The effect of the distribution and numbers of ground control points on the precision of producing orthophoto maps with an unmanned aerial vehicle

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ABSTRACT
Ground control points (GCPs) are used in the process of indirectly georeferencing unmanned aerial systems (UAS) images. The aim of this study was to determine how many GCPs and what kind of distribution is required in order to obtain high precision results. In the study, three scenarios were investigated. The GCPs were tested in edge distribution in the first scenario, in the middle distribution in the second scenario, and in homogeneous distribution in the third scenario. In the first scenario, the edge distribution was supported by the central GCPs, while in the second scenario, the central GCPs were supported by the edge GCPs. Each scenario was initiated with four GCPs. The number of GCPs was increased by four, resulting in the utilization of a total of 35 GCPs. In addition, 30 check points (CHP) were used. The number of orthophoto and DSM produced in the study was 33. In the study, the best planimetric accuracy was obtained with the first scenario, namely with the edge distribution (RMSE xy: 0.033 m). Altimetric accuracy was obtained with the third scenario, namely with homogeneous distribution (RMSE z: 0.048 m).

1. Introduction
In investment projects, digital elevation models (DEMs) and orthophotos are used as basic materials to design and run the projects. Unmanned aerial vehicle (UAV) photogrammetry has made it possible to economically and practically obtain such information. However, the accuracy of the acquired data must be within acceptable limits. DEMs are one of the products of UAV photogrammetry in orthophoto maps.

There are various techniques that are used to achieve high precision DEMs. These techniques include terrestrial laser scanning systems (TLS) (Lague, Brodu, and Leroux 2013), Lidar (Sallenger et al. 2003) and UAV techniques. UAV photogrammetry combines the advantages of close-range photogrammetry and aerial photogrammetry. It requires less time and ensures inexpensive data collection compared to aerial photogrammetry. As a result of the integration of photogrammetry and computer systems (Atkinson 2001; Hartley and Zisserman 2003; Ulvi 2018) more accurate data is obtained.

UAVs are a suitable alternative to both airborne and orbital imaging platforms and can be used for small area mapping projects as well as monitoring tasks that require a high temporal resolution (Vaccari et al. 2015; Pessoa et al. 2020). These platforms allow image acquisition with large overlaps (70% to 80% forward and 60% to 80% side overlaps), thereby providing a consistent image matching reliability (Forlani et al. 2019).

Evaluating the quality of photogrammetric products is a complex task as many variables have to be taken into consideration. None of the experimental studies that have been conducted have covered all of the variables. Among all of the possible factors that directly impact the quality of a photogrammetric product, surveying ground control points (GCPs) is one of the most time-consuming tasks. Thus, neglecting or reducing the quantity of GCPs while maintaining the required level of accuracy, can improve UAV-based photogrammetric projects, as the time spent in both the field and office can be reduced (Pessoa et al. 2020).

Considering that the use of GCPs directly affects the accuracy of photogrammetric products, over the years many researchers have conducted a variety of studies to evaluate the accuracy of products obtained from UAV images by changing the number of GCPs.

Agüera-Vega, Carvajal-Ramirez, and Martínez-Carrondo (2016) investigated the influence of flight altitude, terrain morphology and the number of GCPs on a digital surface model (DSM) and orthophoto accuracy. For their study, they carried out 60 photogrammetric projects, taking into account five terrain morphologies, four flight heights (i.e., 50, 80, 100 and 120 m) and three different GCPs (i.e. 3, 5 and 10). The most accurate combination of flight altitude and GCP number was found to be 50 m and 10 GCPs.
respectively. At the end of the study, the root mean square error (RMSE) were determined as RMSE x: 0.038, RMSE y: 0.035, RMSE xy: 0.053 and RMSE z: 0.049 m.

Lucieer et al. (2013) evaluated the high-resolution DSM of Antarctic moss beds generated from UAV imagery and obtained an overall RMSE of 4.2 cm.

Ruzgiene et al. (2015) determined the quality of DSMs generated using UAV photogrammetry techniques and the influence of the number of GCPs on the accuracy. The flight altitude was determined as 150 m. As a result, it was found that the average RMSE values were 0.064 m and 0.078 m for the images that were processed with 10 and five GCPs, respectively.

Sanz-Sanz-Ablanedo et al. (2018) conducted a study on the frequency and accuracy of GCPs in an area of 1200 ha. They flew at an altitude of 120 m and took 2514 pictures within this area. In addition, they employed 102 GCPs in the specified area. The approximate ground sampling distance (GSD) value was 6.86 cm. In the initial analysis, 60 out of the 102 points were used as GCPs, while the remaining 42 were used as check points (CHPs). The accuracy obtained was ± 16 cm. In the second analysis, they employed 90 out of the 102 points as GCPs and 12 as CHPs. The accuracy achieved was ± 12 cm.

In their study, Rangel, Gonçalves, and Pérez (2018) tested the accuracy of DSM and orthophoto maps. They employed 177 GCPs in their test field and flew a rotary wing UAV at an altitude of 228 m. They tested a total of 13 scenarios in the test field. As a result, they recommended using 18 to 20 GCPs in each image block for a high accuracy DSM.

Aguera-Vega, Carvalaj-Ramirez, and Martinez-Carricondo (2017) investigated the planimetric and altimetric accuracy of the number of GCPs on orthophoto and DSM in their study conducted on an area of 17 ha. The number of GCPs they utilized in the area varied between 4 and 20. They achieved the optimal results for root mean square errors with 15 GCPs (RMSE xy = 4.6 cm, RMSE z = 5.8 cm).

Mesas-Carrascosa et al. (2014) evaluated the mapping quality of orthophotos obtained from a multi-rotor UAV and a standard camera (16 mm focal length). Although they used four mapping standards to assess the planimetric accuracy of the generated orthophoto, they only used eight GCPs on a flight with a single strip configuration.

2. Ground control point and rectification

There are many factors that affect the accuracy of products that result from UAV photogrammetry. Among these, the effect of the number of GCPs and their distribution in the study area are particularly significant (Carricondo et al. 2018).

Orthophoto generation aims to eliminate relief displacement from perspective imagery. As a result, orthophotos are characterized as having a uniform scale and showing objects in their true geographical locations. In other words, orthophotos share the same characteristics as a map. Therefore, the user can position objects, measure distances, compute areas, quantify changes and derive other useful information with orthophotos (Habib, Kim, and Kim 2007).

GCPs ensure the connection between the image coordinate system and the ground coordinate system in both photogrammetry and remote sensing during the rectification of images. For this purpose, calibration information and the GCPs of the cameras with which the images were taken are used. When digital cameras are utilized, the global positioning system (GPS) and inertial measurement unit (IMU) are both employed to directly determine the external orientation elements used in rectification. However, GCPs are required to resolve systematic GPS errors and datum transformation. In photogrammetric studies, GCPs are assigned in the study area before the images are taken. The selection, distribution and accuracy of GCPs are very important as they affect the rectification outcomes.

The number and distribution of GCPs depend on various factors such as the mathematical model that is employed in rectification, the point selection method (field study, map reading, etc.), the type of sensor and the resolution of the image, the structure of the study area (flatland, mountainous etc.), and the desired position accuracy and sensitivity. Nonparametric mathematical models, such as polynomial transformation or direct linear transformation (DLT), require a higher number of GCPs than theoretical requirements as they do not reflect the imaging geometry. These models also depend on point distribution (Toutin 2003a). However, parametric models that utilize data such as imaging geometry and orbital elements require a lower number of GCPs when compared to nonparametric models and are less affected by point distribution (Toutin 2003b).

Aerial photos and satellite images do not show features in their correct locations due to displacements caused by the tilt of the sensor and terrain relief. Orthorectification transforms the central projection of the photograph into an orthogonal view of the ground, thereby eliminating the distorting effects of tilt and terrain relief. Orthorectification is the process of eliminating the non-systematic errors of aerial photos, namely the horizontal and vertical shifts (Figure 1). The product obtained from the orthorectification process (Figure 2) is called orthoimage or orthophotos (Ulvi et al. 2020).

Various methods can be applied to generate digital orthophotos. The three most commonly used methods, namely polynomial, projective, and differential rectifications, were analyzed and compared in this study. These methods can be applied to rectify both digitized aerial photographs and satellite scenes. Polynomial and projective rectifications, which are
imagery. The procedure of differential rectification is applied in combination with the back projection (indirect) method of orthoimage reprojection (see section 3 below). This is based on the well-known collinearity principle, which states that the projection center of a central perspective image, an object point, and its photographic image lie upon a straight line. The collinearity principle is described by means of equations (1) and (2) (Kraus 1992) given below:

\[ x = x_n - \frac{r_{11}(X - X_n) + r_{21}(Y - Y_n) + r_{31}(Z - Z_n)}{r_{13}(X - X_n) + r_{23}(Y - Y_n) + r_{33}(Z - Z_n)} = f(x', y') \]

\[ y = y_n - \frac{r_{12}(X - X_n) + r_{22}(Y - Y_n) + r_{32}(Z - Z_n)}{r_{13}(X - X_n) + r_{23}(Y - Y_n) + r_{33}(Z - Z_n)} = f_y(x', y') \]

where \( x' \) and \( y' \) are equivalent to the map coordinates of \( X \) and \( Y \), respectively.

To perform this transformation between the coordinates, the following parameters have to be available:
- the interior orientation of the camera: \( x_0, y_0, c \)
- the exterior orientation of the camera: \( X_0, Y_0, Z_0 \) – perspective centre and the \( r \) a rotation matrix composed of \( \omega, \phi, \kappa \) rotation angles,
- the pixel-spacing of the digital image in camera units: \( p_x, p_y \) (mm),
- the reference coordinates of one DEM pixel in the given map projection (usually the left upper corner of the DEM file).

\[ x = f_x(x', y') \] indirect transformation of point \( (x', y') \)

\[ y = f_y(x', y') \] from the result to the original image.

Digital differential rectification is the best rectification method to eliminate image errors. It also corrects image errors that may occur due to altitude differences. It uses both sensor geometry and the altitude information from the digital surface model and removes any errors that may occur in the image. The

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**Figure 1.** Orthogonal vs. perspective projection.

**Figure 2.** Orthorectification process: each 3D surface point defined as a pixel of the DSM is transformed into the image the colour intensity value from the source image. This value is assigned to the orthophoto raster at the same pixel location as the DSM point (Novak 1992).

2.1. **Differential rectification**

The objective of differential rectification is the assignment of grey values from the image (usually aerial image) to each cell within the orthophoto. Differential rectification is a phased procedure that uses several XYZ control points to georeference an image to the ground. Novak (1992) emphasized that differential rectification corrects both relief displacement and camera distortions, yields the best results, and can be applied for both aerial and satellite
major disadvantage of this method is its high initial data requirement, and the fact that in most cases the numerical altitude model may not be available.

3. Materials
3.1. Study area
The study area included an open mining area near the Sorgun district of the province of Yozgat in Turkey. The area was approximately 2590 ha (Figure 3).

3.2. Unmanned aerial vehicle
The most significant advantage of fixed wing UAVs is their ability to cover large areas in a shorter period of time compared to rotary wing UAVs. The fixed wing UAVs can generally fly for 40 to 60 minutes, while the flight time of rotary wing UAVs is almost half. As the study area was over 1000 ha, a fixed wing UAV was preferred in this study. The UAV used is presented in Figure 4, the technical data are presented in Table 1 and the technical specifications of the camera used are given in Table 2.

The eBee Plus survey drone is a large-coverage photogrammetric mapping system that features RTK/PPK upgradeability for survey-grade accuracy on demand. The senseFly S.O.D.A. (Figure 4) is the first photogrammetry camera to be built for professional drone use and has quickly become a reference sensor in its field. The camera image residuals are shown in Figure 5. It captures amazingly sharp aerial images, across a variety of light conditions and produces detailed, vivid orthomosaics and ultra-accurate 3D digital surface models.

The image resolution of the camera used is shown in Figure 5. When the image is examined, it is understood that the distortion is slightly more at the edges.

![Figure 3](image3.jpg) The location of the mining field (Turkey/Yozgat/Sorgun).

![Figure 4](image4.jpg) Ebee Plus and overview of the camera.
4. Methodology

The photogrammetric study was conducted in two main stages (Figure 6). The first stage included the field work, which comprised the installation of the GCPs and CHPs on the land, the measurements and flight operations, while the second stage included the office work, which included the transfer of the flight images to the computer and the analysis of these images with the photogrammetric software, the production of the point cloud, orthophoto map and the DSM. The study was concluded with the comparison of the CHP coordinates measured on the land and the map coordinates obtained with the software.

Table 1. Ebee Plus UAV technical specifications.

| Wingspan Weight | Camera | Control Software | Maximum Flight Time | Wing Resistance |
|------------------|--------|-------------------|---------------------|-----------------|
| T10 cm           | 1.1 kg | S.O.D.A.          | Emotion 3           | 59 minute       | Up to 45 km/h   |

Table 2. Technical specifications of the camera used.

| Camera Model | Resolution | Focal Length | Pixel Size | Pre-calibrated |
|--------------|------------|--------------|------------|----------------|
| S.O.D.A.(10.6 mm) | 5472 × 3648 | 10.6 mm | 2.4 x 2.4 μm | No |

Figure 5. Image residuals for S.O.D.A. (10.6 mm).

The balancing and evaluation process of the images was carried out using Agisoft software. This software uses a structure from motion (SFM) algorithm. The calibration parameters of the software for the camera used are given in Table 3.

4.1. Distribution of the ground control points and check points

In this study, a total of 125 points consisting of 95 GCPs and 30 CHPs were measured (Figure 7).

Three scenarios were tested in the distribution of the GCPs in the study area. For the first scenario, 30 GCPs were homogeneously distributed around the study area, while five were installed in the center. For the production of the orthophoto map, balancing and orthophoto production was conducted with four GCPs. In each balancing and production work, the number of GCPs was increased by four. Then, the orthophoto was produced by employing 30 GCPs in addition to the variation of 2, 4 and 5 CGPs located in the middle of the study area. A total of 11 orthophoto maps and DSM were produced (Figure 8).

For the second scenario, 30 GCPs were installed homogenously in the center of the study area, while five were placed on the edges. For the production of the orthophoto map, balancing and orthophoto production was conducted with four GCPs. In each balancing and production, the number of GCPs was increased by four. Then, the orthophoto was produced by employing 30 GCPs in addition to the variation of 2, 4 and 5 CGPs located in the edges of the study area. A total of 11 orthophoto maps and DSM were produced (Figure 9).

For the third scenario, 35 GCPs were distributed homogeneously throughout the study area. Balancing and orthophoto production was initiated with four GCPs and increased by four for each trial. As a result, a total of 11 orthophoto and DSM were produced (Figure 10).

Table 3. Calibration coefficients and correlation matrix.

| Value | Error | F  | Cx  | Cy  | K1  | K2  | K3  | K4  | P1  | P2  | P3  | P4  |
|-------|-------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| F     | 4391.07 | 0.049 | 1.00 | −0.39 | −0.82 | 0.01 | −0.06 | 0.08 | −0.06 | −0.03 | −0.03 | −0.00 | −0.01 |
| Cx    | −54.9332 | 0.0089 | 1.00 | 0.34 | −0.02 | 0.03 | −0.03 | 0.02 | 0.40 | 0.25 | 0.36 | −0.36 |
| Cy    | 5.34935 | 0.012 | 1.00 | 0.00 | −0.05 | 0.09 | −0.11 | 0.08 | 0.40 | 0.11 | 0.02 | −0.01 |
| K1    | 0.0486147 | 0.000016 | 1.00 | 0.97 | 0.93 | −0.89 | 0.05 | 0.03 | 0.06 | −0.06 |
| K2    | −0.351645 | 0.00012 | 1.00 | −0.99 | 0.96 | −0.06 | −0.06 | −0.07 | 0.08 |
| K3    | 0.737476 | 0.00034 | 1.00 | −0.99 | 0.09 | 0.07 | 0.06 | 0.08 | −0.09 |
| K4    | −0.425131 | 0.00032 | 1.00 | −0.07 | −0.06 | −0.09 | 0.10 |
| P1    | −0.0014652 | 9.2E-07 | 1.00 | 0.67 | 0.99 | −0.98 |
| P2    | −0.0001337 | 1.2E-07 | 1.00 | 0.67 | 0.99 | −0.98 |
| P3    | 9.26094 | 0.0084 | 1.00 | −1.00 | 1.00 |
| P4    | −12.2552 | 0.012 | 1.00 | 1.00 | 1.00 | 1.00 |
4.2. Global navigation satellite system survey

The GCPs were measured before the flight in real-time kinematic (RTK) mode using virtual reference stations from the permanent global navigation satellite system (GNSS) (Figure 11) station network of Turkey (TUSAGA-Active Turkish National Permanent GPS Active Stations Network). From the repeated measurements of the fixed locations, it was estimated that the mean accuracy of the measurements was 1–2 cm.

4.3. Flight planning and data processing

In this study, the camera of the Ebee device, namely the S.O.D.A camera, was employed. Based on the size of the study area (2590 ha), the flight was planned as 9.03 GSDs. The flight altitude corresponded to 396 m based on the GSD. A total of 12 flights were conducted. In all flights, the forward and lateral overlap rates were selected as 75% and 60%, respectively. Each flight took approximately 40 minutes (Figure 12).

A total of 3581 photos were taken as a result of the 12 flights. 3554 photos were taken in GNSS Fix mode, while 27 were taken in GNSS flood mode. The number of photos taken during each flight is presented in Table 4. After the photos taken in flood mode were processed in the office, all photos were converted into 100% fix mode.

Today, there are several inexpensive software that allow the 3D modeling of surfaces based on photographs taken with non-metric cameras. Many software are based on special algorithms such as the structure-from-motion (SfM), which is the photogrammetric technique that automatically resolves camera positions, orientation and scene geometry without a known 3D position.

The camera positions derived from the SfM algorithm do not have the scale and orientation provided by the coordinates of the GCPs. Consequently, the 3D

Figure 6. Workflow of the work carried out.

Figure 7. GCP and measurement in the study.
point cloud is generated in relative coordinates, referring to the image coordinate system. The georeferencing of this model is generally carried out using a small number of GCPs places in clearly visible locations both on the ground and in each of the photographs (Carricondo et al. 2018).

Figure 8. Distribution of GCPs around and inside the area.

Figure 9. Homogenous installation of the GCPs in the center of the study area.
For the UAV measurements, Agisoft Metashape software, which is an SfM based software, was employed for bundle block balancing and intensive image mapping. In this software, all operations are automatic, except for the measurement of the GCP coordinates. The UAV data processing workflow was as follows:

- Data entry into software (photographs, IMU and GPS data)
- GCP entry
- Camera optimization
- Intensive image processing
- Point cloud production and classification
- DSM and orthophoto production

4.4. Comparison of the point coordinates

The coordinates (X, Y and Z) of the 30 checkpoints determined in the study area were measured with the GNSS technique. These coordinates were accepted as the reference coordinates. In the accuracy analysis, the following square mean error equations were employed.

4.4.1. Accuracy assessment

The accuracy of all photogrammetric projects was evaluated using the surveyed points that had not been used for georeferencing (CPs), using the typical RMSE formulation (Agüera-Vega, Carvajal-Ramírez, and Martinez-Carricondo 2017; Tahar 2013). Within this scope, the CPs were identified in the orthoimages and their coordinates were compared to the surveyed GNSS coordinates, resulting in...
in the RMSE x, RMSE y and RMSE xy horizontal accuracy measures, as defined in the equations given below:

\[
RMSE_x = \frac{\sum_{i=1}^{n} (X_i - X_{\text{GNSS}})^2}{n} \quad (1)
\]

\[
RMSE_y = \frac{\sum_{i=1}^{n} (Y_i - Y_{\text{GNSS}})^2}{n} \quad (2)
\]

\[
RMSE_{xy} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - X_{\text{GNSS}})^2 + (Y_i - Y_{\text{GNSS}})^2}{n}} \quad (3)
\]

Where:

(a) \( n \) is the number of CPs tested for each project.
(b) \( X_i \) and \( Y_i \) are the x and y coordinates, respectively, measured in the orthoimage for the \( i^{th} \) CP.
(c) \( X_{\text{GNSS}} \) and \( Y_{\text{GNSS}} \) are the x and y coordinates, respectively, measured with GNSS for the \( i^{th} \) CP.

Furthermore, the height values were derived from the grid DSM for the x and y coordinates of the CP on the orthoimage and compared to the GNSS coordinate. As a result, an RMSE\(_z\) accuracy measure for the z direction, as defined in Equation (4) was produced.

\[
RMSE_z = \frac{\sum_{i=1}^{n} (Z_i - Z_{\text{GNSS}})^2}{n} \quad (4)
\]

Where:

(a) \( Z_i \) is the height in the \( i^{th} \) CP derived from the DSM, taking into account its coordinates X and Y, measured on the orthoimage.
(b) \( RMSE_{zxy} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - X_{\text{GNSS}})^2 + (Y_i - Y_{\text{GNSS}})^2}{n}} \) is the Z coordinate of the \( i^{th} \) CP measured with GNSS.

The planimetric differences obtained with the equations are presented in Table 5 Table 6 and Graphic 1.

5. Results and discussion
In classical photogrammetry, GCP must be distributed widely and uniformly throughout the whole block, particularly towards its periphery (Luhmann and Robson 2011; DeWitt and Wolf 2000). In UAV-SfM photogrammetry where non metric cameras are used, the best option is to try to distribute the GCP evenly or homogeneously in the periphery but also in the center of the area (Shahbazi et al. 2015; Harwin, Lucieer, and Osborn 2015; Martinez-Carricondo et al. 2018).
Table 5. Results of the effect of GCP number and distribution on RMSE xy.

| GCP Numbers | 4   | 8   | 12  | 16  | 20  | 24  | 28  | 30  | 30+2 | 30+4 | 30+5 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|
| EDGE Distribution RMSE xy (m) | 0.073 | 0.062 | 0.057 | 0.049 | 0.046 | 0.044 | 0.043 | 0.043 | 0.039 | 0.035 | 0.033 |
| Central Distribution RMSE xy (m) | 0.161 | 0.147 | 0.126 | 0.114 | 0.099 | 0.077 | 0.074 | 0.074 | 0.072 | 0.070 | 0.069 |
| HOMOGENEOUS Distribution RMSE xy (m) | 0.089 | 0.077 | 0.070 | 0.059 | 0.055 | 0.053 | 0.052 | 0.052 | 0.051 | 0.050 | 0.050 |

Table 6. Altimetric mean square error values according to GCP number.

| GCP Numbers | 4   | 8   | 12  | 16  | 20  | 24  | 28  | 30  | 30+2 | 30+4 | 30+5 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|
| EDGE Distribution RMSE z (m) | 0.085 | 0.078 | 0.075 | 0.071 | 0.067 | 0.064 | 0.061 | 0.061 | 0.056 | 0.053 | 0.052 |
| Central Distribution RMSE z (m) | 0.264 | 0.241 | 0.220 | 0.208 | 0.183 | 0.169 | 0.156 | 0.155 | 0.142 | 0.139 | 0.137 |
| HOMOGENEOUS Distribution RMSE z (m) | 0.094 | 0.082 | 0.067 | 0.058 | 0.054 | 0.052 | 0.050 | 0.050 | 0.049 | 0.048 | 0.048 |

**Graphic 1.** Graphical representation of the results of the effect of GCP number and distribution on RMSE xy, which is represented by the horizontal line.

**Graphic 2.** Graphical representation of the results of the effect of GCP number and distribution on RMSE z, which is represented by the horizontal line.

The review of Table 5 demonstrated that the highest RMSE values were obtained in the 4 GCP area, while the lowest values were determined for 35 GCPs. The RMSE xy values varied between 0.073 and 0.033 m in the edge distribution, between 0.161 and 0.069 m in the central distribution, and between 0.089 and 0.050 m in homogeneous distribution. Based on these values plotted in Graphics 1–2, it can be said that the number and distribution of the GCPs had a significant impact on the accuracy of the DSMs and orthophotos obtained in the UAV-photogrammetric projects. To observe the orthophoto and DSM planimetric changes, five GCPs in the central distribution were employed in addition to the ones placed on the edge. As can be seen from Graphic 1, the error rate became stationary when 28 and 30 GCPs were used. The error rate was reduced when 2, 4 and 5 GCPs were added to the center of the study area. The data analysis conducted to test the planimetric change in the edge distribution
revealed that the best planimetric accuracy was obtained with the support of the edge distribution by the 1/6th of the GCPs (five GCPs) in the center distribution.

The worst planimetric accuracy was observed in the central distribution. The error rate, which became stationary between GCPs 28 and 30, was reduced with five GCPs in the edge distribution.

Likewise, to observe the change in orthophoto and DSM altimetric accuracy, five GCPs in the central distribution were employed in addition to those on the edge. The review of Graphic 2 revealed that the error rate, which became stationary between GCPs 28 and 30, reduced with the use of GCPs in the central distribution. The analysis of the central distribution demonstrated that the worst altimetric accuracy was observed in this distribution. Thus, the error rate, which became stationary between GCPs 28 and 30, was reduced with five GCPs placed on the edge. In these three distributions, the best altimetric was obtained in the homogeneous distribution.

The review of both graphs demonstrated that the impact of edge distribution on planimetric and altimetric accuracy was very significant.

If we look at some studies in the literature that focus on the analysis of the effect of the number and distribution of GCPs on orthophotos and DSMs produced by UAV photogrammetry;

Tahar (2013) conducted a similar study on an area of 150 ha and reported that the planimetric accuracy was better than altimetric accuracy for any number and distribution of GCPs employed in the study. He also determined that when the number of GCPs was increased, both accuracy figures increased (planimetric accuracy from 0.49 to 0.46 m and altimetric accuracy from 0.830 to 0.780 m).

Carvajal-Ramírez, Agúeria-Vega, and Martínez-Carricondo (2016) employed three GCPs in their study conducted on a landslide area of approximately 1 ha. They distributed all the GCPs on the edges and concluded that the three GCPs should be placed along the edges to minimize both planimetric and altimetric errors. They obtained a planimetric accuracy of 0.047 m and a altimetric accuracy of 0.100 m.

In their study, Resheteyuk and Mårtensson (2016) investigated the effect of different GCP variations in an area of 2.73 ha on the accuracy of the UAV photogrammetry products. In the study, five GCPs were evenly distributed over the entire area. Flights were made at two altitudes of 81 m and 163 m. The RMSE T values for these flights were 0.030 m and 0.080 m, respectively. In conclusion they recommended 1.8 GCPs per ha to achieve this accuracy.

In their study, Carricondo et al. (2018) suggested 0.5 to 1 GCP per ha for minimum altimetric accuracy.

Ablanedo et al. (2018) suggested that more than three GCPs should be used per 100 photos when high accuracy is desired in large projects.

The implementation of the GCP figures suggested in previous studies for the present project revealed that for 2590 ha (3581 photos),

\[
2590 \times 1.8 = 4645.8 \text{GCPs}
\]

\[
2590 \times 1 = 2581 \text{GCPs}
\]

\[
(3581 \times 3)/100 = 107.43 \text{GCPs would be required.}
\]

UAVs are used in mapping to shorten the time spent on land surveys and to save costs. If the number of GCPs proposed in previous studies were employed in the present project, that would deviate from the purpose of using UAVs in mapping.

In the present study, GCP distribution was conducted accurately and with a small number of GCPs, and similar and accurate results were obtained when compared to other similar studies.

6. Conclusions

When conducting photogrammetric studies with UAVs, one of the most time-consuming and restrictive tasks in the fieldwork is the positioning of GCPs. Knowledge regarding the placement of the GCPs prior to the study and the magnitude of the possible errors can contribute to the project.

It is obvious that a comprehensive investigation regarding GCP locations is required to maximize the accuracy in UAV photogrammetry studies. This study determined that to achieve optimum planimetric accuracy, GCPs should be placed on the edges of the study area. However, this may not lead to optimum altimetric accuracy. Thus, it is necessary to reinforce the GCPs by placing some the center of the study area, thus, minimizing the total error.

It could be concluded that both the number and distribution of GCPs have a significant impact on the accuracy of DSMs and the orthophotos produced in UAV-photogrammetric studies.

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