

AUTONOMOUS AERIAL RADIOMETRIC MAPPING

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Abstract - This project needs to establish safe and precise radiation monitoring systems which can operate in dangerous environments that include areas near nuclear power plants and former blast zones. The existing manual surveying techniques require workers to handle hazardous conditions without providing sufficient detail for creating safety assessments. Unmanned Aerial Vehicles (UAVs) with GPS systems and high-definition cameras and radiation detectors perform geospatial surveys to reduce operational hazards. It transforms acquired data into "Risk Heatmaps" which display safety levels through colour coding that uses a green, yellow and red system. The project aims to create a public information resource which enables communities to access real time spatial data for safer movement and living in areas that might be contaminated.

The project achieves its main value through its ability to display an unseen danger which connects advanced nuclear physics with public safety measures. The traditional method to detect radiation exposure needs workers to enter hazardous areas, which creates dangerous conditions. The project uses drones to collect data through high resolution, which protects workers from dangerous situations.

The system functions as an essential early-warning mechanism for leaks and environmental problems. The project holds significant value because it transforms scientific data into essential information which helps people near nuclear facilities to safely navigate their environment.

1. INTRODUCTION

The safety of communities living near industrial or nuclear facilities is a paramount concern in modern society. The most important element for reducing damage during accidents is the time period after the event. Traditional methods for assessing radiation levels

require human experts to enter hazardous areas which results in their exposure to serious health dangers.

There is an urgent requirement to establish safer and better methods for detecting and mapping radiation danger zones. The current manual surveying process operates at a slow pace while its results are affected by human mistakes and it creates unsafe conditions. This project develops a drone system which can autonomously detect and map radiation through its use of drone technology to create safe operating conditions for human operators.

This initiative combines advanced computer aided design with sophisticated flight control software. The drone has been designed to achieve lightweight and aerodynamic performance through the application of Autodesk Fusion 360 software. The system uses a Geiger Muller sensor which works with accurate navigation capabilities to create systematic and precise mission execution.

The main goal of this project is to develop an autonomous system which creates a protective barrier to defend against public threats. The system produces real time heatmaps which show hidden dangers, enabling authorities to make quick, informed choices. The project functions as an environmental monitoring solution, proving that autonomous systems combined with advanced data analysis methods protect human life and preserve environmental security.

2. PROBLEM DESCRIPTION

Description of Problem

Radiation monitoring and mapping in hostile conditions are important issues for ensuring safety and environmental integrity. Conventional approaches for

detection of ionizing radiation depend heavily on manual terrestrial surveys that are not only lengthy and tedious but also expose people to hazardous radiation levels.

For example, in cases of nuclear incidents, leakage from industries, or improper dumping of radioactive waste, quick assessment of radiation distribution becomes inevitable. There are many drawbacks associated with existing methods for radiometric mapping, which include:

Difficult terrain accessibility

Slow data gathering and non-real-time data processing

Inaccuracies in spatial analysis due to low resolution

Danger to field workers

Moreover, most of these systems cannot be automated and do not have the capability to efficiently integrate the collected data.

It is apparent from the above discussion that a safer, more efficient, and automated approach is required to collect and analyze radiation data and create highly accurate maps without putting people at risk. The proposed research will help fill the gap by developing an automated drone-based system for radiometric mapping.

3. LITERATURE REVIEW

Literature Review on Authors

Many authors have worked in the field of drone based radiometric mapping systems for enhancing safety, efficiency and accuracy in radiation measurement systems.

1. Felipe Mamed et al. (2025)

Proposed a drone based radiometric mapping system based on Geiger-Müller detectors.

Performed experimentation using the radioactive source, Cesium-137.

Provided an innovative approach towards generating 3D radiation distribution maps.

Proved the ability of drones in remote detection and localization of radiation sources. □

ResearchGate

2. Devina Chandra Dewi & Fitri Suryaningsih (2023)

Proposed a drone based radiation detection system with GPS and GIS (QGIS) integration.

Made use of Geiger-Müller sensors and waypoints.

Highlighted real-time radiations detection and map generation.

3. Ryan Pavlovsky et al. (2018)

Developed real-time 3D radiation mapping system called LAMP.

Combined data fusion technology with SLAM mapping.

Allowed high-quality, real-time visualization of radioactive materials.

Showcased sophisticated use of UAVs for emergencies and nuclear facility surveillance.

4. S. Van Der Veeke et al. (2024)

Presented guidelines for UAV-based radiometric surveys.

Stressed optimal data collection, calibration, and planning procedures.

Pointed out potential difficulties such as sensor capabilities and environmental conditions.

5. Comprehensive Review Papers (2024)

Recent literature reveals the extensive application of UAVs in:

Monitoring nuclear accidents

Inspection of radioactive waste

Evaluation of environmental radiation levels

UAV applications considerably lower human risk and enhance coverage efficiency.

6. Martin P. K. and Anders Johansson (2016)

Created a UAV-mounted system for measuring gamma radiations.

Designed the system for application after nuclear accidents.

Indicated superiority in area coverage and minimized risks associated with exposure.

7. Hiroki Tsuruta et al. (2014)

Performed radiation mapping after Fukushima Daiichi Nuclear Disaster.

Applied aerial mapping technique for large areas with radiation contamination.

Called for faster and automated systems in aerial monitoring.

8. J. Sanada et al. (2016)

Undertook aerial surveys to measure radiation using helicopters and UAVs.

Created maps of radiation distribution in wide areas.

Proved aerial mapping provides higher spatial resolution than ground surveys.

9. David A. Miller et al. (2017)

Suggested a small-size radiation measuring system for the incorporation into UAVs.

Concentrated on payload optimization to enhance aircraft flight characteristics.

Ensured efficient radiation information measurement in real time.

10. Kromek Group Research (2020)

Created self-guided radiation measuring systems carried by UAVs.

Combined sophisticated gamma sensors with unmanned aircraft.

Offered practical products for security and nuclear monitoring purposes.

11. Connor R. et al. (2019)

Explored the utilization of multi-UAV systems for radiation mapping.

Employed the swarm approach to radiation information gathering.

Enhanced efficiency and reliability under hazardous conditions.

12. B. Martin and P. Payton (2015)

Expounded the problem of radiation detection via unmanned systems.

Stressed the significance of remote sensing in detecting threats and ensuring national security.

4. PROPOSED SYSTEM

The autonomous aerial radiometric mapping platform utilizes UAV technology to locate, classify, and map sources of ionizing radiation or RF fields automatically. By 2026, these platforms have evolved from experimental instruments into industrial benchmarks for nuclear safety, environmental surveillance, and geological surveys.

1. Autonomous Mapping System Design

The successful proposal for an autonomous mapping solution generally involves the following four main components:

Aerial Vehicle: Heavy-duty or medium-range quadcopters (such as DJI Matrice 350 or bespoke vertical takeoff and landing vehicles), selected based on their stability and flight duration (approximately 30-55 minutes).

Payload Components:

- **Gamma Spectrometers:** It detects radioisotopes such as Potassium (K), Uranium (U), and Thorium (Th).

- **RF Sensors:** Used for Spectrum Mapping to evaluate cell network coverage and interference.

- **Onboard Intelligence (Brain):** This refers to the secondary computer (like Raspberry Pi 5 or NVIDIA Jetson) that will process information from the sensors.

- **Ground Control Station (GCS):** Software used for mission planning and 3D heatmaps visualization.

2. Key Technologies for 2026

Nowadays, sophisticated sensors are employed to provide accurate data in complicated environments.

| Technology | Function | Benefit |

LiDAR Terrain Following| Keeps a constant height (e.g., 1m to 25m) from the ground surface. | Ensures equal radiation measurements independent of any terrain irregularities. |

| RTK / PPK GNSS | Offers precision to centimeter accuracy. | Required for high-density mapping and identifying “hotspots.” |

| Obstacle Detection| Incorporates 360-degree laser scanners and visual sensors. | Facilitates autonomous operation in dangerous environments (e.g., mines, city blocks). |

| Radiation Source Discrimination | Onboard software for real-time spectral analysis. | Differentiates between naturally occurring radiation levels and distinct artificial sources. |

3. Recommended Operational Flowchart

The mapping activity is conducted using an automated, minimal intervention workflow:

1. Flight Planning: The operator specifies the scanning domain (square meters) and resolution using a smartphone/tablet interface.
2. Autonomous Operation: The drone takes off, navigates using a lawnmower path, and utilizes AI-enabled flight control to maximize efficiency.
3. Processing in Real Time: Onboard equipment merges geospatial coordinates with radiation counts. Cloud solutions can offer global access to this information.

5. HARDWARE AND SOFTWARE DESCRIPTION

The suggested system is an unmanned aerial vehicle with radiation detection and communication capabilities.

1. Unmanned Vehicle System

Quadcopter/hexacopter airframe designed for aerial survey

Features brushless motors, electronic speed controllers, and propellers

Flight stabilization and payload capacity

2. Flight Controller

Stabilizes the drone and enables navigation

Typical flight controller: Pixhawk Flight Controller

Includes:

Attitude stabilization

Waypoint navigation

Autonomous flight mode

3. Radiation Detector

Measures ionizing radiation intensity

Typical sensors:

Geiger-Muller (GM) tube

Scintillation counter

Converts radiation to electrical impulses (Counts per Second)

4. Microcontroller / Onboard Computer

Performs data processing and communication control

Typical microcontroller: Arduino Uno/Raspberry Pi

Tasks include:

Data acquisition

Signal processing

Sensor interface

5. GPS Module

For providing location information

For geo-tagging the data obtained

A crucial module in terms of mapping and navigation

6. Communication Module

Allows communication with the ground station

Communication Technologies include:

Telemetry (433 MHz/915 MHz)

Wi-Fi/RF modules

For real-time monitoring

7. Power Supply

Li-Po battery

Powers:

Motors

Sensors

Controller

Flight time and endurance

Software Description

The system employs embedded software, control software, and data visualization software.

1. Flight Control Software

Examples include ArduPilot and PX4

Tasks performed:

Navigation

Route planning

Control and stabilization

2. Ground Control Station (GCS)

Software for tracking and controlling UAV

Example is Mission Planner

Displays information about:

Drone's location

Route of flight

Telemetry information

3. Data Processing Software

Responsible for processing radiation data collected by the sensors

Converts raw data into meaningful values such as $\mu\text{Sv/hr}$

Filters and calibrates data to ensure accuracy

4. Mapping & Visualization Software

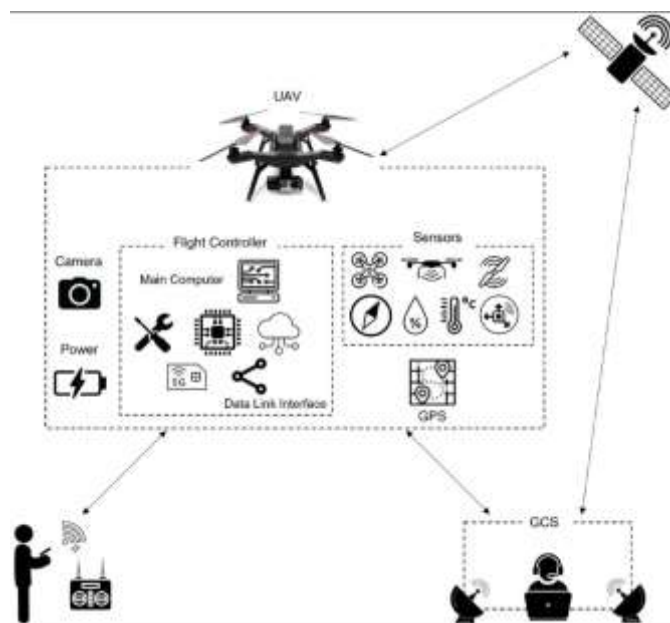
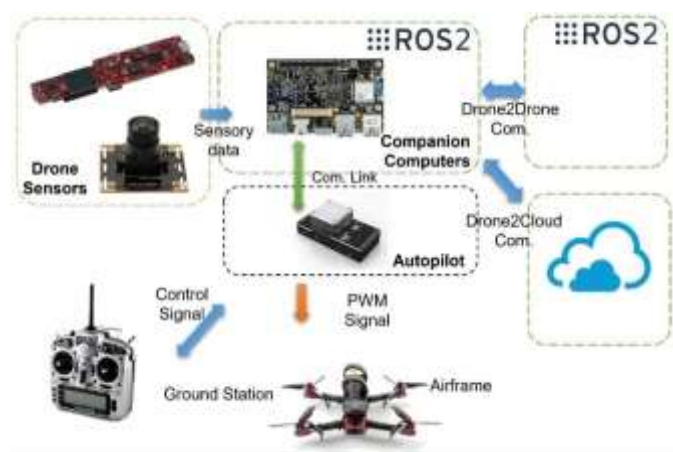
Example is QGIS

Used for:

Creation of radiation heatmaps

Geo-referencing maps

6. SYSTEM ARCHITECTURE DIAGRAM



7. WORKING PRINCIPLE

The proposed model makes use of a detection mechanism that includes remote detection, geotagging, and mapping of ionizing radiation based on an unmanned aerial vehicle (UAV).

Step 1: UAV Deployment

A defined path or route for the drone is created by the UAV through waypoint navigation.

Flight is controlled by the in-built controller (for example, Pixhawk Flight Controller).

The drone flies autonomously, performing its surveys over the area of interest.

Step 2: Detection of Radiation

An on-board ionizing radiation detector is used to detect any form of ionizing radiation in the target area.

Any interaction between the radiation and the detector results in the production of electrical pulses.

The pulses are measured either in CPS or converted to radiation units like $\mu\text{Sv/hr}$.

Step 3: Data Acquisition and Processing

This step involves collecting data from the sensor in real-time by the microcontroller such as Arduino Uno or Raspberry Pi.

Step 4: Geotagging Using GPS

A GPS unit stores the precise location (longitude, latitude, altitude) at which each observation is made.

Radiation readings are fused with location readings to produce geotagged data sets.

Step 5: Data Transfer

Transferred data is sent to a receiving station using telemetry or radio link.

The data transfer is carried out in real time through Mission Planner software.

Step 6: Map Generation & Visualizations

Data collected is transferred to mapping software such as QGIS.

This process results in:

Maps displaying radiation heat

2D and 3D distribution maps of radiation

Identification of hotspots where high levels of radiation exist.

Step 7: Data Analysis & Decision Making

Maps produced are analyzed for:

Hazardous areas

Radiation strength

Emergency plans and safety measures

8. FLOWCHART

Autonomous Aerial Radiometric Mapping - Workflow



9. RESULTS AND DISCUSSION

1. Results of Data Acquisition

UAV radiometric system was employed to conduct aerial radiometry surveying of the specified area based on the pre-specified waypoints.

Geiger-Muller detector continuously measured radiation count in CPS (counts per second).

These measurements were translated to radiation units such as $\mu\text{Sv/hr}$ based on calibration coefficients.

Each reading was geotagged using GPS coordinates.

Observation:

Radiation measurements showed stable low readings in most areas.

Some locations had high radiation measurements.

2. Results of Radiation Mapping

The acquired data was analyzed using QGIS software to produce 2D and 3D radiation maps.

Analysis of 2D Heatmaps:

Gradient of colors was used:

Green/Blue: low radiation

Yellow/Orange: moderate radiation

Red: high radiation hotspot

The produced heatmap was an indicator of radiation variation throughout space.

Results of 3D Maps:

3D surface maps helped identify:

Variations in radiation readings throughout the mapped region

Peaks of radiation readings in particular areas

3. System Performance Analysis

Accuracy

The system had a positive correlation between actual and predicted amounts of radiation.

Small differences were because of:

Sensor inaccuracies

Environmental effects

Response Time

Data was transmitted instantly allowing for real-time observation and analysis.

The system had little lag time when updating the levels of radiation.

Coverage Efficiency

The UAV had a better coverage than manual survey:

Scanning large areas in a short span of time

Even distribution of data throughout the region

Key Findings Discussion

a. Enhanced Safety

The system does not require humans to be physically present in dangerous areas.

Important for cases involving:

Radiation leak from nuclear reactors

b. Real-time Monitoring

Real-time data transmission capabilities provide:

Prompt detection of sudden increases in radiation levels

Quick response during emergency situations

c. High Spatial Resolution

Utilization of GPS allows precise tracking of radiation source locations.

Produces dense data points.

d. System Limitations

Although advantageous, there are some limitations to this system:

Power Supply

Flight duration limits data collection time.

Limitations of Sensors

Gamma meter sensors could potentially have:

Low sensitivity to very weak levels of radiation

Saturation from extremely high levels of radiation

Environmental Conditions

Wind and weather conditions influence:

Stability of flight

Accuracy of collected data

Data Noise and Calibration

Correct calibration of system necessary for accurate data collection.

Filtering out noise essential for reliability of results.

6. Real-world Applications

Application area includes:

Monitoring in nuclear power plants

Disaster management and emergency responses

Radiation analysis of environment

Offers a viable solution for large-scale areas monitoring at an economical cost.

7. Possible Enhancements (Further Discussion)

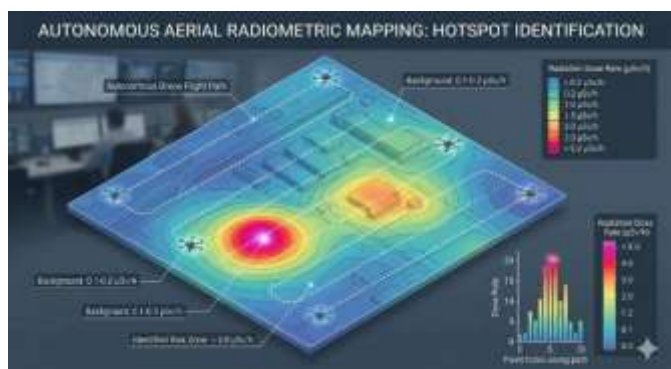
Incorporation of AI and machine learning algorithms for predicting radiation maps

Utilization of swarm drones technology for enhanced coverage range and speed

Incorporation of new-age sensors (e.g., scintillation detectors)

Advanced energy management systems

10. GRAPHS



Graph 1: Radiation Heat Map Visualization

The first graph shows the output generated by an unmanned aerial survey mission.

Description:

The graph provides a three-dimensional view of a localized area (maybe an industrial complex). On this graph, there is a radiometric heat map plotted on the map. There is a dotted white trajectory that represents the path flown by the drone on its raster scan.

It is easy to see the levels of radiation represented by colors in the graph:

Deep Blue: Indicates the normal level of background radiation.

Yellow and Orange: Indicates high levels of radiation.

Red: Identifies the area of radiation hotspot (risk zone).

This graph identifies the exact location, level, and gradient of the contamination. This makes it easy for public safety officials to spot the risk zone without putting people on the ground.



Graph 2: Multi-sensor data fusion and analysis

Graph 2 demonstrates the technical background of the project. Specifically, it demonstrates how the drone

collects data and converts it into actionable information to mitigate risks.

Description:

This graph specifically illustrates data fusion. It is an advanced data analysis graph that consists of three vertically aligned panels:

Top Panel: The panel contains the drone's altitude/position data during its autonomous flight.

Middle Panel: This panel displays the drone's raw gamma counts data in the form of total gamma counts per second (CPS), which increases significantly once the drone enters the plume (the shaded area in the middle).

Bottom Panel: Finally, this panel represents data conversion. Specifically, the bottom panel displays the drone's calculated dose rate (blue curve) and the predetermined public safety action threshold (red curve).

11. CONCLUSION AND FUTURE SCOPE

This project successfully proves the integration between unmanned aerial vehicles (UAV) and radiation sensors that enables efficient and accurate monitoring of environments in a safe way by acquiring data in real time, referencing it with the help of geopositioning system (GPS), and automating the flight process to map radiometric differences in a fast and human-free way.

The benefits provided by this technology include successful production of maps showing radiometric data in high resolution to enable further application of this technique to monitor nuclear plants, environmental assessment, disaster relief operations, and even mineral exploration missions.

Even though the system proved to be very effective, some restrictions are to be acknowledged, like restrictions in sensitivity of the sensors used, external environment disturbances, and dependency of flight process on stable atmospheric conditions. In order to overcome those problems, future improvements can be aimed at enhancing sensor sensitivity, using more complicated data processing techniques, and implementing path optimization.

Overall, this project provides an efficient approach to autonomous monitoring and creates a base for further development.

12. ACKNOWLEDGEMENT

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2. Pospisil, S., et al. (2026). Feasibility of low cost UAV based gamma radiation surveys for environmental monitoring. ResearchGate. This study validates the use of consumer grade drone technology for radiation detection, supporting your emphasis on lightweight, accessible drone solutions.

3. The International Atomic Energy Agency is the primary global authority on nuclear safety. They publish technical documents that discuss the use of drones in radiological emergencies.

Website: www.iaea.org

4. Research Gate is a repository where researchers publish their work. Many papers there discuss the Grid Survey or Lawnmower pattern for radiation mapping.

Website: www.researchgate.net

5. MDPI Sensors is an open access journal that focuses on sensor technology and drone applications. This is an excellent source for technical literature regarding how sensor data is collected and processed.

Website: www.mdpi.com/journal/sensors

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