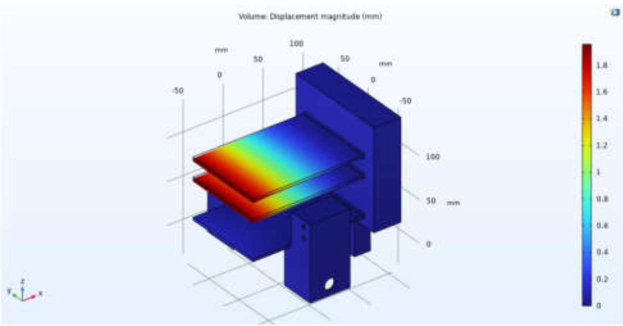


Figure 2.1 Deformation of main body

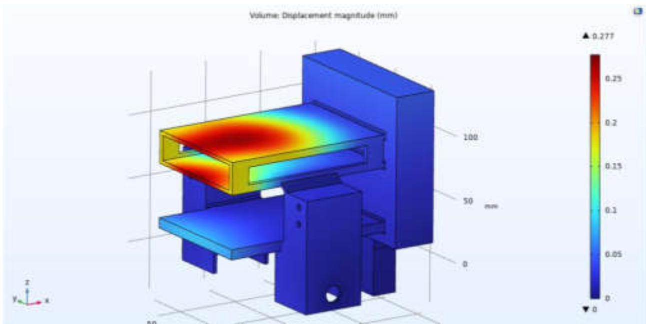


Figure 2.2 Deformation of main body

Henceforth, support was provided to the slabs by adding two pillars connecting both the slabs.

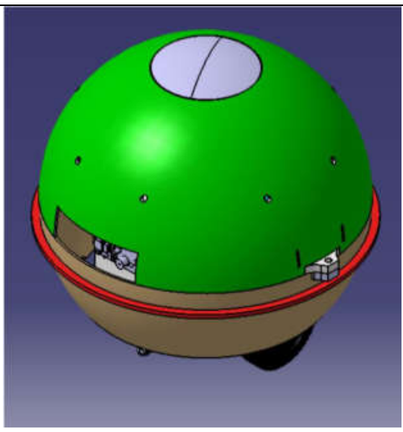
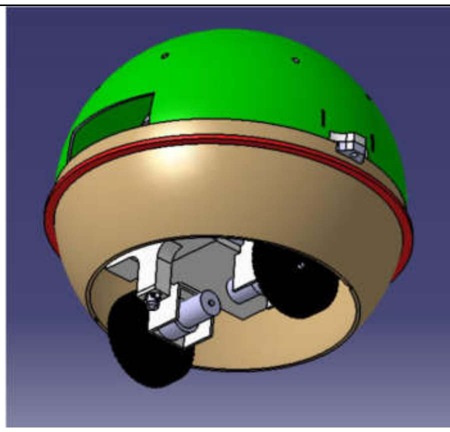
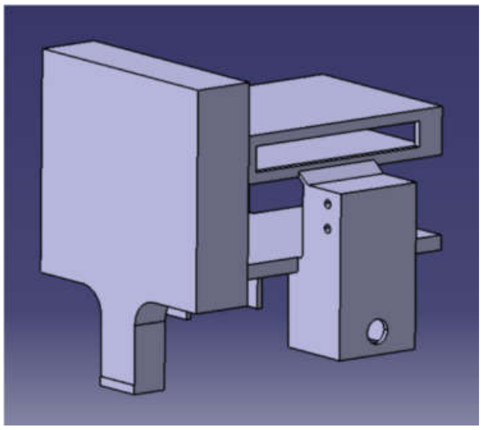
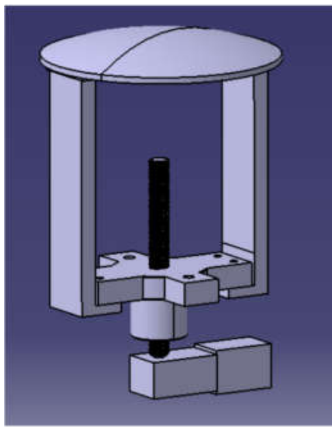
 Iso view of Robot	 Iso view of Robot
Iso view of main body 	Iso view of Camera Mount Assembly 

Figure 3 Project Model

The design was manufactured using FDM 3D printing method. The material used for manufacturing was Polylactic Acid (PLA). The manufacturing took around 3-4 days depending on the number of parts, infill percentage and internal structure.

Figure 4 Top cover Bottom cover of the housing of the robot

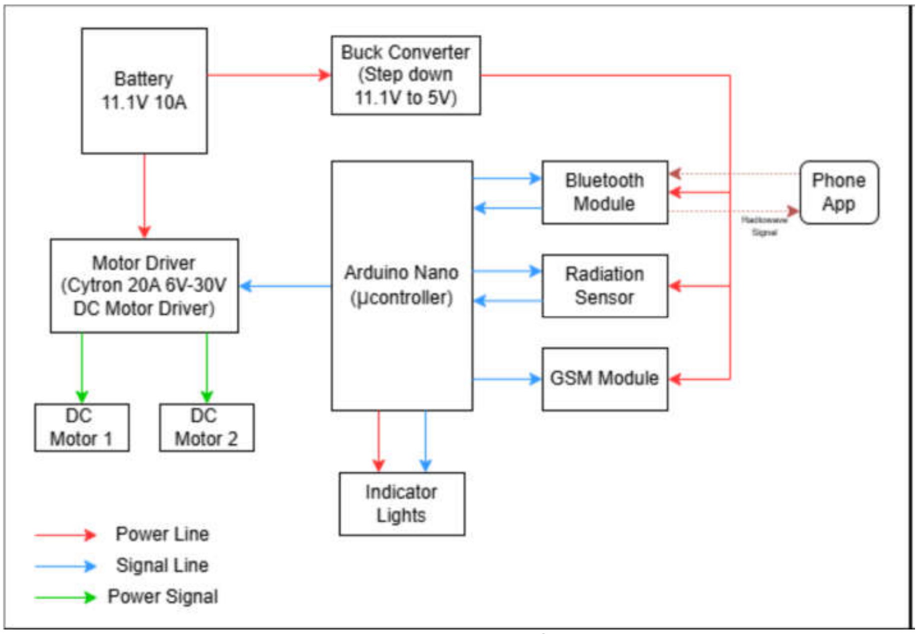


Figure 5 Block diagram of the Robot

Figure 7.1 illustrates the overall system architecture of the Radiation-Sensing Surveillance Robot controlled via Bluetooth and GSM communication. The system is powered via an 11.1V battery. Arduino Nano acts as the brain, controlling motors, LEDs, and communication modules. The motor driver drives two DC motors for motion. The radiation sensor continuously checks for ionizing radiation. The user controls the robot using a mobile app via Bluetooth. If radiation is detected, alerts are sent via GSM. Status indicators give visual cues about system state.

5. RESULT AND DISCUSSION

The various results obtained using theoretical calculations and the performance of designed robots is compared by its response time to critical scenarios. The designed and manufactured robot could serve its purpose. The system integration worked as intended showing great performance.

The Table 1 result shows the test runs that were conducted several times to determine the response time of the SIM alert system upon detecting any radiation.

Table 1 Test run results

Trial No	Radiation Sensor		SIM Alert
	Initial Value (µsv)	Radiation Value (µsv)	Response Time for call in seconds (s)
1	0.20	1.25	25
2	0.25	1.57	30
3	0.20	2.05	27
4	0.27	1.85	25
5	0.25	1.63	25

Looking ahead, the robot can be equipped with sensors like LiDAR for autonomous navigation. The design incorporates placement of camera considering future possibilities. Machine Vision systems using AI and Machine Learning can be employed using a camera, for additional capability and security features.

6. CONCLUSION

The project "Design and Development of Robot for Surveillance and Critical Area Inspection" was successfully executed with the development of a multi-functional robotic system capable of operating in hazardous zones such as nuclear power plant environments. The robot integrates crucial features such as radiation detection, wireless control via Bluetooth, emergency SMS alerting via GSM, and mobility mechanisms suitable for inspection and surveillance tasks.

From concept to prototype, the robot was built using cost-effective components and manufactured using 3D printing technology, making it an accessible and practical solution for real-world applications. Structural simulations confirmed the mechanical robustness of the design, and functional testing demonstrated reliable performance in both surveillance and emergency response scenarios.

Through this project, the objectives of reducing human risk in high-radiation zones and enhancing inspection efficiency were effectively met. The system's adaptability and modularity make it suitable for future advancements, including AI-based monitoring and autonomous navigation. This work contributes to the growing field of robotics in nuclear safety and national security, emphasizing the importance of innovation and interdisciplinary engineering.

7. REFERENCES

[1] Chang-Hwan Choi, Seungho Kim, Chang-Hoi Kim, Yong-Chil Seo, Hocheol Shin, Sung-Uk Lee, Kyung-Min Jung, Seung-Ho Jung, and Youngso Choi, “The Robots for Nuclear Power Plants”, Transactions of the Korean Nuclear Society Spring Meeting, Vol. 1, Issue 1, pp. 588-593, 2019.

[2] Bethan Davies, “Novel Portable Robot Used to Inspect Nuclear Infrastructure”, Vol. 1, Issue 1, pp. 1-2, 2022.

[3] Benjamin Bird, Matthew Nancekievill, Andrew West, Jim Hayman, Chris Ballard, Will Jones, Shaun Ross, Toby Wild, Tom Scott, and Barry Lennox, “Vega—A Small, Low-Cost, Ground Robot for Nuclear Decommissioning”, Journal of Nuclear Robotics, Vol. 5, Issue 2, pp. 45-53, 2021.

[4] Jinke Li, Xinyu Wu, Tiantian Xu, Huiwen Guo, Jianquan Sun and Qingshi Gao, “A Novel Inspection Robot for Nuclear Station Steam Generator Secondary Side with Self-Localization”, International Journal of Nuclear Energy Science and Technology, Vol. 8, Issue 4, pp. 321-330, 2017.

[5] Qiang Wang and Yifa Sheng, “Surface Contamination Measurement by Combining Detectors and Robots”, Journal of Physics: Conference Series, 2724/1/012029, 2024.

[6] Yinlin Chang, Shuliang Zou, Guang Lin, Dewen Tang, Cuiyue Wei and Shoulong Xu, “Research on Radiation Damage and Reinforcement of Control and Sensing Systems in Nuclear Robots”, Nuclear Science and Techniques, Vol. 30, Issue 5, pp. 74-82, 2021.

[7] Shuying Liu, “Research on Performance Comparison of Patrol Path Planning Techniques for Mobile Robots in Nuclear Power Plants”, Annals of Nuclear Energy, Vol. 85, Issue 1, pp. 15-23, 2023.

[8] Qihao Zhang, Wei Zhao, Shengnan Chu, Lei Wang, Jun Fu, Jiangrong Yang and Bo Gao, “Research Progress of Nuclear Emergency Response Robot”, IOP Conf. Ser.: Mater. Sci. Eng. 452 042102, 2018.