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A Drone-Based Approach for Radiometric Mapping of Gamma Radiation

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Abstract: This work presents the results of an experiment conducted with an Unmanned Aerial Vehicle (UAV) equipped with a Geiger-Müller detector module, aimed at validating a gamma radiation detection methodology. The experiment took place at the Batalhão Central de Manutenção e Suprimentos (BCMS) in Rio de Janeiro, where a Cesium-137 source was positioned at a specific point within a designated area for the drone flight. The measurement methodology involves continuous flight, with point-by-point readings taken at designated locations. Subsequently, during the data processing stage, each measurement point was organized into cells, forming a structured grid that served as the basis for generating a three-dimensional map of gamma radiation dose distribution. After processing the data collected by the drone, a dose profile was reconstructed, allowing for a satisfactory estimation of the location where the Cesium-137 source was positioned based on the radiation peak. Since specific patterns in the graphs, such as a sudden increase in dose rate in a particular direction, can indicate the presence of a source, we consider that this method can be employed as a useful strategy for the remote detection of radiation sources in various environments, offering a satisfactory approximation of the radiological conditions present in the analyzed environment.

Keywords: Drone, Radiometric Mapping, Gamma Radiation, Geiger-Müller.

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Uma Abordagem Baseada em Drones para o Mapeamento Radiométrico de Radiação Gama

Resumo: Este trabalho apresenta os resultados de um experimento realizado com um Veículo Aéreo Não Tripulado (VANT) equipado com um módulo detector Geiger-Müller, com o objetivo de validar uma metodologia de detecção de radiação gama. O experimento ocorreu no Batalhão Central de Manutenção e Suprimentos (BCMS) no Rio de Janeiro, onde uma fonte de Césio-137 foi posicionada em um ponto específico dentro de uma área designada para o voo do drone. A metodologia de medição envolve um voo contínuo, com leituras ponto a ponto realizadas em locais designados. Posteriormente, durante a fase de processamento dos dados, cada ponto de medição foi organizado em células, formando uma grade estruturada que serviu como base para a geração de um mapa tridimensional da distribuição da dose de radiação gama. Após o processamento dos dados coletados pelo drone, um perfil de dose foi reconstruído, permitindo uma estimativa satisfatória da localização onde a fonte de Césio-137 estava posicionada com base no pico de radiação. Como padrões específicos nos gráficos, como um aumento repentino na taxa de dose em uma direção particular, podem indicar a presença de uma fonte, consideramos que esse método pode ser empregado como uma estratégia útil para a detecção remota de fontes de radiação em diversos ambientes, oferecendo uma aproximação satisfatória das condições radiológicas presentes no ambiente analisado.

Palavras-chave: Drone, Mapeamento Radiométrico, Radiação Gama, Geiger-Müller.

1. INTRODUCTION

During a radiological event, it is necessary to implement measures to mitigate the impacts generated by exposure to radiation sources, as such events - whether a nuclear accident or the unintended dispersion of radioactive material - can pose significant health risks to people near the incident site. In these situations, it is imperative to conduct a rapid and comprehensive environmental assessment using safe methods, enabling the implementation of timely response measures [6].

In this context, UAVs (Unmanned Aerial Vehicles) emerge as key players in the technological revolution in radiological detection, offering an agile and efficient approach to mapping and monitoring areas potentially affected by radiation. The combination of UAV use and radiation detection not only provides a faster response to nuclear and environmental incidents but also allows for more accurate detection, as detectors can get closer to the radioactive source with longer exposure times, without putting operators at risk [5].

The ability of these vehicles to fly over difficult-to-access areas, combined with the use of specialized sensors, allows for precise real-time data collection. This not only reduces unnecessary human exposure to risk but also facilitates a more comprehensive assessment of radiation sources, aiding in the implementation of effective containment and mitigation strategies [5].

This article presents the results of a UAV measurement of a radioactive source of the isotope Cesium-137, conducted at the Central Maintenance and Supply Battalion (BCMS) in the city of Rio de Janeiro. The objective was to validate a detection method by analyzing the obtained results and producing a radiological map using data collected by a Geiger-Müller detector attached to the UAV.

2. MATERIALS AND METHODS

This work involved the use of a custom-built drone, equipped with a Geiger-Müller detector module model RadiationD v1.1 (CAJOE) J305, as well as a Cesium-137 source with an activity of 165 mCi and a manufacturing date of 25/01/1989, as illustrated in Figure 1.

Figure 1: Drone and Radioactive Source

Source : The Authors (Own).

In order to map the distribution of the radioactive dose rate in a pre-established area, we planned and executed a flight plan through the Mission Planner software, defining the overflight area, altitude, speed, and spacing between flight lines, as shown in Figure 2.

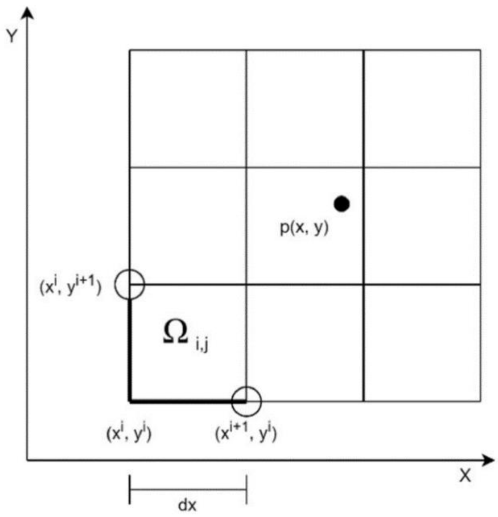
A survey flight was carried out, where the UAV flew continuously over the area at an altitude of 5.0 meters, a speed of 2.0 m/s, and a spacing between sampling points of 1.5 meters, with the radiation sensor measuring the dose rate data (μSv/h).

Figure 2: Aerial view (GPS) of the drone's Flight Plan.

Source : Mission Planner (Own).

To process the measured data, a methodology was established that involves dividing the area of the survey flight into small cells, forming various subareas, as illustrated in Figure 3. This methodology aims to organize and process spatial data, allowing for a systematic and efficient analysis of the data sets on Matlab.

Figure 3: Grid Division Method.



Source : Molnar *et al.* [3].

The creation of a bounding rectangle establishes the condition that each cell belongs to the plane where the drone's measurement points are located, hence we have that $\Omega ij \subset R^2$, covering an area that ranges from Xmin to Xmax, and from Ymin to Ymax, according to equations 1, 2, 3, and 4. The points, represented by p = (x,y), are the GPS coordinates that make up the path which the drone used to acquire field data [3].

$$X_{\min} = min\ p_x \text{, } such\ that\ p \in P \tag{1}$$

$$X_{\max} = max\ p_x \text{, } such\ that\ p \in P \tag{2}$$

$$Y_{\min} = min\ p_y \text{, } such\ that\ p \in P \tag{3}$$

$$Y_{\max} = max\ p_y \text{, } such\ that\ p \in P \tag{4}$$

These expressions define the minimum and maximum limits along the x and y axes, thereby delineating the space in which the measurement points are contained. This condition is crucial to ensure that the cells formed are representative of the area of interest and that the subsequent analysis is meaningful in relation to the spatial distribution of the obtained data.

The next step is to perform the division of the rectangle into n×m divisions (cells), following the formation law described by the set of equations 5, allowing each specific cell at the coordinates (i, j), to have its intervals along the x and y axes, denoted as [xi, xi+1) and [yj, yj+1), determined [3].

$$\Omega_{ij} = \begin{cases} [x^i, x^{i+1}) \times [y^i, y^{i+1}) & if \quad i \in [0, n, \dots, n-2] \; and \; j \in [0, m, \dots, m-2] \\ [x^i, x^{i+1}) \times [y^i, y^{i+1}) & if \quad i = n-1 \; and \; j \in [0, m, \dots, m-2] \\ [x^i, x^{i+1}) \times [y^i, y^{i+1}) & if \quad i \in [0, n, \dots, n-2] \; and \; j = m-1 \\ [x^i, x^{i+1}) \times [y^i, y^{i+1}) & if \quad i = n-1 \; and \; j = m-1 \end{cases} \quad (5)$$

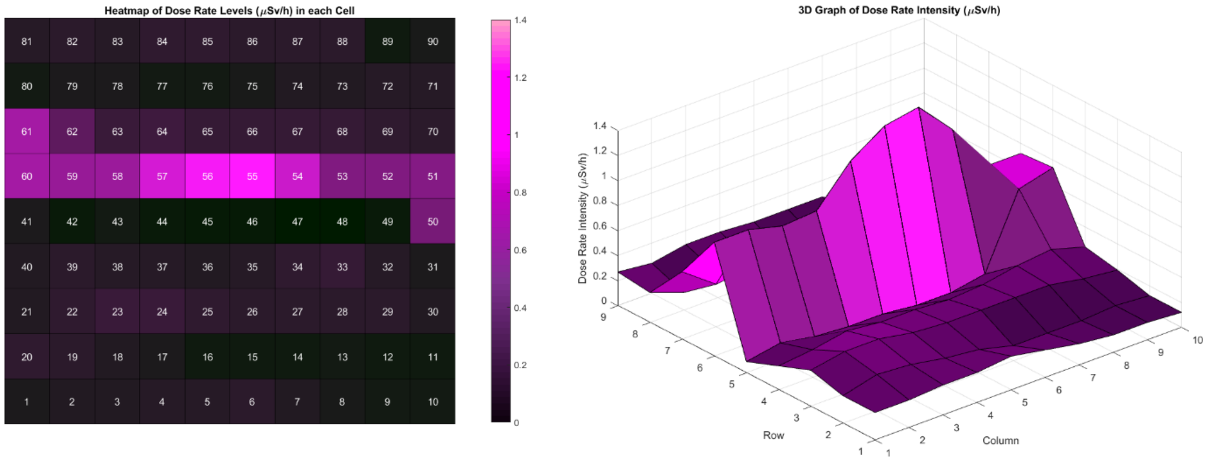
This modeling allows for the creation of a function f(p) that assigns values to each cell based on the measured GPS points. This function provides a quantitative representation of the data within each delimited area, allowing for a more detailed and specific analysis compared to a global approach to the measurement area [3].

3. RESULTS AND DISCUSSIONS

Figure 4 depicts the implementation of this methodology through the creation of a heat map generated based on the data obtained experimentally by the drone's reconnaissance flight.

Ninety quadrants (cells) were marked, corresponding to the dose measurement points by the drone. This delineation provides a representation of the spatial distribution of radiation in the study area. For each cell in the map, identified by bounding rectangles, the values of the dose rate intensity measured by the drone at the corresponding coordinates were assigned.

Figure 4: Heat Map of Dose Rate Distribution.



Source : Matlab (Own).

The darker areas on the map indicate regions with lower radiation dose rates, while shades closer to pink reveal areas of higher intensity. Remarkably, the areas of higher intensity correlate directly with the location of the radiation source in the field (near quadrant 55), highlighting a significant correlation between the values calculated by the model and those measured experimentally.

The heat map allows us to observe that the variation in measured values ranges from the background radiation level (0.17 μSv) to the maximum intensity measured by the drone (1.39 μSv). It is noteworthy that the highest intensity was recorded in the quadrant where the Cesium-137 source was placed (quadrant 55), clearly indicating the direct influence of the radioactive source on the radiation intensity in the region.

Figure 4 also highlights a region with pronounced intensity along the line of quadrants where the source was positioned. This intensity becomes more pronounced as the drone approaches the source, providing a dynamic and spatially detailed representation of radiation dispersion along the drone's path.

It's interesting to note that some quadrants showed slightly higher values than the background, even at some distance from the physical source. This could be attributed to several factors, such as variations in the drone's speed and altitude during flight, potential measurement deviations generated by the detector or even the drone's telemetry system, the geometry of the radiation distribution, and the inherent probabilistic nature of radiation measurements, reflecting stochastic variations inherent in the radiological detection process.

4. CONCLUSIONS

We can conclude that the drone-based detection and analysis method yielded consistent results aligned with expectations, providing a satisfactory approximation of the radiological conditions present in the analyzed environment.

Additionally, the possibility of overlaying the heat map of dose rate distribution with GPS data from the drone's geolocation modules allows for the estimation of the location of the radiation peak within the surveyed area. This provides preliminary assistance to the precursor teams, who can use this information to act more effectively in the case of a potential radiological event.

It is important to emphasize, however, that despite the positive results, challenges such as maintaining a stable flight path and ensuring precise data synchronization during measurement posed operational difficulties. These challenges highlight critical aspects that need to be addressed for more refined radiometric surveys.

Overall, we consider that this method can be employed as a useful strategy for remotely detecting radiation sources in various environments, as specific patterns in the plots, such as a sudden increase in dose rate in one direction, may indicate the presence of a source.

For future research, given the complexities of using drones for radiometric mapping, there's a need to analyze how flight characteristics, like altitude and speed, impact results. This analysis could optimize data collection methods and enhance measurement accuracy, improving the reliability and practicality of radiation detection across different environments.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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