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Optimization of Flight Parameters for Gamma Radiation Detection and Mapping Using Drones

Mamed[a*], F.; Vaz[a], A.; Machado[a], A.; Oliveira[a], J.; Silva[a], L.; Barreto[a], P.; Iack[a], P.; Silveira[a], P; Curzio[a], R.; Souza[b], R.; Vallory[a], W.

[a] Instituto Militar de Engenharia, IME, 22290-270, Rio de Janeiro, RJ, Brazil.
[b] Instituto de Engenharia Nuclear, IEN, 21941-906, Rio de Janeiro, RJ, Brazil.

*Correspondence: felipe.mamed@ime.eb.br

Abstract: The application of drones in radiometric surveys has emerged as a promising solution, particularly for mapping radiation in areas that are difficult to access. This approach enables the creation of detailed distribution maps. However, the accuracy of the results is strongly influenced by the chosen flight strategy. This study explores how different flight parameters, such as speed and grid spacing, impact the quality of gamma radiation mapping, aiming to optimize the trade-off between measurement precision and operational efficiency, such as flight time and mapping coverage. To achieve this, two experimental flights were conducted using a drone equipped with a Geiger-Müller detector, with a Cs-137 source serving as a reference. The methodology involved continuous radiation measurements during flight, with data collected at predetermined points arranged in a structured grid, via GPS coordinates. This setup facilitated the development of a three-dimensional representation of the gamma dose distribution. By comparing the results of both flights, each configured with distinct operational settings, it was possible to evaluate the impact of flight parameters on the effectiveness of radiometric detection of dose rate distribution using drones. The results suggest that dose rate mapping tends to achieve higher resolution when lower flight speeds are adopted and when data collection points are more densely distributed across the surveyed area.

Keywords: Drone-Based Mapping; Gamma Radiation Detection, Flight Parameters Optimization.

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Otimização dos Parâmetros de Voo para Detecção e Mapeamento de Radiação Gama utilizando Drones

Resumo: A utilização de drones para levantamentos radiométricos tem se mostrado uma abordagem promissora, especialmente em áreas de difícil acesso, pois possibilita a geração de mapas detalhados da distribuição da radiação. No entanto, a qualidade dos resultados depende diretamente da estratégia de voo adotada. Este trabalho teve como objetivo investigar como a variação de diferentes parâmetros de voo, como velocidade de voo e espaçamento entre os pontos de medições, influenciam na qualidade do mapeamento de radiação gama, buscando otimizar a relação entre a precisão das medições e a eficiência operacional, como o tempo de voo e cobertura de mapeamento. Para isso, foram conduzidos dois voos experimentais com um drone equipado com um detector Geiger-Müller, utilizando uma fonte de Cs-137 como referência. A metodologia adotada baseou-se em medições contínuas durante o voo, com coleta de dados em pontos específicos predefinidos, via coordenadas de GPS. Esses pontos foram organizados em uma grade estruturada, permitindo a criação de um modelo tridimensional da distribuição da dose de radiação gama. A análise comparativa dos dois voos, cada um com configurações distintas, permitiu avaliar como os parâmetros de voo afetam a eficiência da detecção radiométrica da distribuição da taxa de dose utilizando drones. Os resultados sugerem que o mapeamento da taxa de dose de radiação tende a obter maior resolução quando a velocidade de voo do drone for reduzida e quando os pontos de coleta de dados forem mais densamente distribuídas pela área do voo de interesse.

Palavras-chave: Mapeamento Baseado em Drones; Detecção de Radiação Gama; Otimização de Parâmetros de Voo.

1. INTRODUCTION

The monitoring and detection in areas under the influence of ionizing radiation have increasingly benefited from the use of remote sensing technologies, such as drones and robots equipped with detectors capable of identifying and alerting about potential ionizing radiation hazards [4].

In critical situations, such as nuclear incidents or attacks involving radioactive materials, Unmanned Aerial Vehicles (UAVs) can be rapidly deployed to map the extent of the affected area. This agility allows radiological emergency response teams to access preliminary information in a timely manner, facilitating the prompt implementation of mitigation measures, such as planning possible evacuations and decontamination processes [6].

However, the effectiveness of these operations directly depends on the configuration of flight parameters, which influence the quality and reliability of the collected data.

The quality of radiometric measurements performed by drones is affected by several factors, including flight altitude, equipment speed, the number of measurement points, and the spacing of the sampling grid. Adjusting these parameters is crucial to achieving an optimal balance between data accuracy, mapping execution speed, and operational safety. For instance, higher-altitude flights can cover larger areas more quickly but may compromise data resolution. Conversely, lower-altitude and slower flights tend to provide more detailed measurements but require more flight time [4].

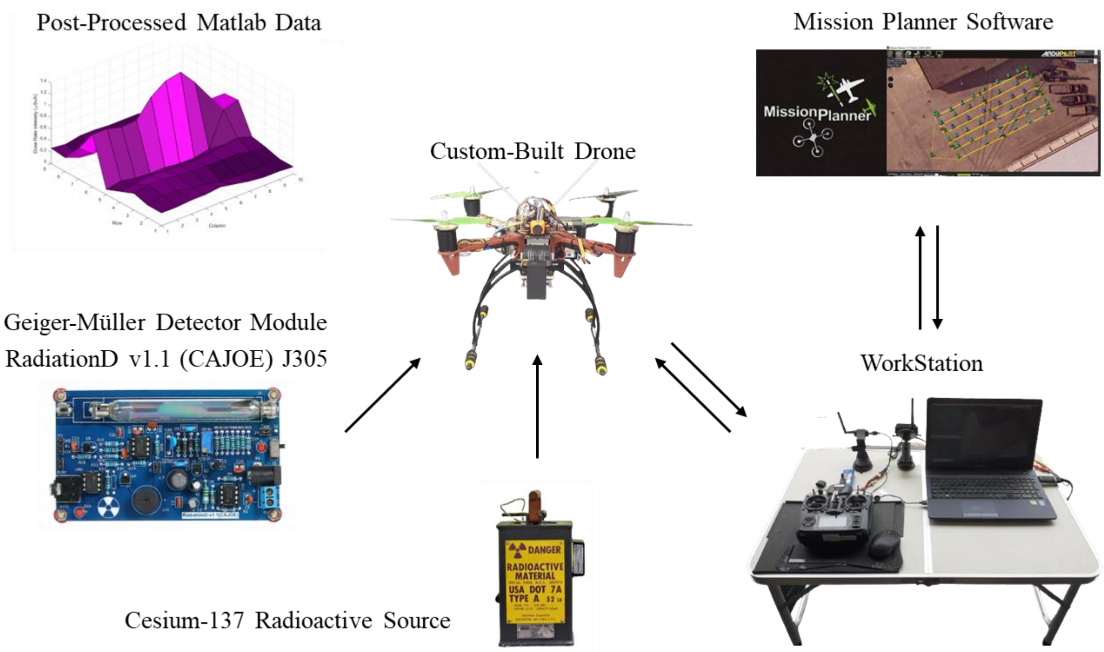
Thus, this study aims to investigate how variations in flight parameters impact the quality of radiometric mapping performed by drones. To achieve this, two flights were conducted with different configurations, varying parameters such as speed, altitude, the number of measurement points, and grid spacing.

2. MATERIALS AND METHODS

For the experiment, a Cesium-137 source with an activity of 6.11 GBq was used, referenced to the manufacturing date of January 25, 1989. The declared activity is traceable to calibration standards provided by the IDQBRN (Instituto de Defesa Química, Biológica, Radiológica e Nuclear).

The source was positioned in the courtyard of the Batalhão Central de Manutenção e Suprimentos (BCMS), where its gamma radiation emissions could be detected by a drone equipped with a Geiger-Müller detector, model RadiationD v1.1 (CAJOE) J305. The objective of this work is to provide situational awareness to precursor teams through a preliminary dose rate map, which justifies the use of a Geiger-Müller detector. The system is lightweight and easily integrable with drones, making it well-suited for quick deployment in the field. Figure 1 illustrates a diagram of the experimental setup used.

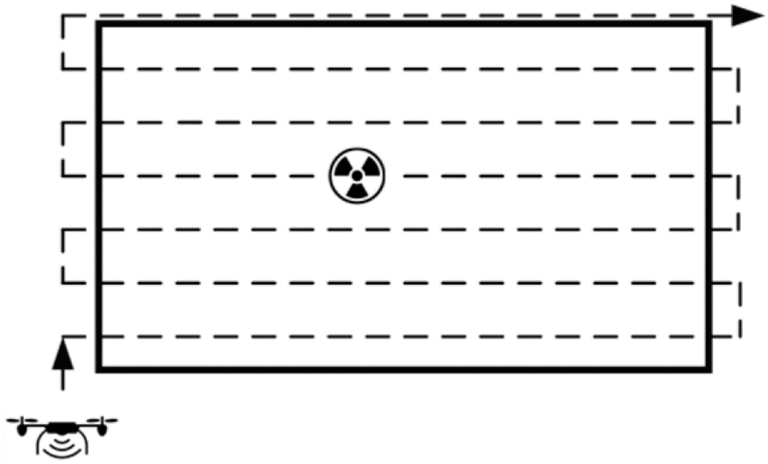
Figure 1 - Diagram for Experimental



Source: The Authors (Own).

The drone's flight plan was developed using Mission Planner software, which suggests a series of possible trajectories for the drone to follow and allows the configuration of additional parameters, such as speed and altitude. The selected trajectory followed a grid pattern, in which the drone continuously covered the area of interest, performing point measurements of the dose rate (μSv/h) at predefined locations using a cross-search method, via GPS coordinates, as illustrated in Figure 2.

Figure 2: Diagram for the Transversal Search Algorithm Method.



Source: Adapted from Li *et al.* [3].

During the first flight, the drone operated at a speed of 3.0 m/s, with a spacing of 3.0 meters between grid lines and a fixed altitude of 5.0 meters. This configuration was adjusted to enable faster and broader coverage of the area of interest.

In the second flight, to refine measurement accuracy, the drone's speed was reduced to 2.0 m/s. Additionally, the spacing between grid lines was decreased to 1.5 meters, increasing the number of measurement points. However, the altitude remained fixed at 5.0 meters to maintain consistency in flight conditions between the two experiments.

The flight altitude for both surveys was selected to be low enough to allow measurements without exposing the drone's sensitive electronic components, such as cameras and embedded circuits, to high levels of ionizing radiation. Furthermore, since the flight took place in a military area, it was necessary to comply with the established maximum altitude limit of 5 meters.

Table 1 summarizes the flight parameters configured in the Mission Planner software for both reconnaissance flights.

Table 1 - Parameters for the First and Second Fligth

--	1st Flight	2nd Flight
Drone Speed (m/s)	3.0	2.0
Drone Heigth (m)	5.0	5.0
Measurements Points	36	90
Grid Spacing (m)	3.0	1.5
Flight Time (m)	1:58	3:51

3. RESULTS AND DISCUSSIONS

3.1. Dose Rate Distribution

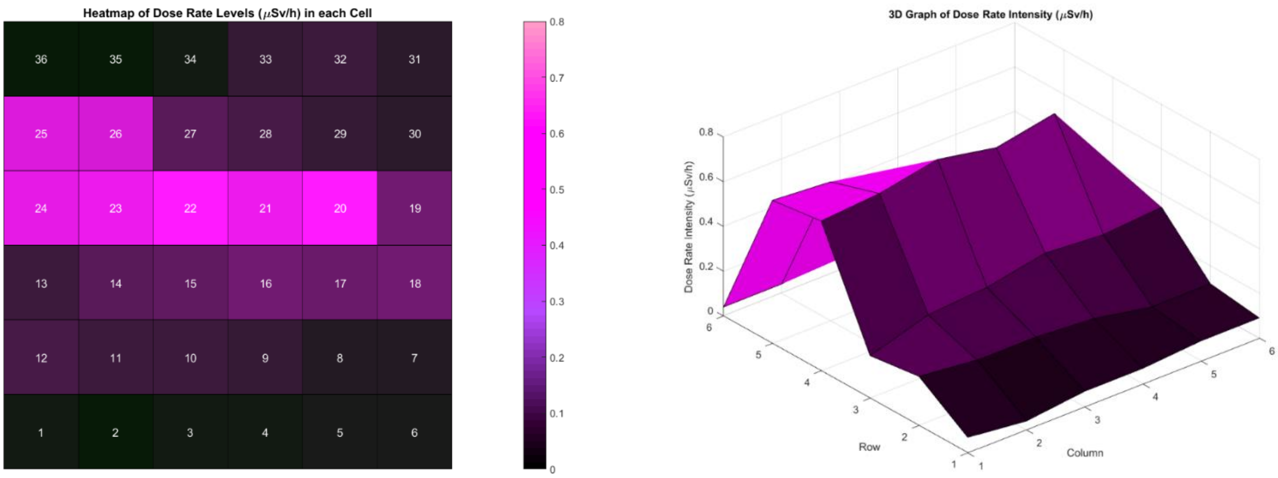
Based on the point-by-point data collected by the drone, it was possible to generate a heatmap of the dose rate for the mapped area, as well as a three-dimensional (3D) graph representing the spatial distribution of radiation. These visualizations are detailed in the figures presented in the following sections.

In the heatmap, darker shades correspond to dose rate values close to the background level. Conversely, areas with colors closer to violet indicate higher values, approaching the detected radiation peak in the region [4].

During the first flight, the recorded background radiation level was 0.17 μSv/h, while the detection peak reached 0.67 μSv/h. Figure 3(a) displays the heatmap of the dose rate for each measured quadrant, while Figure 3(b) presents the corresponding three-dimensional representation.

Although the heatmap suggests that the dose rate distribution is more concentrated in the central region of the battalion's courtyard, the 3D graph indicates that it is not possible to clearly identify the estimated location of the Cesium source, as the figure does not exhibit a well-defined radiation peak.

Figure 3: (a) Heat Map of Dose Rate Distribution from the First Flight. (b) 3D Map of Dose Rate Distribution from the First Flight.

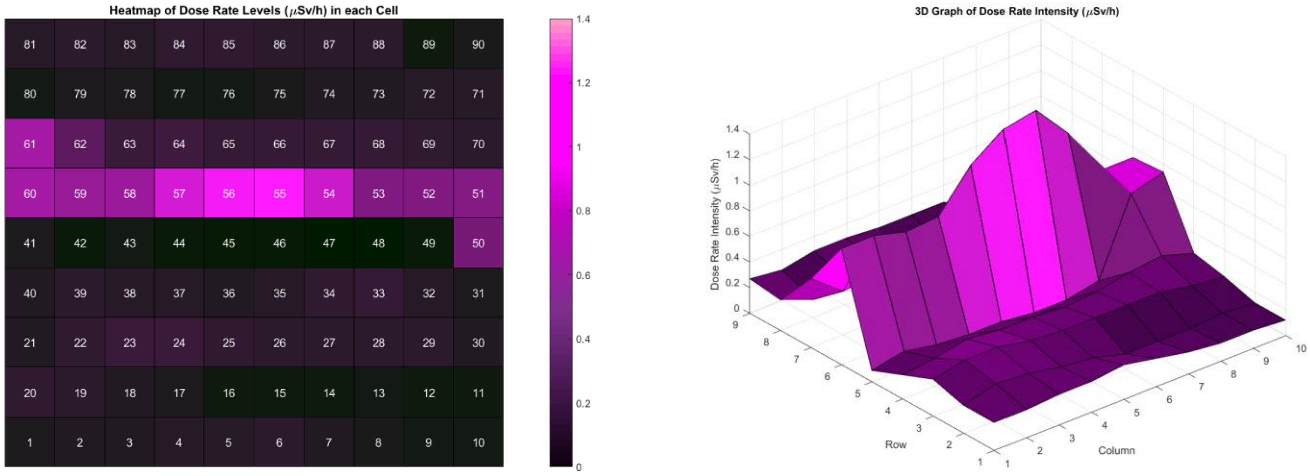


Source: Matlab (Own).

In the second flight, with adjusted parameters, a peak of 1.39 μSv/h was detected, while the background radiation level remained at 0.17 μSv/h. The data collected during this stage are represented in Figures 4(a) and 4(b), which respectively show the dose rate heatmap and the spatial radiation distribution in a three-dimensional (3D) graph.

In contrast to the results of the first flight, the heatmap obtained in the second flight presents a clearer definition of the dose rate distribution, particularly in quadrants 56 and 55. This difference is even more evident in the 3D graph, which displays a well-defined peak, suggesting the approximate location of the Cesium source.

Figure 4: (a) Heat Map of Dose Rate Distribution from the Second Flight. (b) 3D Map of Dose Rate Distribution from the Second Flight.



Source: Matlab (Own).

3.2. Variation of Drone Altitude

Another relevant factor to analyze is the variation in the drone's altitude during flight. Ideally, the drone should maintain a constant altitude, as predefined in the flight plan. However, altitude fluctuations are an undesirable yet inevitable effect during operation.

The importance of the drone's altitude during measurements is directly linked to the principle of the Inverse Square Law. This principle states that radiation intensity decreases proportionally to the square of the distance from the source, as demonstrated in Figure 5. [2].

Depending on the sensitivity level of the detector used on the drone, the count rate may fluctuate due to altitude variations.

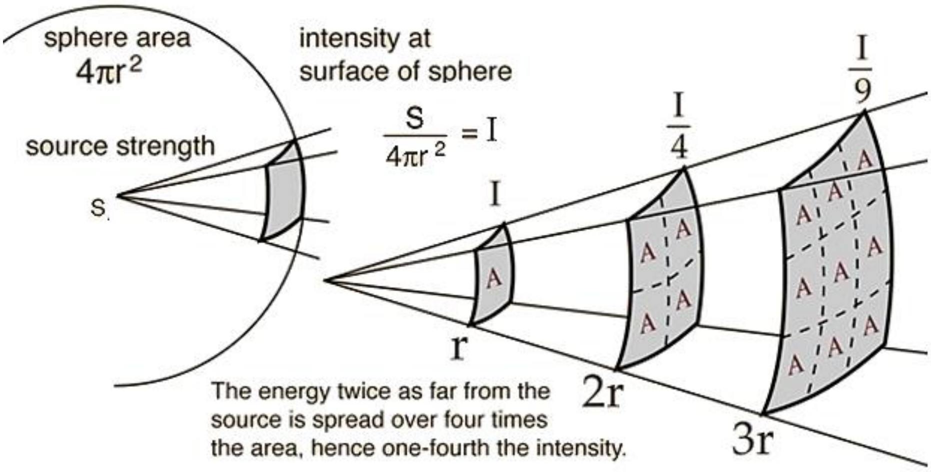
Thus, when the detector attached to the drone moves away from the radioactive source, the sensitivity of radiation detection is reduced. Similarly, at a very short distance, the sensitivity becomes too high, potentially leading to count saturation due to the detector’s dead time.

The detector used on the drone was a Geiger-Müller, model RadiationD v1.1 (CAJOE) J305. This type of detector has a dead time in the microsecond range, which, although small, still influences the efficiency of radiation detection [2].

This reinforces the need for flight altitude adjustments to ensure reliable measurements while maximizing detection efficiency and maintaining a safe operational distance.

It is also important to emphasize that each type of detector has its own saturation limit, and since this study is not focused on a specific detector model, we chose to fly at an altitude that provides suitable parameters for a range of commonly available Geiger-Muller detectors on the market, as the RadiationD v1.1 (CAJOE) J305.

Figure 5: Inverse Square Law

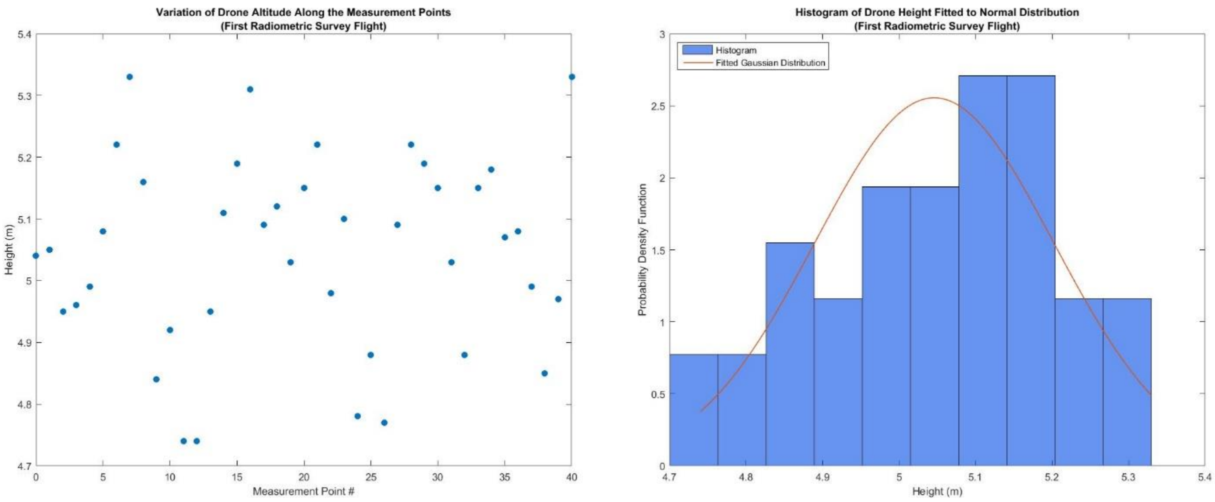


Source: HyperPhysics.

A histogram of the altitude data for both flights was plotted and fitted with a normal distribution using the probability density function (pdf), allowing visual assessment of the data's adherence to Gaussian behavior and the altitude stability throughout the flight path. Additionally, a scatter plot of the drone's altitude fluctuations was also generated to visualize point-to-point variations along the trajectory.

Figure 6(a) illustrates the altitude fluctuation of the drone during the trajectory as established in the flight plan of Figure 3, which was planned for a constant height of 5 meters. Figure 6(b) presents the corresponding representation of this variation.

Figure 6: (a) Graph of Drone Altitude Variation During the First Flight. (b) Histogram of Drone Altitude Distribution During the First Flight.



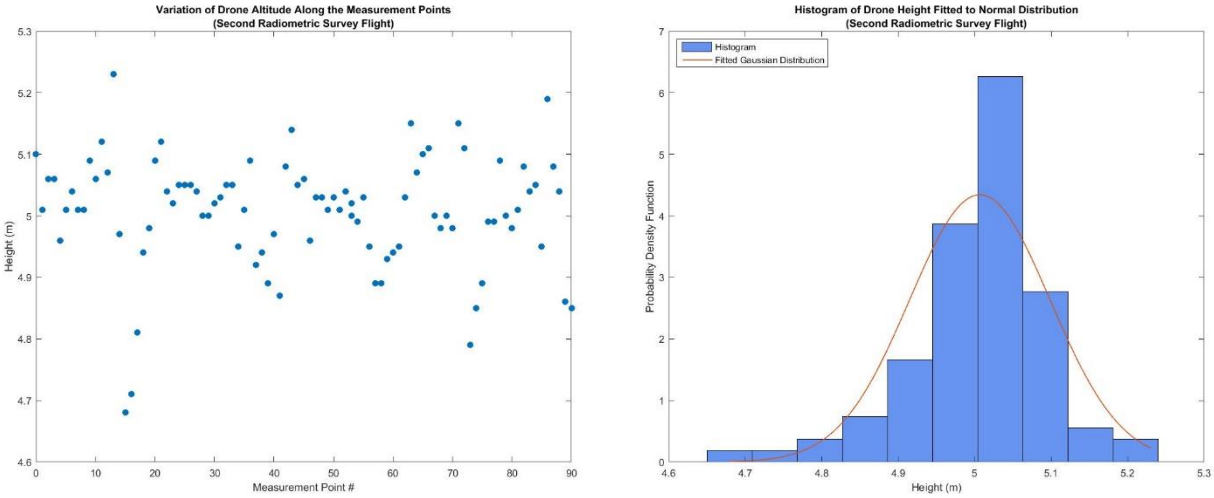
Source: Matlab (Own).

The mean, standard deviation, and coefficient of variation were calculated using Matlab's built-in statistical functions, based on repeated measurements. This corresponds to a Type A uncertainty evaluation, in accordance with the general principles outlined in ISO/IEC Guide to the Expression of Uncertainty in Measurement (GUM).

The average altitude of the drone during the first flight was 5.046 meters, with a standard deviation of 0.156 meters and a coefficient of variation of 2.44%.

The analysis of the drone's altitude parameter for the second flight was carried out similarly to the approach described in the previous section. The results are presented in Figures 7(a) and 7(b), which respectively show the altitude fluctuation along the trajectory as established in the flight plan of Figure 4 and the distribution of these values through a histogram.

Figure 7: (a) Graph of Drone Altitude Variation During the Second Flight. (b) Histogram of Drone Altitude Distribution During the Second Flight.



Source: Matlab (Own).

In the second flight, the average altitude of the drone was 5.006 meters, with a standard deviation of 0.092 meters and a coefficient of variation of 0.84%. Table 2 shows the altitude variation values between the two flights.

Table 2 - Comparative Table of Drone Altitude Variation between the First and Second Flight

--	1st Flight	2nd Fligth
Mean (m)	5.046	5.006
Standard Deviation (m)	0.156	0.092
Coeficient of Variation (%)	2.440	0.840

It is noted that, during the second flight, the higher density of measurement points resulted in a smaller altitude variation relative to the planned value of 5 meters. This trend is also clearly observed in the histogram, which presents a distribution closer to the normal curve.

3.3. Variation of Drone Speed

The first flight lasted 1 minute and 59 seconds, while the second flight lasted 3 minutes and 51 seconds. This difference occurred due to the reduced drone speed in the second flight—a factor that, combined with the increased number of measurement points, enabled a more detailed radiometric mapping.

Beyond altitude, previously discussed, the drone's speed during the scan is a crucial factor to consider. This is directly related to the detector's ability to capture events. If the drone flies too fast, the detector may not register enough samples while passing over or near the source, potentially compromising the spatial resolution of the survey [3].

Although it is not possible to quantify the exact difference in counts based solely on the two flights conducted, it is important to highlight that, given the probabilistic nature of radioactive emissions, the ideal approach would be for the drone to remain over each measurement point for an adequate amount of time. A mean count for each point could then be calculated, minimizing the influence of drone speed on the radiometric mapping results.

However, for a preliminary and rapid survey, the cross-search method used in this study provides a satisfactory approach to estimate the presence and location of potential radiation sources in an area of interest. Notably, when using this method, the drone's speed must be adjusted to balance area coverage and measurement accuracy, ensuring the detector has enough time to capture significant events.

4. CONCLUSIONS

The results obtained in this study demonstrate that variations in drone flight parameters—such as speed and grid spacing—significantly impact the quality of radiometric mapping in areas affected by ionizing radiation.

The first flight, characterized by higher speed and wider grid spacing, allowed for faster area coverage but resulted in a limited resolution of the dose rate distribution, making it difficult to establish an estimate of the location of the Cesium-137 source in the surveyed area. In contrast, the second flight, conducted at a lower speed with increased measurement point density, provided a clearer definition of the dose rate distribution. This improvement was evident in both the heatmap and the three-dimensional graph presented in Figures 3 and 4, enabling an approximate localization of the radioactive source.

Additionally, the analysis of altitude variation, presented in Table 2, revealed that the second flight exhibited greater stability, with a smaller deviation from the planned altitude, contributing to the reliability of the collected data. This finding reinforces the importance of fine-tuning operational parameters, taking into account factors such as the Inverse Square Law and the dead time of the Geiger-Müller detector, to optimize measurement sensitivity.

Drone speed, in turn, proved to be a critical factor in balancing area coverage efficiency and detection accuracy, suggesting that slower configurations may be preferable in scenarios requiring greater detail.

Thus, this study highlights the importance of an approach that considers these parameters when planning drone missions for radiological monitoring, adjusting flight settings according to the specific objectives of the operation—whether to ensure a rapid response in emergency situations or to achieve higher precision in detailed surveys.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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