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Ground-Based Gamma-Ray Spectrometer Application on Drone-Borne: Suitability and Height Attenuation

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ABSTRACT

Rapid development in the use of unmanned aerial vehicles (UAVs) in many applications, such as topographic mapping, agricultural management, marine monitoring, and others, has also brought the radiometric mapping application to this drone-borne application. Before the application, several corrections are performed to the data, including stripping corrections obtained from calibration results and height attenuation corrections. This study aims to determine the effectiveness and the height attenuation of the ground-based spectrometer attached to the drone. The method is carried out to determine the optimal altitude and conduct direct testing in the field of a small detector of 0.1 l of RS-125 gamma-ray spectrometer using drone-borne radiometric applications. In ideal conditions without obstacles in the flying path, 15 m is considered the ideal height, proportional to the detector size. Based on the results of field measurements at a drone height of 24 m, the comparison of drone and ground data is acceptable for dose rate, thorium, and potassium concentration with Pearson correlation of 0.67, 0.49, and 0.45, respectively. The drone measurement result is less acceptable for uranium data, with a Pearson correlation of 0.05 to the ground measurement. In conclusion, the RS-125 gamma-ray spectrometer is generally suitable for drone-borne radiometric applications.

INTRODUCTION

Radiometric mapping determines the amount of potassium (K), uranium (U), and thorium (Th) as naturally occurring radioactive materials (NORM) that undergo decay on Earth's crust. Gamma spectrometry uses multispectral sensors to record radioelement content individually based on their energy window. The values can identify and characterize various rock units as they contain different content of these radioelements [1,2].

This approach has been utilized extensively in various fields of geosciences. Some publications have applied this method to discover the host rock or alteration related to gold mineralization [3-8]. The potassic alteration in volcanic-hosted massive sulfide correlated with the formation of porphyry deposits [1,9,10]. A study on the technique of detailed sand-mud ratios of aquatic sediments using radiometric mapping was also developed to replace extensive sediment sampling [11]. The approach was also successful in identifying U and Th anomalies. Radiometric mapping was conducted in Mamuju, West Sulawesi, for detailed mapping of the radioelements concentration in soil and rocks, the distribution of rock types and the occurrence of U and Th anomalies [12,13].

Radiometric measurements can be carried out through ground-based or air-borne surveys, depending on the spatial resolution and area to be mapped. The ground-based measurements use an

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off-road vehicle, while the air-borne measurements use a helicopter or an airplane (fixed wings). Ground-based surveys are preferred for an area that requires high spatial resolution because the detector is closer to the surface and has small footprints. Meanwhile, air-borne measurements are used for a wider area because they have many advantages over ground-based measurements, since they are applicable to measuring in rocky, wet, dangerous, and dense vegetation terrain. The disadvantage of air-borne surveys is that the spatial resolution could be lost because of the height and speed of the airplane or helicopter [14].

At the same time, the rapid development of unmanned aerial vehicles (UAV) or drones has brought in many applications, like topographic mapping, agricultural management, marine monitoring, and others, including radiometric mapping [15-18]. The development of gamma-ray spectrometers has led to lightweight spectrometers that can be attached to a drone. The drone-borne surveys could measure the NORM concentration on the ground. There are lots of efforts to explore the possibility of using drones. Although some limitations are still noticed, drone-borne radiometric surveys have been recognized, and further studies have been conducted to pioneer this new field [14].

The air-borne system's field of view (FOV) is essential in the resolution of material property boundaries. The FOV varies with survey altitude. It is a challenging spatial function because it peeks below the air-borne receiver when the flux source is considered an isolated body. The one-second measurement corresponds to the ground area or footprint the plane covers, depending on the drone's or plane's speed and height [19]. A helicopter or drone can hover so that the measurements get a circle instead of an oval. Some adjustments are applied to the data, including eliminating aircraft, cosmic, and radon backgrounds, implementing stripping corrections based on calibration data, and adding height attenuation corrections [20]. The gamma-ray flux spectrum at aerial heights is influenced by the concentration and geometry of the source radio-elements, the thickness of any non-radioactive overburden, and the height of the detector above ground [21].

In radioactive mineral explorations, the ground-based spectrometer RS-125 was commonly used [12,13]. RS-125 is a handheld-type spectrometer with a 5.0 cm × 5.0 cm (103 cm^3) NaI(Tl) crystal. The spectrometer has high accuracy and a probable error of around 5 %. It comes with ample data storage, which allows the measurement of multiple readings [22,23]. The spectrometer has a smaller detector than those designed for drone-borne applications [24], which generally costs more for the exploration program. This research aims to determine the effectiveness of the ground-based spectrometer RS-125 for drone-borne applications regarding height attenuation. As it was not initially designed to be drone-borne, this study can be a remark for the ground-based spectrometer RS-125 applications in drone-borne surveys, especially to reach areas that are difficult to access for a ground-borne survey and to reduce exploration costs.

METHODOLOGY

The UAV that is used in the testing is the DJI Matrice 600. It weighs 9.1 kg, and the maximum payload is 6 kg. This series has two versions, the DJI Matrice 600 and DJI Matrice 600 Pro, with several specifications. Nevertheless, the take-off weight and maximum flight time are no different. It can fly up to 18 m/s, but this study mostly used flight speeds from 3 to 4 m/s for data quality. If the flight time is maximized for 18 minutes, it can cover a range of more than 4 km [15,16]. According to drone specifications, in no-load operation with six batteries, the maximum flight time is 35-40 minutes, depending on the battery type. A drone carrying a 5.5 kg load can fly for 18 minutes. This UAV has been used in many applications, which are mapping fireline intensity and flame height [25], topographic mapping [15], agriculture [16], forest management [26], water quality monitoring [27], and marine monitoring [17].

The RS-125 spectrometer was installed on the DJI Matrice 600 drone with the detector directed downward. The reason was to adjust the available space on the drone. In addition, the readings are expected to be more idealized and representative of the measurement area.

The research methodology was divided into determining optimal flying height and the actual field-based trial. Several assessments are conducted to determine height attenuation [28]. In order to carry out the height attenuation evaluation, an extensive database of secondary data on soils, land use, and vegetation height was reviewed [19]. The testing area to select preliminary height attenuation variability is located in Jakarta. The height attenuation in this study is represented by the decreasing ratio to the ground measurement value (the percentage of the value of a height divided by the value on the ground, which is subtracted to 1) as other factors influencing the attenuation are neglected. The field measurements for the drone-borne survey are located in the tin mining area on Bangka Island. Bangka was chosen because the area has monazite as a radioactive accessory mineral in tin deposits [29-31]. The location selected for measurement in both stages was as flat as possible to avoid any topographic effect on the measurement. The source geometry over flat ground, broad topographic change, sharp hills, and narrow valleys have very different radiometric in terms of source geometry [32].

In Jakarta, optimal flying height (Stage 1) was determined by a comparative study of the radiometric response on different flying heights. The drone was incrementally raised from ground level to 50 m (Fig. 1) to determine the best height for radiometric measurements. Elevation is obtained from the recording made by the drone's global positioning system (GPS). The spectrometer is also equipped with GPS to obtain elevation data. The parameters gained from the RS-125 are Total count (cpm), K (cpm), U (cpm), Th (cpm), and dose rate (nSv/h). The K energy window monitors the 1.46 MeV gamma rays emitted by ^{40}K. The U and Th energy windows monitor the emission of decay products in the U and Th decay series, 1.765 MeV of ^{214}Bi and 2.614 MeV of ^{208}Tl, respectively [33]. There were 5 measurements at each height. The data gained from each elevation was compared with the ground-measurement results. The count per minute (cpm) unit was chosen instead of part per million (ppm) or percentage because it is higher in number and also to increase the spectrometer energy resolution.

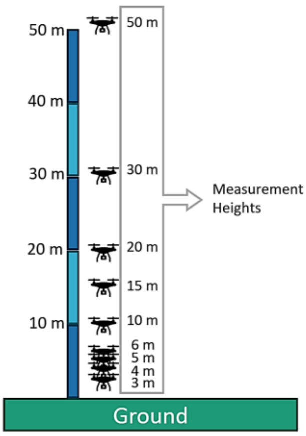

Fig. 1. Vertical flying path of drone for the flight experiment.

The actual field drone-borne measurement in Bangka Island (Stage 2) was conducted simultaneously with ground-borne measurement. The purpose of ground-borne measurement was to compare the effectiveness, especially in the horizontal variation. One of the disadvantages of the DJI Matrice 600 is that it does not have a collision avoidance system. Therefore, before measurement, a preliminary survey was conducted with a smaller drone to ensure the track was free of any obstacles. The track for this stage is a horizontal line with a length of 900 m. The ground measurements were wider than the drone-borne measurements to ensure that the ground measurement was still within the FOV of the drone-radiometric measurements.

RESULTS AND DISCUSSION

In stage 1, the attenuation is calculated by comparing radiometric responses on each measurement height to the values measured on the ground. Overall, the decreasing ratio to the ground measurement increases as the elevation increases (Fig. 2). The potassium measurement shows an increase in attenuation height except at 6 and 20 m (Fig. 2, dashed blue line). The uranium measurement shows an increase in height attenuation except at 15 and 50 m (Fig. 2, dashed orange line). The thorium measurement shows an increase in height attenuation, except at 6, 20, and 30 m (Fig. 2, dashed purple line) where it decreased. Meanwhile, the dose rate measurement shows an increase in height attenuation, but decreased at 6 m (Fig. 2, dashed green line). The total count (TC) measurement shows more consistency in the height attenuation, especially at elevations up to 15 m (Fig. 2, dashed red line; Fig. 3b). Beyond 15 m, the measurement is likely stagnant. Noting that the radiometric method in mineral exploration is implemented to detect any anomaly from various data values, stagnancy is unfavorable. Thus, on optimal height determination, especially from the TC data, the ideal height for drone measurement is 15 m. This finding is considered relatively proportional to the smaller volume of the RS-125 detector, given that research on effective flying altitudes for UAVs with larger detector sizes suggests that an altitude of 20 m is the limit for generating sufficient extreme value sensitivity and spatial structure of the surface radiometric response [14].

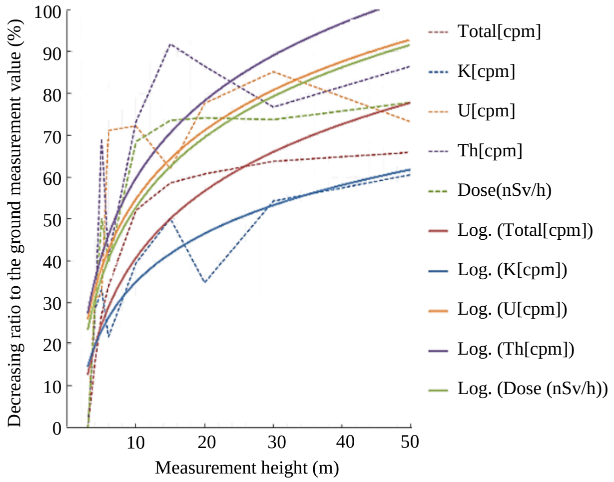

Fig. 2. Decreasing ratio to the ground measurement value for the corresponding height.

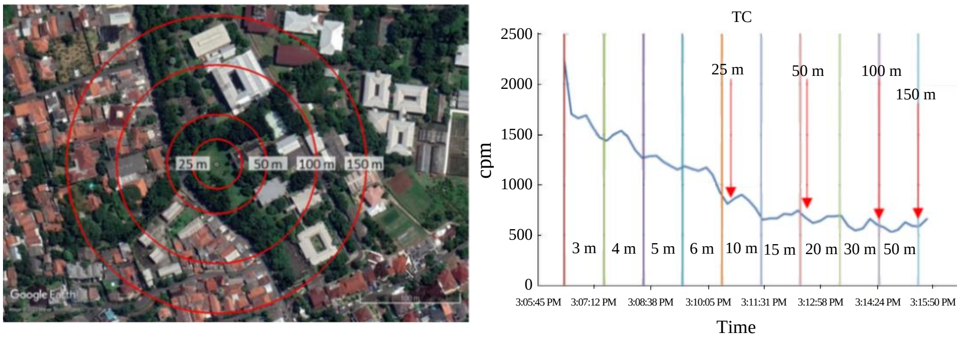

Fig. 3. (a) Radius of the field of view (FOV); (b) Total count (TC) data and the mark of FOV measured.

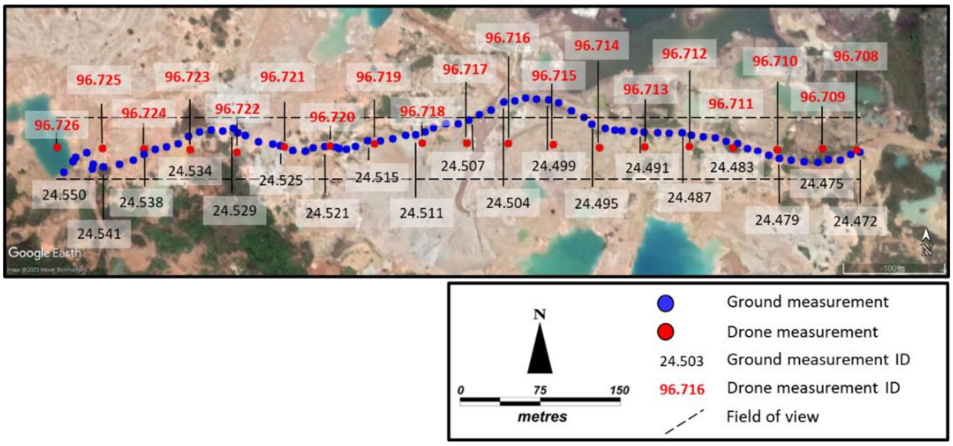

Fig. 4. Track of the drone and ground measurement. The blue dot is data taken during ground measurement, and the red dot is drone measurement. The dashed line is the field of view, an area three times the height. The measurement ID is the number selected for further radiometric comparison analysis.

As an evaluation of this fact, an FOV radius was created to figure the area measured during the test. In aerial spectrometry surveys, the sample volume is the product of the surface area visible to the air-borne detector and the thickness of the source material. The sample volume for an aerial measurement highly depends on the aircraft's height above the ground. This situation influences the region of the surface that is being investigated. Several authors have referred to the surface area as the FOV, instantaneous FOV, circle of investigation, or area of influence. In FOV works, 95 % of gamma-ray infinite sources are defined as about three times the height [32]. Comparisons were made between the FOV radius and the TC measurement results. Based on the evaluation, a radius of 25 m (drone height of 8 m) is the most ideal because there are no buildings. The measurement is still suitable for a radius of 50 m (drone hover height of about 15 m). There is one building to the east, but the ground area is mostly open, allowing radiation to be emitted. At a radius of more than 50 m (100 and 150 m), the cover of buildings and roads in office and residential areas is estimated to be the main factor in gamma ray attenuation (Fig. 3).

In stage 2, one of the main factors that become an obstacle in measurement is the stabilization process of the detector, which takes quite a long time. The detector experienced instability several times, so the data was not measured. Based on observations, the low level of gamma radiation in the measurement area is the cause of the detector's difficulty in stabilizing. In order to speed up the stabilization process, some monazite ore was used and brought closer to the detector during the stabilization process.

Based on stage 1, at 24 m height, the radiometric response attenuated about 50 % on K, 75 % on eU, 84 % on eTh, 62 % on TC, and 74 % on dose rate (Fig. 2). This change in flying height is implemented in consideration to the vegetation height in the survey area. The ground measurement was used to judge whether the flying height of 24 m was acceptable.

The measurement points, both on aerial and ground, can be seen in Fig. 4. The area included in the FOV of the detector on aerial measurement was considered appropriate as there are no additional factors leading to attenuation. The area is relatively flat and has less vegetation cover. From the measurement results, in general, the radiometric data from the drone shows a smaller resolution than the ground data (Fig. 5). In the dose rate data, the drone data is similar, with an up-and-down pattern that is almost similar to the ground data. The Pearson correlation between the two measurement methods is 0.67 (Fig. 5a). The same is true for thorium (0.49) and potassium (0.45), as seen in Fig. 5b and Fig. 5d, respectively. Meanwhile, in the uranium data, the difference in measurement results is quite noteworthy, with some peaks located at different distances. The Pearson correlation for uranium data is 0.05 (Fig. 5c).

The Box and whisker of the drone measurement data at an altitude of 24 m shows that the drone-ground comparison is ideal in the dose rate (Fig. 6a) and potassium (Fig. 6d) data. The data shows that the values read on the drone were smaller than those read on the ground. This difference is indicated by the drone quartile group being smaller than the ground. In the uranium data, this condition also occurs. However, the difference is remarkably significant that even the median quartile value of the drone elevation does not match the ground quartile data (Fig. 6b). In thorium data, the measurement resolution of the drone elevation is smaller than the ground data. This condition is indicated by the median quartile of the drone, which is entirely smaller than the ground (Fig. 6c).

This work also notes that the ideal flying height for RS-125 gamma spectrometer drone-borne application is not always applicable due to the field conditions and the limitations of the drone specification. Thus, it is advised that ground measurements should also be done, if possible, to re-assess if the radiometric response from the specific flying height is acceptable. Ground measurement is also essential if any correction regarding the atmospheric effect on the radiometric survey is conducted [18]. Additionally, the FOV should be considered to see if there is any additional factor causing attenuation.

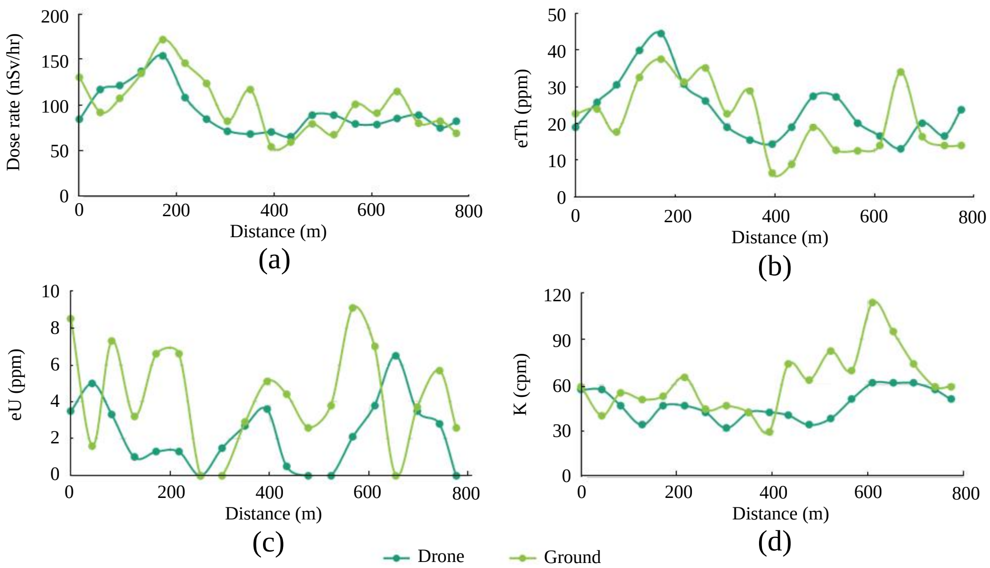

Fig. 5. Comparison of the drone and ground-radiometric: (a) dose rate; (b) thorium; (c) uranium; and (d) potassium.

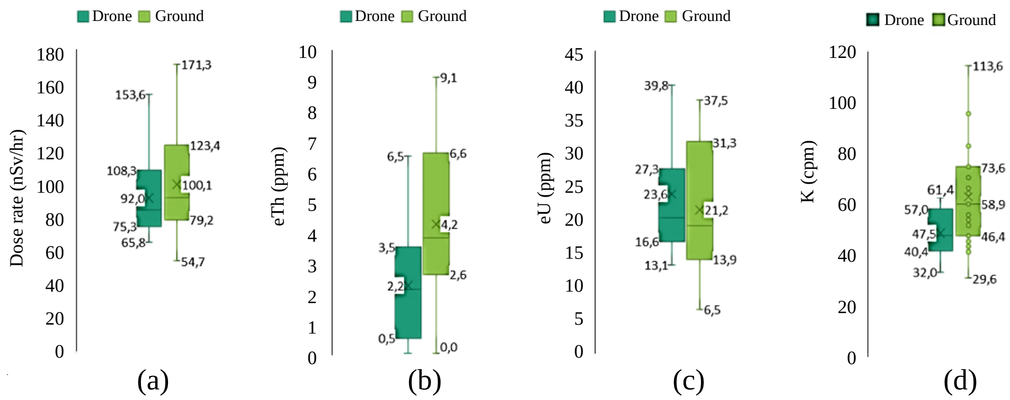

Fig. 6. (a) Comparison of drone and ground for dose rate; (b) uranium; (c) thorium; and (d) potassium.

CONCLUSION

The testing results for the ideal vertical height showed results of 15 m, while the data was too flat above that height. However, based on the FOV analysis, it is estimated that attenuation factors from surrounding buildings influence this. Based on the results of field measurements at a drone height of 24 m, the comparison of drone and ground data is acceptable for dose rate, thorium, and potassium. For uranium data, the drone measurement results are less acceptable. The RS-125 gamma-ray spectrometer is generally suitable for drone-borne radiometric applications.

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AUTHOR CONTRIBUTION

Heri Syaeful, Adi Gunawan Muhammad, Adhika Junara Karunianto, Frederikus Dian Indrastomo, and Roni Cahya Ciputra are equally contributed as the main contributors. Everyone who contributed reviewed and approved the final version of the article.

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