# Evaluation of UAV Photogrammetric Accuracy for Mapping of Open Dump Based on Variation of Image Overlaps

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## Abstract

Urbanization in developing countries has led to an increase in both quantified amount of municipal solid waste (MSW) generation and final disposal. While many countries are utilizing open dumping to dispose MSW, such a practice can cause environmental, social, and economic problems. Accurate spatial data in the form of mapping is necessary for construction and proper management of a disposal site as well as for systematic operation, site maintenance, and monitoring of the site. Although unmanned aerial vehicle (UAV) has widely been used in many survey applications, UAV has not yet been applied to the work related to open dumpsite. The aim of this study was to evaluate the accuracy of open dump mapping with different image overlaps for setting basic and standard UAV flight information. Ground sampling distance values were set to 5 cm/pixel, while flight configurations were varied from 80% to 90% and 75% to 90% for frontal and side overlaps, respectively. Root mean square error (RMSE) was used to represent the accuracy of the measurement. Ten ground control points for geo-referencing and 26-28 check points for accuracy evaluation were utilized. The results were classified based on the accuracy class as per the American Society for Photogrammetry and Remote Sensing standard. The best results were obtained when using 80% frontal overlap and 75% side overlap; these values resulted in the lowest RMSE on both horizontal and vertical coor-dinations for open dump mapping.

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## บทคัดย่อ

การขยายตัวของชุมชนเมืองในประเทศที่กำลังพัฒนาส่งผลให้ปริมาณขยะมูลฝอยและการฝังกลบขยะมูลฝอยมีมากขึ้น ประเทศส่วนใหญ่จัดการขยะเหล่านี้ด้วยการนำไปกำจัดที่บ่อขยะแบบเทกองกลางแจ้ง ซึ่งทำให้เกิดผลกระทบต่อสิ่งแวดล้อม สังคม และเศรษฐกิจ ในการสร้างและบริหารจัดการบ่อขยะอย่างเหมาะสม ซึ่งประกอบไปด้วยขั้นตอนของการดำเนินการ การซ่อมบำรุง และการตรวจสอบอย่างเป็นระบบนั้น จำเป็นต้องมีข้อมูลเชิงพื้นที่ ซึ่งแสดงในรูปแบบของแผนที่ ที่มีความถูกต้อง แม้ว่าอากาศยานไร้คนขับจะถูกนำมาใช้เพื่อการสำรวจอย่างแพร่หลาย แต่ยังไม่มีการนำมาใช้สำรวจบ่อขยะแบบเทกองกลางแจ้งมาก่อน งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อประเมินผลความถูกต้องของการทำแผนที่บ่อขยะแบบเทกองกลางแจ้งด้วยการกำหนดการซ้อนทับภาพที่แตกต่างกัน ซึ่งทำให้ทราบรูปแบบการบินถ่ายภาพที่เหมาะสมสำหรับเป็นแนวทางมาตรฐานของการรังวัดทำแผนที่ด้วยอากาศยานไร้คนขับในบ่อขยะแบบเทกองกลางแจ้งต่อไป งานวิจัยนี้กำหนดค่า Ground Sample Distance เท่ากับ 5 ซม./จุดภาพ กำหนดรูปแบบการบินถ่ายภาพให้มีการซ้อนทับด้านหน้าและการซ้อนทับด้านข้างอยู่ที่ 80% ถึง 90% และ 75% ถึง 90% ตามลำดับ ประเมินความคลาดเคลื่อนเชิงตำแหน่งด้วยค่า Root Mean Square Error (RMSE) มีการวางจุดควบคุมภาพ จำนวน 10 จุด และจุดตรวจสอบ จำนวน 26-28 จุด ทั้งนี้ เปรียบเทียบการประมวลผลตามมาตรฐาน American Society for Photogrammetry and Remote Sensing จากการศึกษา พบว่า รูปแบบการบินถ่ายภาพที่ให้ค่าความถูกต้องสูงสุดสำหรับการทำแผนที่บ่อขยะแบบเทกองกลางแจ้ง คือ การบินถ่ายภาพด้วยการซ้อนทับด้านหน้าที่ 80% และซ้อนทับด้านข้างที่ 75% ซึ่งให้ค่า RMSE น้อยที่สุดทั้งในแนวระนาบและแนวดิ่ง

## 1. INTRODUCTION

Urbanization and industrialization of many developing countries have led to an increasing amount of municipal solid waste (MSW) generated and sent to final disposal sites. Open dumping is the most popular method for the disposal of MSW in developing countries due to low operating costs and skilled personal requirements [1-2]. Nowadays, the amount of waste has increased, so there must be more space to support the disposal. Correspondingly, it affects the environment, ecosystem community and real estate nearby [3-5]. Therefore, the operation and maintenance of open dumps are important tasks for solid waste disposal site management. The waste that is degraded in open dumps can change its chemical, biological, and physical characteristics, which produces leachate, gases and materials productions [6-7]. However, this degraded waste can be processed back into recyclable materials that have economic value. The study of changes in open waste disposal areas provides important information for social, economic and environmental assessments as well as social impacts from the discharge of leachate, gas, and materials. [8-9].

The tools used to identify the change of open dumping are spatial information. Map can be used for monitoring, tracking and planning the operation as well as planning for closure and rehabilitation of open dump. Open dump monitoring needs to monitor the amount of waste, waste height, slope of dumped waste, overflow of leachate, and litter problem. Open dump mining recovers materials from disposed waste, especially plastic; this mining needs to know the amount of waste that can be converted into Refuse Derived Fuel (RDF), which leads to estimation of potential energy recovery [10].

Topographic map by land surveying is necessary for estimating the amount of disposed waste. Normally, surveyors use various equipments for mapping, e.g. total stations, theodolites, Global Navigation Satellite System (GNSS) receivers, which are used for collecting the three-dimensional (3D) positions of points and distances data. However, these methods are the direct measurements that need to set up survey instruments in the field. In actual conditions, surveying equipment on non-compact waste is very complicated and leads to severe uncertainty data. In addition, final disposal site is a hazardous area because wastewater, toxic gases, and dust can affect surveyors. Thus, traditional survey methods do not only cause harm to surveyors but it is also difficult for field working.

Nowadays, Unmanned Aerial Vehicle (UAV) or drone technology has been used in manifold fields such as terrain mapping, construction industry, environmental monitoring, precision agriculture [11-12]. For mapping process, UAV has been operated with geospatial information and used for producing maps with a low-cost option. The strength of UAV photogrammetry for mapping, i.e., capability, flexibility, and high quality of photo acquisition, can produce a 3D model by structure-from-motion (SfM) method [13-15]. Kristen Cook (2017) and Ewertowski et al. (2019) defined the meaning of the SfM as a generation of photogrammetric technique that automatically solve the geometry of scene, camera positions, and the orientation without requiring a priori specification of a network in term of 3D positions. [16-17]. Many factors that affect accuracy of maps and 3D models obtained by Unmanned Aircraft System (UAS) photogrammetry are flight altitude, terrain morphology, number of ground control points (GCPs), frontal and side overlaps, and weather condition [18].

This study aims to evaluate the photogrammetric mapping accuracy of 3D models and orthophotos derived from UAV Photogrammetry, based on the variation of frontal overlap and side overlap in open dump mapping in order to increase mapping accuracy of disposal operation.

## 2. MATERIALS AND METHODS

### 2.1 Study site

The studied site is open dump in Muang district, Nakhon Pathom province, Thailand (13°52'03"N 100°02'37"E), as presented in Fig.1. This site covers 4.78 hectares (0.0478 km2). Currently, this studied site is collected the MSW from 19 municipalities. The open dump mapping was conducted from January to February 2019.

### 2.2 Image acquisition

This study generated images from a low-cost rotatory wing UAV with four rotors (DJI Phantom 3 professional). This UAV has an built-in digital camera, Sony EXMOR 1/2.3" CMOS camera with lens and fixed focal length of 20 mm The resolution of the camera sensor was 12.0 megapixels (4000×3000 megapixels) equipped with a gimbal.

The flight height was set at 114 m above the home point level, covered the surface of 390×250 m each photo and it is equivalent to the Ground sampling distance (GSD) of 5.0 cm/pixel. All flights were set as a single grid pattern. All flight plans in this study were automatically photographed above the study area by the Pix4Dcapture application.

To address the objectives, this study varied the overlapping between 80-90% and 75-90% for frontal and side overlap, respectively. Six flight configurations were used to determine a photogrammetric project (Table 1). The sets of 10 GCPs and 28 checkpoints (CPs) were placed in the studied area (Fig.1). The GCPs are used to produce photogrammetric output, likewise the CPs are used for accuracy

**Table 1** Flight configurations (FC)

| Flight configuration code | Frontal overlap (%) | Side overlap (%) | Number of captured images | Number of GCPs | Number of CPs |
|---|---|---|---|---|---|
| FC1 | 80 | 75 | 159 | 10 | 27 |
| FC2 | 80 | 90 | 249 | 10 | 27 |
| FC3 | 85 | 75 | 155 | 10 | 27 |
| FC4 | 85 | 90 | 287 | 10 | 28 |
| FC5 | 90 | 90 | 307 | 10 | 26 |
| FC6 | 85 | 85 | 186 | 10 | 28 |

assessment.

According to American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data (2014), the number of static 3D checkpoints in Non-vegetated Vertical Accuracy (NVA) is at least 20 points based on a project area with less than 500 m2 [19].

The 3D coordinates of positions at 10 GCPs and 28 CPs for geo-referencing and accuracy assessment in the image processing were measured before UAV flight by GNSS receptor working in Real-time kinetic (RTK) mode. Both rover and base GNSS receivers were Hi-target V100 system. For RTK measurements, these dual-frequency geodetic instruments have a manufacturer’s stated accuracy specification of ±8 mm +0.5 ppm horizontal RMS and ±15 mm + 0.5 ppm vertical RSM. However, GCP and CP targets must have appropriately designed for minimizing error during geo-referencing and accuracy assessment processes. The dimension of GCP was 1.20×1.20 m, which had resembled a chequered block sheet. The dimension of CP was 0.40×0.40 m, which had a black circle with a diameter of 25 cm inside the orange square sheet. The figure of GCP and CP are shown in Fig.2.

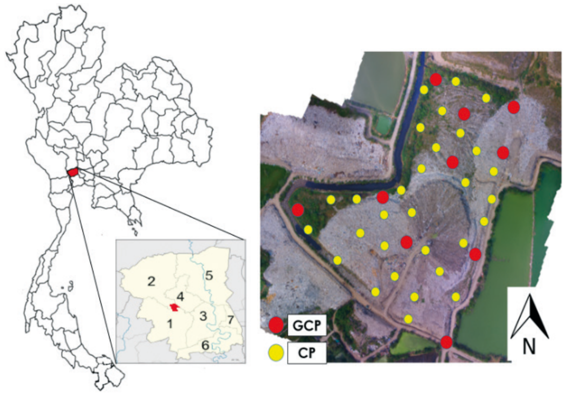


**Figure 1** Location of the study area and the position of GCPs and CPs with orthoimage

(a) (b)

**Figure 2** The GCP (a) and CP (b) targets

## 2.3 Image processing

The image processing was implemented by using the software package Agisoft PhotoScan Professional version 1.4.4. This software classified as the SfM algorithm. Agisoft Photoscan software was used for processing the photos, which illustrates the possibility of the generation of georeferenced point clouds, digital surface elevation models, and mosaiced image for geographic information system data in order to build a layer of mapping on the image processing. Aligning Photos, the first step of image processing, is performed to tie the images together in an automated image correlation process in order to create a sparse point cloud. The next step is "Optimizing the Photo-Alignment"; it is used for performing photogrammetric least squares bundle adjustment. The next is "Build the Dense Point Cloud", which is estimated camera positions, calculating of several X,Y,Z points in order to accurately create the model of processing. Finally, the inspection of textured model, which is important for a precise marker of GCP and CP placement generating into orthophoto, is conducted in this study, as shown in Fig.3. [18].

**Figure 3** 3D reconstruction from UAV image data

## 2.4 Accuracy assessment

The spatial accuracy of this study was evaluated based on the positions of the CP that were obtained from the RTK-GNSS and the positions generated by the 3D model. The accuracy of X, Y, and Z axes were evaluated in this study by using Root Mean Square Error (RMSE) for determining the accuracy classes.

The accuracy of all photogrammetric projects were evaluated by typical RMSE formulation, following to Martínez-Carricondo et al. (2018).

$$RMSE_X = \sqrt{\frac{\sum_{i=1}^{n}(X_{Oi}-X_{GNSSi})^2}{n}} \quad (1)$$

$$RMSE_Y = \sqrt{\frac{\sum_{i=1}^{n}(Y_{Oi}-Y_{GNSSi})^2}{n}} \quad (2)$$

$$RMSE_r = \sqrt{\frac{\sum_{i=1}^{n}[(X_{Oi}-X_{GNSSi})^2+(Y_{Oi}-Y_{GNSSi})^2]}{n}} \quad (3)$$

$$RMSE_Z = \sqrt{\frac{\sum_{i=1}^{n}(Z_{Oi}-Z_{GNSSi})^2}{n}} \quad (4)$$

$$RMSE_T = \sqrt{(RMSE_{XY})^2 + (RMSE_Z)^2} \quad (5)$$

Where:

- n is the number of CPs tested for each project.
- $X_{Oi}$ and $Y_{Oi}$ are the X and Y coordinates, respectively, measured in the orthophoto for the ith CP.
- $X_{GNSS}$ and $Y_{GNSSi}$ are the X and Y coordinates, respectively, measured with GNSS for the $i^{th}$ CP.
- $Z_{Oi}$ is the height in the ith CP, derived from the digital surface model (DSM), taking into account its coordinates X and Y, measured on the orthophoto.
- $Z_{GNSSi}$ is the Z coordinate of the $i^{th}$ CP measured with GNSS.

## 3. RESULTS AND DISCUSSION

Waste quantity and settlement can be calculated from 3D mapping by X, Y and Z coordination. The total station is used as a traditional survey in order to map and study the ground settlement. This method obtained the measurement of an accurate position [20]. However, this method has some limitations for implementation on open dump site. The accuracy of mapping by UAV photogrammetry should be studied because UAV photogrammetry is an appropriate method for open dump mapping.

The GCPs and CPs were used to investigate accuracy of the project; the independent accuracy of georeferencing was checked by GCPs, and project accuracy was checked by CPs [21]. Both parameters are represented in terms of RMSE of horizontal and vertical positions. $RMSE_X$ is the standard deviation of the horizontal linear RMSE in the X direction (Easting). $RMSE_Y$ is the standard deviation of horizontal linear RMSE in the Y direction (Northing). RMSEr is the horizontal linear RMSE in the radial direction that includes both X- and Y-coordinate errors. $RMSE_Z$ is the standard deviation of the vertical linear RMSE in the Z direction (Elevation).

The results of the horizontal accuracy of both GCPs and CPs in each flight configuration are presented in Fig.4. The results of these flight configurations were based on the ASPRS standard Version 1.0-November 2014. This standard defines geolocation accuracy to geospatial products [19]. This standard recommends the use of orthoimage in three categories according to their orthoimage $RMSE_X$ and $RMSE_Y$ values. When these values do not exceed 1-pixel, the orthoimagery can be used in the highest accuracy work. If these values do not exceed 2-pixel, this orthoimagery can be used in standard mapping and geographic information system (GIS) work. On the other hand, if these values are equal to or greater than 3-pixel, the orthoimage can be only used in visualization and less accurate work [19].

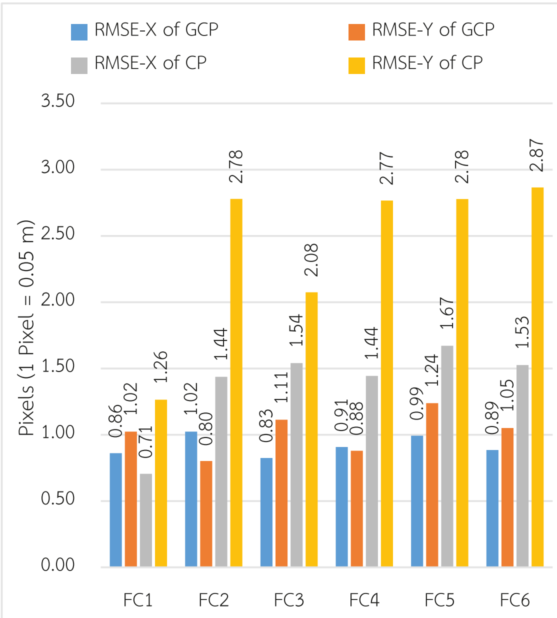


**Figure 4** $RMSE_X$ and $RMSE_Y$ of GCPs and CPs for each flight configuration

From Fig. 4, the $RMSE_X$ of GCPs were lower than 1 pixel (5 cm) in all flight configurations except FC2. The RMSEY of GCPs in FC2 and FC4 were lower than 1 pixel or 5 cm. The $RMSE_Y$ of GCPs in FC1, FC3, FC5, and FC6 were between 1 and 2 pixels. The results showed that the FC4 had the best geo-referencing in this study.

The $RMSE_Y$ of CPs was found that only $RMSE_X$ of CPs in FC1 had lower than 1 pixel. $RMSE_X$ of CPs in FC2-FC6 was between 1 and 2 pixels. The $RMSE_Y$ of CPs in CF1 was between 1 and 2 pixels. However, in FC2 to FC6, the $RMSE_Y$ of CPs were more than 2 pixels. According to the ASPRS standard (2014), it was found that the FC1 can be the recommended use in standard mapping and GIS work. For the cases of (FC2 to FC6), it can be recommended to be used only in the visualization and less accurate work.


**Figure 5** $RMSE_r$ of GCPs and CPs for each flight configuration

Fig.5 presents the horizontal linear RMSE in radial direction, which is shown in terms of $RMSE_r$. The results of GCPs of all flight configurations were between 6.30-7.95 cm. $RMSE_r$ of FC1 gave the lowest value (7.25 cm). In contrast to the FC2 to FC6, the values of RMSEr of CPs were greater than FC1, which were between 12.90-16.25 cm.

The ASPRS standard also gives the recommendation for the comparison of $RMSE_Z$ result with vertical accuracy criteria. [19]. This study assessed vertical accuracy in a non-vegetated terrain condition, which is suitable for the open dump. The vertical accuracy for the $RMSE_Z$ of CPs in FC1, FC3, FC4, and FC6 can be defined as 5 cm-vertical accuracy class (Fig.6). The $RMSE_Z$ of CPs in FC2 and FC5 can be defined as 10 cm and 15 cm-vertical accuracy class, respectively. The $RMSE_Z$ of GCPs in FC1–FC4 also provided an accurate geo-referencing in vertical accuracy which showed the RMSEZ below 5 cm In addition, the 3D model process is referred to accurately position of $RMSE_Z$ generated into a digital elevation model (DEM), as shown in the Fig.7.

The overall of horizontal and vertical accuracies are presented in term of $RMSE_T$ (Fig.8). The range of $RMSE_T$ of GCP in FC1-FC6 was between 1.41–2.87 pixels. The lower $RMSE_T$ of GCP was in the FC1 and the higher $RMSE_T$ of GCP was in the FC5. The range of $RMSE_T$ of CP in FC1-FC6 was between 1.55–3.86 pixels. The lower $RMSE_T$ of CP was in the FC1 and the higher RMSE of CP was in the FC5. The horizontal and vertical accuracy according to the ASPRS 2014 standard and their equivalent to map scale in ASPRS 1990 standard are summarized as shown in Table 2.

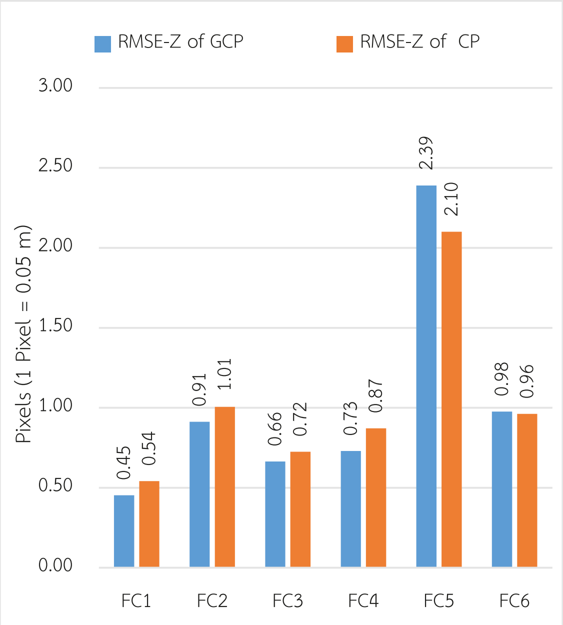


**Figure 6** RMSE$_Z$ of GCPs and CPs for each flight configuration

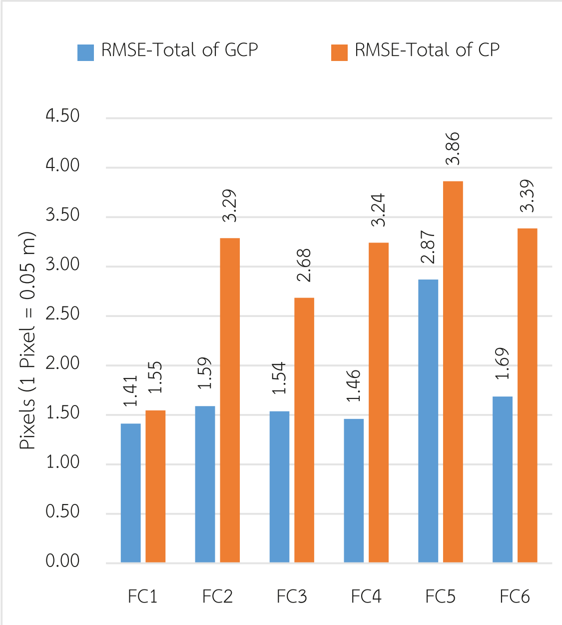


**Figure 8** RMSE$_T$ of GCPs and CPs for each flight configuration

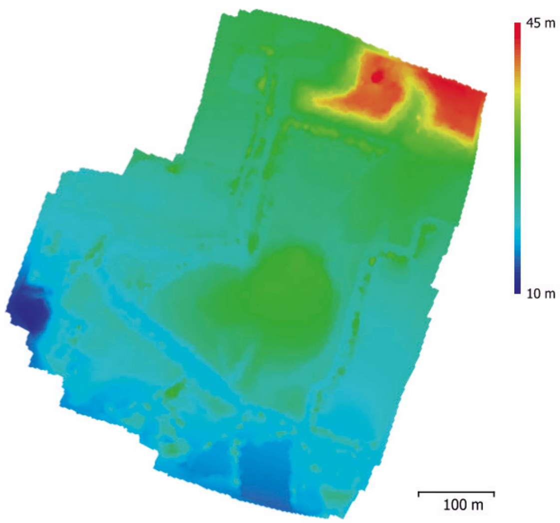


**Figure 7** The digital elevation model (DEM) construction

**Table 2** Summary of accuracy in all flight configurations

| Flight configuration code | Horizontal Accuracy | | | | Vertical Accuracy |
|---|---|---|---|---|---|
| | ASPRS 2015 | | Equivalent to map scale in | | |
| | Horizontal Accuracy Class RMSE$_X$ and RMSE$_Y$ (cm) | RMSE$_r$ (cm) | ASPRS 1990 Class 1 | ASPRS 1990 Class 2 | |
| FC1 | 7.50 | 10.60 | 1:300 | 1:150 | 5-cm |
| FC2 | 15.00 | 21.20 | 1:600 | 1:300 | 10-cm |
| FC3 | 12.50 | 17.70 | 1:500 | 1 :250 | 5-cm |
| FC4 | 15.00 | 21.20 | 1:600 | 1:300 | 5-cm |
| FC5 | 15.00 | 21.20 | 1:600 | 1:300 | 15-cm |
| FC6 | 15.00 | 21.20 | 1:600 | 1:300 | 5-cm |

## 4. CONCLUSIONS

The UAV photogrammetry, which is a disruptive methodology, was implemented in this study. The othomosaic maps and 3D models for open dump mapping were successfully generated based on 6 flight configurations that varied in frontal and side overlap. The images were captured by the low-cost UAV and processed by SfM software. This study shows a considerable advantage of UAV photogrammetry over the traditional survey method at open dump site. Based on the analysis part, each flight configuration contributed to different errors in terms of horizontal and vertical positions. The RMSE analysis showed that flight configuration at 80% frontal overlap and 75% side overlap gave the best results for RMSEX and RMSEY within 7.5 cm. as well as $RMSE_Z$ within 5 cm. Thus, this flight configuration can be suggested as the recommended UAV photogrammetry practice for the mapping at the open dump. However, the accuracy of mapping does not only depend on flight configuration but also depends on the appropriate GCP configuration of both numbers and alignment. In further study, the appropriate GCP configuration should be investigated for finding the minimum GCP number to ensure level of accuracy with the most appropriate and feasible facility.

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