TURKGEO TURKISH JOURNAL OF GEOSCIENCES

ISSN: *2717-7696*
Research Article
Vol; 5, Issue; 1, pp. 1-11, 2025
DOI: *10.48053/turkgeo.1517771*
Journal homepage:
https://dergipark.org.tr/en/pub/turkgeo

Accuracy Investigation on Orthophotos Produced from Digital Aerial Imagery Recorded from Different Altitudes

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Keywords
Accuracy
Digital air photographs
GSD
Orthophoto map

ABSTRACT

A digital orthophoto is a topographic image that has a fixed scale like a map and on which values such as coordinates and lengths can be read, which is obtained by eliminating the errors caused by tilts and rotations in aerial images and minimizing the point shifts caused by height differences in the terrain. Digital orthophotos offer more flexible, cost-effective, and higher-quality outputs than classical methods. There is no decrease in the quality of the image as in the analog technique, and it can also be presented quickly and easily in the digital environment. The geometrical accuracy of orthophoto maps used in geomatics applications is of even greater importance. This study compared the orthophoto maps, that have a fixed scale like maps, obtained from digital aerial photographs at a GSD of 7, 15 and 25 cm in 2011 in the campus area of Aksaray University, in terms of their positional accuracy. Orthophoto mosaic images were created using “Erdas LPS” software. When the accuracy is compared, it was found that digital orthophoto maps produced at three different GSDs gave us similar results for standard techniques. It was also concluded that the positional accuracy of orthophoto maps for all three GSDs is suitable for use as a reference and basis in application areas where very high accuracy is not required, such as 3D modeling studies, highway projects, archaeological documentation, disaster management, cadastral studies, and determination of forest areas.

1. INTRODUCTION

Photogrammetry is a map production technique or science applied with measurements made on images taken from the ground with ground cameras or, more commonly used, images taken from the air with cameras placed on aircraft. The most commonly used sources in the production of data and current maps by photogrammetric method are aerial images and satellite images. However, due to various reasons, fully vertical images (aerial and satellite images) cannot be taken from airplanes and satellite systems, and the images taken have a certain degree of obliquity and rotation with the axes of the land coordinate system (X, Y, Z). In addition, due to the fact that the terrain is not perfectly flat, has various height differences, and is not perfectly parallel to the horizontal plane, the scale changes at every point of the aerial and satellite images taken, and the raw image data obtained cannot be used directly as a map (Özbalmumcu, 2007; Polido Mantas et al., 2023). The recent surge in the utilisation of photogrammetry can be attributed to the concurrent advancement of both the hardware and software for unmanned aerial vehicles (UAVs). Through the application of photogrammetry, aerial images can be captured and valuable insights can be derived from the vast quantities of data generated. Thus enabling the measurement of changes in terrain and properties over time (Rábago and Portuguez-Castro, 2023). An orthophoto is a topographic image that has a fixed scale like a map and on which values such as coordinates and lengths can be read, which is obtained by eliminating the errors caused by tilts and rotations in aerial images and minimizing the point shifts caused by height differences in the terrain (Rossi, 2004; Nikolakopoulos et al., 2023; Dev et al.,2023). Digital orthophotos are more flexible, cheaper, and provide high-quality outputs than conventional methods. There is no decrease in the quality of the image as in the analog technique, and it can also be presented quickly and easily in the

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Received: 17/07/2024; Accepted: 08/10/2024

Cite this article

Yaman, A., & Yılmaz, H.M. (2025). Accuracy Investigation on Orthophotos Produced from Digital Aerial Imagery Recorded from Different Altitudes. Turkish Journal of Geosciences 5(1), 1-11.

digital environment (Akdeniz, 2004; Zhang et al., 2023). Orthophotos with information such as map edge information, grids, elevation curves, and place names are called orthophoto maps, and the image on a single base formed by combining many orthophotos is called an orthophoto mosaic. Today, the need for up-to-date maps is increasing in every field, and orthophoto maps, which have the accuracy and precision criteria of a standard map are preferred in many application areas.

The accuracy of the orthophotos produced in the studies is very important, and there are regulations on this subject in both Turkey and European countries. In Turkey, production standards for digital photogrammetric and orthophoto map production are determined in Articles 51- 73 of LSMIPR (Large Scale Map and Map Information Production Regulation). In the directive "Accuracy Standards for Digital Geospatial Data, March 2014," put into effect by ASPRS (American Society for Photogrammetry and Remote Sensing), the location (x, y) and elevation (z) accuracies of digital orthophoto images are classified according to the method and accuracy values in obtaining these data (Yıldız et al., 2015; ASPRS, 2014).

In literature, Daramola et al., (2017) tested the geometric accuracy of digital aerial images obtained with an unmanned aerial vehicle in their study titled "Assessing the geometric accuracy of UAV-based orthophotos". They took 669 aerial photographs at a flight altitude of 100 meters and a ground sampling distance of 3.2 cm. Then, they produced a digital elevation model and orthophotos of the study area in ArcMap software. As a result, horizontal accuracy was found to be 3.207 m and vertical accuracy was found to be 0.884 m. Jacobsen (2011), in his study named "Geometric property of large format digital camera DMC II 140", performed test flights with 71 control points at three different ground sampling distance of 5.7 cm, 9.5 cm and 20.2 cm to analyze the accuracy of the DMC II 140 digital aerial camera. As a result, the root mean square error value was found as 0.14 μm (0.020 pixels) for 5.7 cm ground sample distance (GSD) block, 0.17 μm (0.024 pixels) for 9.5 cm GSD block and 0.25 μm (0.035 pixels) for 20.2 cm GSD block. Karasaka et al., (2017), in their study titled "Geometric analysis of digital aerial images", in order to investigate the geometric accuracies of DMC-II 250-d and Vexcel Ultracam X digital aerial cameras, they performed flights at 10 cm and 30 cm ground sampling distances in Bursa Province and used the "Match-At" software in the evaluation of the images. As a result of the balancing process for ground control points (GCPs) and check points in each block, mean square errors were calculated and for the block with 30 cm ground sampling distance, mean square errors of GCPs were found to be below 1.0 pixels in horizontal and vertical directions, mean square errors of check points were found to be below 1.0 pixels in horizontal and vertical directions. For 10 cm GSD, mean square errors of GCPs were found to be below 1.0 pixels in horizontal and vertical directions, mean square errors of check points were found to be below 1.0 pixels in horizontal and vertical directions. The results were found to be suitable for ASPRS standards and national standards in Turkey. As a result, it was concluded that 1/5000 scale digital topographic maps can be produced using digital aerial images with a ground sampling distance of 30 cm, and 1/1000 scale digital topographic maps can be produced using digital aerial images with a ground sampling distance of 10 cm. Madani et al. (2004) investigated the geometric accuracy of the DMC aerial camera in their study. In the study, aerial images taken with the Z/I Imaging aerial camera at a scale of 1/13000 and a flight altitude of 1500 m are given as an example. In this case, a pixel size of 12 μm corresponds to a ground sampling distance of approximately 13 cm. The accuracy of the control points was found to be approximately 0.065 m horizontally and 0.010 meters vertically. When the geometry of the camera is examined, it is seen that the results can meet very high accuracy demands and can even be used in Class I studies in ASPRS standards. Spreckels et al. (2005) used a Vexcel UltraCamD digital aerial camera to capture aerial images of a coal mine in Germany. 45 GCPs were used in the study. East-west flights were performed at a scale of 1/5000 and a ground sampling distance of 10 cm, and cross flights were performed at a ground sampling distance of 8 cm. 130 aerial images were obtained for 10 cm GSD and 77 aerial images were obtained for 8 cm GSD. As a result, the root mean square errors for GCPs were found to be 2.15 cm in the x direction and 3.31 cm in the y direction. Vega et al. (2017) investigated the effects of the number of GCPs on the accuracy of orthophotos obtained with an unmanned aerial vehicle. For this purpose, 160 digital aerial images were taken at a flight altitude of 120 meters in an area of 17.64 hectares. An eight-rotor unmanned aerial vehicle and a Nikon D-3100 digital aerial camera were used in image acquisition and the flight was carried out at a ground sampling distance of 3,291 cm. Then, 9 different GCPs were combined in different ways and orthophotos were produced in the "Agisoft PhotoScan" software. As a result, when looking at the 1990 ASPRS map standards, it was seen that maps at a scale of 1/150 and a contour interval of 15 cm could be used in engineering projects for 15 GCPs and a flight altitude of 120 meters. In his study, Yıldız et al., (2015) investigated which GIS product could be used as a base for the ground sampling distances required for the use of digital orthophoto products as a base for geographic information systems, and in this context, orthophoto productions corresponding to ground sampling distances of 10 cm, 30 cm and 50 cm were carried out in the selected test area. As a result of the applications, it was seen that productions with 10 cm ground sampling distances could be used in applications where 1/1000 scale digital orthophotos would be used as a base, productions with 20 cm ground sampling distances could be used in applications where 1/2000 scale digital orthophotos would be used as a base, and productions with 50 cm ground sampling distances could be used in applications where 1/5000 - 1/10000 scale digital orthophotos would be used as a base. In addition, in his study, he compared the accuracy of the digital terrain model with the values deemed appropriate in the EuroSDR (formerly OEEPE) directive, based on the differences between the coordinates of the control points calculated from the digital terrain model data and the real terrain coordinates, and found that the results he found were lower than these values.

This study aims to eliminate the existing geometric errors in digital aerial images with different ground sampling distances and to compare their accuracy by obtaining orthophoto mosaic images on which values such as length, angle, and area of the terrain can be measured directly and which have a fixed scale everywhere like a map. For this purpose, orthophoto mosaic images were obtained using the "Erdas LPS" software, and the location accuracy was investigated by comparing the produced maps with each other and the detail points with the points measured by GPS in the field.

1.1. Factors Ffecting the Accuracy and Quality of Digital Orthophotos

The most important factors affecting the accuracy of digital orthophotos are the scale of the input and output images, the accuracy of internal and external orientation, the distribution and accuracy of GCPs (GCPs), the accuracy of the mathematical model, the accuracy of image matching and the accuracy of the digital elevation model (Ayhan et al., 2007). Factors affecting the accuracy of orthophoto can be listed as follows:

- The quality and focal length of the camera used,
- Enlargement from photo to the scale of the final product,
- The density ratio of dispositive or the quality of the bits in the scanner pixel,
- Scanner's raw data scanning quality and geometric accuracy,
- The quality of scan samples expressed in micron or photo-scale dpi,
- Marking and coordinating the accuracy of GCPs,
- Differential verticalization methods,
- The size of the resulting pixels expressed in terrain units,
- Automatic radiometric correction after differential verticalization,
- Selection of control points,
- Variance in terrain or building that depends on camera focal length,
- The density and quality of digital elevation model data (Ayhan et al., 2007; Yılmaz, 2002).

Accuracy is an important factor in digital orthophotos. Digital orthophotos are valued to the extent that they are produced with a known accuracy. Generally, the relative accuracy of digital orthophotos depends entirely on the scale of the image. In contrast, the absolute accuracy depends largely on the quality of the GCPs, the accuracy of the digital elevation model to be used for downscaling, and the scale of the photograph (Şahin, 2013).

1.2. The Role of GCPs

GCPs are used to calculate the orientation of the sensor position at the time of image acquisition. Standard photogrammetric algorithms such as space back estimation or beam compensation are used in the calculation. The position of the sensor system is expressed in terms of six parameters: X, Y, Z, ω, φ, Ķ. These parameters are used to find the exact location of each pixel of the digital image on the ground surface (Seo et al., 2024; Pathak et al.,2024).

Another important issue is the distribution of GCPs in the image and the number of additional GCPs required for compensation. The GCPs required for orthophoto are usually obtained from ground measurements to reduce the error in orthophoto pixel positions.

Orthophoto image generation uses space back estimation to determine the correspondence between object space and image space. Therefore, the accuracy of GCPs is important for orthophoto accuracy. The absolute accuracy of the orthophoto also depends on the quality of the GCPs (Şahin, 2013).

1.3. Accuracy Criteria in Digital Orthophotos

Production standards for digital photogrammetric and orthophoto map production are determined in Articles 51- 73 of the current LSMIPR (Large Scale Map and Map Information Production Regulation).

Article 54 of the regulation, which entered into force on April 30, 2018, states that depending on the scale of the map and orthophoto to be produced, the ground sampling distance cannot be more than 30 cm if the scale is 1/5000, 20 cm if it is 1/2000, 10 cm if it is 1/1000, and 5 cm if it is 1/500.

Again, as a result of block balancing, the squared average errors of the control points should be less than ±0.75 × GSD (inclusive) in X and Y coordinates and ±1× GSD (inclusive) in Z coordinates for the map or orthophoto scale to be produced in terms of the ground sampling distance specified in Article 54 of the same regulation. Maximum differences at inspection points should be less than ±1.5 × GSD (inclusive) in X and Y coordinates and less than ±2 × GSD (inclusive) in Z coordinates.

In the European Union countries, the accuracy of the digital terrain model is obtained based on the inspection points. In the "Assessment of the Quality of Digital Terrain Models" published by EuroSDR (European Spatial Data Research), the accuracy of the digital terrain model is determined according to the following formula (Yıldız et al., 2015; Kapnias et al., 2008);

$\sigma x,y = 0.75 \times GSD$ $\sigma z = 0.53 \times GSD$

The σx,y, and σz values calculated from the differences between the coordinates of the control points calculated from the digital terrain model data and the actual terrain coordinates should not exceed the values found in the formula published by EuroSDR (Yıldız et al., 2015; Wolf, 1974).

EuroSDR (formerly OEEPE) is an organization established in Paris in 1953 as OEEPE in accordance with an international agreement pursuant to a proposal adopted by the Council of the Organization for Economic Cooperation in Europe. Founded in 1953, OEEPE (European Experimental Photogrammetry Research Association, Organisation Europeenne d'Etudes Photogrammetriques Experimentales) became an official member of Turkey in 1990, and the representation authority was given to the General Command of Mapping. In June 2003, with a new agreement signed in June 2003, the name of the OEEPE organization was changed to EuroSDR, which was accompanied by some technological developments.

In the directive "Accuracy Standards for Digital Geospatial Data, March 2014," put into effect by ASPRS (American Society for Photogrammetry and Remote Sensing), the location (x, y) and elevation (z) accuracies of digital orthophoto images are classified according to the method and accuracy values of obtaining these data (Yıldız et al., 2015; ASPRS, 2014).

Engineering survey-based services that require very high accuracy are grouped as Class-I, high-accuracy map-making activities (large-scale map production) as Class-II, and lower-accuracy map-making activities as Class-III. According to this grouping, the horizontal accuracy standards for digital orthophotos are presented in Table 1 (Yıldız et al., 2015).

Table 1. Horizontal accuracy standards for digital orthophotos (ASPRS,2014)

Horizontal Accuracy Data Generation Class	**Photogrammeric triangulation M.S.E. (x), M.S.E. (y)**	**Orthophoto Image Accuracy**	**GCPs M.S.E. (x), M.S.E. (y), M.S.E. (z)**
Class-I	Pixel × 1.0	Pixel × 2.0	Pixel × 0.5
Class -II	Pixel × 2.0	Pixel × 4.0	Pixel × 1.0
Class -III	Pixel × 3.0	Pixel × 6.0	Pixel × 1.5
…	…	…	…
Class -N	Pixel × N	Pixel × 2N	Pixel × 0.5N

According to Table 1, for example, in order to produce orthophotos with an accuracy of 10 cm, the point accuracies obtained at the end of photogrammetric triangulation balancing should be 5 cm or less, and the geodetic accuracies of the GCPs installed on the land for photogrammetric triangulation should be 2.5 cm or less (Yıldız et al., 2015).

Similarly, in the production of digital orthophotos by ASPRS, the correlations given in Table 2 can be calculated between location (x,y) accuracies and map scales.

Table 2. The relationship between location (x,y) accuracies and map scales in digital orthophoto production

Horizontal Accuracy Data Generation Class	**Photogrammetric triangulation M.S.E. (x), M.S.E. (y) (cm)**	**GCPs M.S.E.(x), M.S.E.(y), M.S.E. (z) (cm)**
Class -I	0.0125 × map scale	0.00625 × map scale
Class -II	0.0250 × map scale	0.01250 × map scale
Class -III	0.0375 × map scale	0.01875 × map scale
…	…	…
Class -N	N × 0.0125 × map scale	N × 0.00625 × map scale

According to Table 2, in Class-I services, it is recommended that the squared mean errors of geodetic GCPs should be less than ± 6.25 cm for 1/1000 scale studies, and the squared mean errors to be obtained at the end of photogrammetric triangulation measurements and balancing with the help of these points should be less than ± 12.5 cm (Yıldız et al., 2015).

In addition, according to international standards in large-scale map production studies, it is recommended that a-priori standard deviations (default data set) during photogrammetric triangulation balancing for photogrammetric blocks;

For GCPs;

$\sigma x,y = 0.03$ m $\sigma z = 0.05$ m

For automatically measured connecting points,

$\sigma 1 = 0.002$ mm

For manually measured connecting and GCPs,

$\sigma 1 = 0.002$ mm

Direct ground referencing system;

For GNSS values; $\sigma x, y,z = 0.10$ m

For INS values; $\sigma\omega, \varphi$, Ꝁ $= 0^{o}.010$.

It is recommended that all of these meet the criteria (Yıldız et al., 2015).

2. METHOD

The orthorectification process requires digital aerial or satellite imagery of the study area, internal orientation parameters, external orientation elements for each image, and a sufficient number of GCPs and coordinates appropriately distributed throughout the study area.

Aksaray University campus area was selected as the study region (Figure 1).

Figure 1. Study area: Aksaray University campus area

In practice, the following GSD values were used, taking into account factors affecting the map scale, such as the scale of analog aerial photographs and scanning density.

- - 7 cm GCPs

for 1/1000 Map Production Scale (Flight Alt.; Ground Alt. +700m),

- 15 cm GSD for 1/2000 Map Production Scale (Flight Alt.; Ground Alt. +1500m),
- 25 cm GSD for 1/5000 Map Production Scale (Flight Alt.; Ground Alt. +2500m).

Flight planning was made to produce aerial images with 7, 15, and 25 cm GSD resolution, and values such as flight columns and flight heights were determined (Cankurt, 2016). In the flight planning for 7 cm ground sampling distance, 106 digital aerial images of the study area were obtained with a longitudinal overlap rate of 70% and a transverse overlap rate of 30%. In the flight planning for 15 cm ground sampling distance, 38 aerial images of the study area were obtained with a 70% longitudinal and 30% transverse overlap ratio. In the flight planning for a 25 cm ground sampling distance, 40 aerial images of the study area were obtained with 70% longitudinal and 30% transverse overlap ratio. Some of the digital aerial images taken at 7 cm ground sampling distance are given in Figure 2.

Figure 2. Examples of digital aerial images taken at 7 cm ground sampling distance

The flight plan for the 7 cm ground sampling distance is presented in Figure 3.

Figure 3. Flight planning for 7 cm ground sampling distance (Cankurt, 2016)

Flights for all three ground sampling distances are presented in Figure 4.

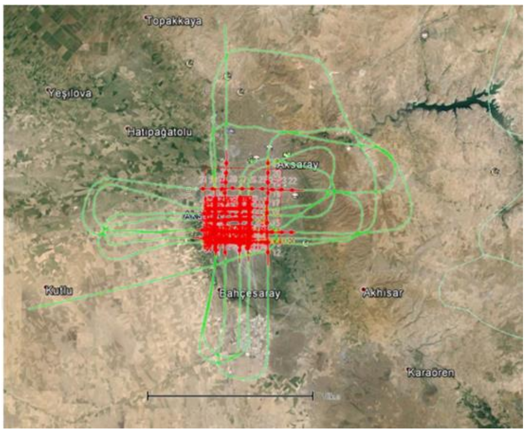

Figure 4. Flights for all three ground sampling distances (Cankurt, 2016)

In this study, it was aimed to create an orthophoto mosaic image of Aksaray University campus by using digital aerial images taken at 7 cm, 15 cm, and 25 cm ground sampling distances in 2011 and to compare the location accuracies.

The digital aerial camera Intergraph DMC was used in the study, and the calibration report is available. The internal orientation parameters were taken from there. The external orientation parameters were obtained directly from GPS/IMU during the flight.

GCPs are points that are installed on the ground so that they can be seen from aerial photographs in the study area to be flown. Since these points establish the relationship between the image coordinate system and the ground coordinate system in the rectification of images in photogrammetry and remote sensing, the accuracy and distribution of GCPs directly affect the position accuracy of the orthophotograph. In this study, 32

GCPs were installed in the study area, four Topcon GR3 GNSS receivers were used for kinematic GNSS measurements, and fixed reference points were used to determine their coordinates. The mobile kinematic measurements were performed with a Novatell OEM V2 model GNSS receiver on the UAV from which the aerial images were taken. The distribution of GCPs in the study area is shown in Figure 5.

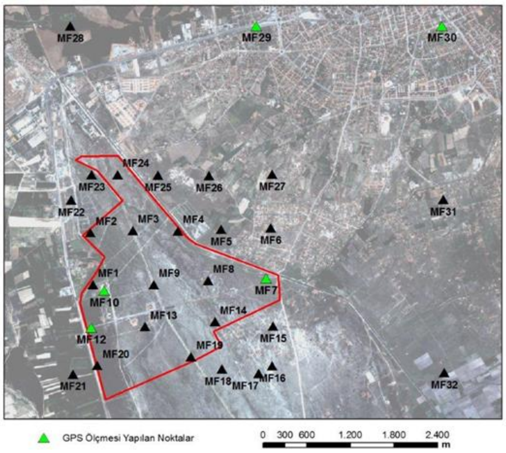

Figure 5. Distribution of GCPs within the study area

Aerial photographs were taken with 70% longitudinal and 30% transverse overlap. In the study, 32 GCPs and 24 checkpoints were used. The study aimed to produce three different orthophoto mosaics in the "Erdas LPS (2013)" software using digital aerial images taken at 7cm, 15cm, and 25 cm ground sampling distances. In the software, internal and external orientation operations were performed by adding aerial photographs. Then, the coordinate values of the GCPs installed in the field were recorded in the software, and tie points were generated. After the coordinates of the GCPs were recorded, the point distributions on the images are shown in Figure 6.

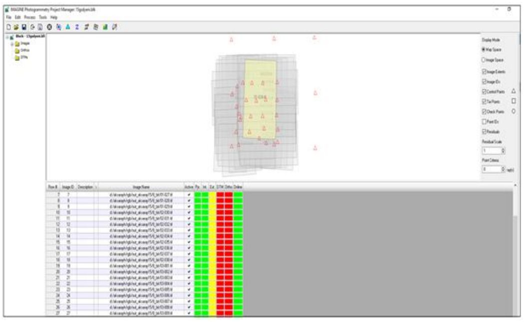

Figure 6. Distribution of GCPs on the images

All GCPs were then precisely marked on the images by opening the digital images containing each point one by one, as shown in Figure 7.

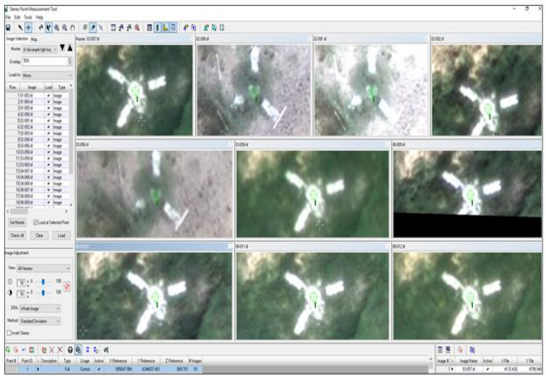

Figure 7. Marking of GCPs on aerial photographs

After this process, digital terrain model production, orthophoto production, and orthophoto mosaic production continued by balancing. The orthophoto mosaic image obtained from the study using digital aerial photographs taken with 7 cm GSD is given in Figure 8, the orthophoto mosaic image produced with digital aerial photographs taken with 15 cm GSD is given in Figure 9, and the orthophoto mosaic image obtained from digital aerial photographs taken with 25 cm GSD is given in Figure 10.

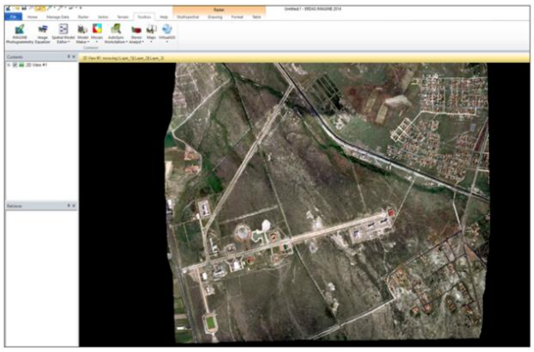

Figure 8. Orthophoto mosaic image produced using digital aerial photographs taken with 7 cm GSD

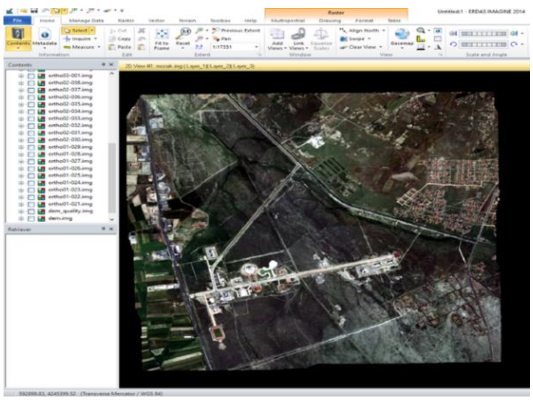

Figure 9. Orthophoto mosaic image produced using digital aerial photographs taken with 15 cm GSD

Figure 10. Orthophoto mosaic image produced using digital aerial photographs taken with 25 cm GSD

After orthophotomosaic images were produced from digital aerial images at three different ground sampling distances, the coordinates of 30 detail points distributed throughout the campus area were measured by GPS, and their coordinates were recorded, as shown in Table 3.

Table 3. GPS-measured coordinates of 30 detail points identified in the study area.

Point Number	Y (m)	X (m)
1	587435.62	4244583.21
2	587446.71	4244538.07
3	587453.84	4244529.36
4	587485.68	4244537.21
5	586483.91	4244276.08
6	586492.34	4244243.59
7	586474.48	4244238.89
8	586466.11	4244271.38
9	586455.66	4244230.83
10	586436.31	4244225.80
11	586426.31	4244264.54
12	586445.61	4244269.46
13	585937.42	4244106.20
14	585953.90	4244045.10
15	586000.84	4244057.69
16	585871.08	4244130.22
17	585939.39	4244148.02
18	585959.86	4244153.48
19	586028.83	4244171.29
20	586032.05	4244117.26
21	586039.96	4244083.82
22	586061.75	4244141.84
23	586065.89	4244127.43
24	586014.06	4244053.64
25	585896.31	4244111.97
26	585983.11	4244159.10
27	585700.07	4244645.59
28	585646.72	4244669.86
29	585662.51	4244524.76
30	587397.45	4244522.77

The general distribution of the detail points in the campus region is shown in Figure 11, divided into A, B, C, and D regions.

Figure 11. Distribution of detail points across the campus area

3. RESULTS

The coordinates of 30 detail points were measured with GPS in the field and then compared with the coordinates read on each orthophoto mosaic, and their location accuracy was calculated.

In this study, first of all, in order to test the absolute (external) accuracy of the block balancing, 24 of the 32 GCPs within the photogrammetric blocks were selected as checkpoints, and the block absolute accuracies were checked for each orthophoto mosaic produced using digital aerial images taken at three different ground sampling distances.

First of all, the coordinates of the control points measured from the model produced with 7 cm GSD were compared with the coordinates calculated by the geodetic method, and the block absolute accuracy values were found as follows;

σx = 4.52 cm, σy = 9.73 cm and σz = 9.14 cm.

Then, the coordinates of the control points measured from the model produced with 15 cm GSD were compared with the coordinates calculated by the geodetic method, and the block absolute accuracy values were found as follows;

σx = 2.47 cm, σy = 7.25 cm and σz = 8.79 cm.

After this process, the coordinates of the control points measured from the model produced with a ground sampling distance of 25 cm were compared with the coordinates calculated by the geodetic method, and the block absolute accuracy values were found as follows;

σx = 6.41 cm, σy = 9.08 cm and σz = 9.06 cm.

The values found are within the accuracy criteria given by ASPRS.

After the block absolute accuracies were calculated for all three models, the mean squared errors of ω, φ, and Ķ values were calculated for each block in the IMU calculation. Accordingly, the orthophoto quadratic mean squared error values for 7 cm GSD are as follows;

σω = 00.0544, σφ = 00.0447 and σϏ = 00.0115.

Then, the orthophoto quadrature mean squared error values for 15 cm GSD were calculated in the IMU calculation, and the results were found as follows;

σω = 00.0479, σφ = 00.0523 and σϏ = 00.0128.

Then, the orthophoto mean squared error values for 25 cm GSD were calculated in the IMU calculation, and the results were found as follows;

σω = 00.0004, σφ = 00.0006 and σϏ = 00.0012.

The results were found to be close to or below the recommended values for IMU values in the direct ground referencing system within the a-priori standard deviations during photogrammetric triangulation balancing for photogrammetric blocks according to international standards in large-scale map production studies.

Another step in the study was to compare the coordinates of 30 detail points whose coordinates were read by GPS in the field with the coordinates read from the orthophoto mosaics obtained from the pictures taken at all three ground sampling distances and to calculate the (mp) position error for each of them.

The actual errors in the "Y" and "X" directions and the squared average errors obtained as a result of the comparison;

…are calculated from the formulas.

Here;

Yk, Xk: Classically determined point coordinates taken as reference,

Yg, Xg: Point coordinates determined by digital orthophoto,

Mx = squared mean squared error in the "x" direction,

My = squared mean squared error in the "y" direction,

Mp = position mean error and

n = Number of points (Mutluoğlu and Ceylan, 2005).

In the calculations, the position error for the orthophoto mosaic created at 7 cm GSD was found to be mp = 19.37 cm.

For the orthophoto mosaic created at 15 cm GSD, the position error was found to be mp = 19.43 cm.

For the orthophoto mosaic created at 25 cm GSD, the location error was found to be mp = 19.61 cm.

After these procedures were performed, the height (z) coordinates of the checkpoints, GCPs, and tie points on the digital terrain model produced with digital aerial photographs taken at 7 cm, 15 cm, and 25 cm ground sampling distances and the height coordinates taken from the digital terrain model. The differences between them were taken, and the squared average error was calculated. The results are as follows:

For 7 cm GSD, the squared mean error calculated from the difference between the height coordinate of the control points from the digital terrain model and the height coordinate in the field: σz = 16.58 cm,

For 7 cm GSD, the squared mean squared error of the GCPs calculated from the difference between the height coordinate from the digital terrain model and the height coordinate in the field: σz = 18.92 cm,

For 7 cm GSD, the squared mean error calculated from the difference between the height coordinate of the tie points from the digital terrain model and the height coordinate in the field: σz = 17.86 cm,

For 15 cm GSD, the squared mean squared error calculated from the difference between the height coordinate of the control points from the digital terrain model and the height coordinate in the field: σz = 11.80 cm,

For 15 cm GSD, the squared mean squared error of the GCPs calculated from the difference between the height coordinate from the digital terrain model and the height coordinate in the field: σz = 20.08 cm,

For 15 cm GSD, the squared mean squared error calculated from the difference between the height coordinate of the tie points from the digital terrain model and the height coordinate in the field: σz = 22.28 cm,

For 25 cm GSD, the squared mean squared error calculated from the difference between the height coordinate of the control points from the digital terrain model and the height coordinate in the field: σz = 23.25 cm,

For 25 cm GSD, the squared mean squared error of the GCPs calculated from the difference between the height coordinate from the digital terrain model and the height coordinate in the field: σz = 26.04 cm,

For 25 cm GSD, the squared mean squared error was calculated from the difference between the height coordinate of the tie points from the digital terrain model and the height coordinate in the field: σz = 45.67 cm.

4. CONCLUSIONS

Recently, with advances in technology, the demand for orthophoto maps has increased rapidly, considering the need for up-to-date maps, as well as speed and cost.

Orthophoto maps are highly preferred products due to the fact that they do not lose the details of the terrain, have the quality of photographs and maps, and can be easily read and interpreted by all professional groups.

In orthophoto maps, it is one of the important advantages of these products that aerial images with central projection are combined into a single image in the form of a single base with a vertical projection like a map and that values such as coordinates, distance, angle, and area can be read with sufficient accuracy on this image.

In this study, three different orthophoto mosaic images of Aksaray University campus region was produced using digital aerial images taken at 7 cm, 15 cm, and 25 cm ground sampling distances, and the location accuracy of these images was investigated. The results were compared with the values recommended in the guidelines put into effect by ASPRS (American Society for Photogrammetry and Remote Sensing).

In previous studies, Daramola et al. (2017) found the horizontal accuracy to be 3.207 m and the vertical accuracy to be 0.884 m for a flight altitude of 100 m and a GSD of 3.2 cm. Jacobsen (2011) conducted test flights with 71 GCPs at three different GSDs of 5.7 cm, 9.5 cm and 20.2 cm. As a result, the root mean square error value was found to be 0.14 µm (0.020 pixels) for the 5.7 cm GSD block, 0.17 µm (0.024 pixels) for the 9.5 cm GSD block and 0.25 µm (0.035 pixels) for the 20.2 cm GSD block. Karasaka et al., (2017) conducted flights at 10 cm and 30 cm GSDs in Bursa province and it was found that the root mean square errors of GCPs and control points for both GSDs were less than 1.0 pixels in horizontal and vertical directions. The results were found to be in accordance with ASPRS standards and national standards in Turkey. Madani et al. (2004) found the accuracy of the control points to be approximately 0.065 m horizontally and approximately 0.010 meters vertically for a GSD of 13 cm. Spreckels et al. (2005) conducted flights at 10 cm and 8 cm GSDs, and as a result, the root mean square errors for GCPs were found to be 2.15 cm in the x direction and 3.31 cm in the y direction. Vega et al. (2017), a flight was performed from a GSD of 3,291 cm, and as a result, when looking at the 1990 ASPRS map standards, it was seen that maps with a scale of 1/150 and a contour interval of 15 cm could be used in engineering projects for 15 GCP and a flight altitude of 120 meters. Yıldız et al. (2015) produced orthophotos corresponding to ground sampling distances of 10 cm, 30 cm and 50 cm, and stated that the results were lower than the values deemed appropriate in EuroSDR. The values found in the study are consistent with the results in the literature and it was observed that the block absolute accuracy values obtained from each orthophoto mosaic image, as well as the squared average errors obtained at the end of photogrammetric triangulation and block balancing of GCPs and the squared average errors obtained at the end of block balancing using the control point were found to be below the accuracy criteria given by ASPRS.

Again, the values found as a result of the squared mean squared error calculation for ω, φ, and Ꝁ values in the IMU calculation were found to be close to and below the values recommended for IMU values in the direct ground referencing system within the a-priori standard deviations during photogrammetric triangulation balancing for photogrammetric blocks according to international standards in large-scale map production studies.

In addition, the accuracy of the positional data obtained from each orthophoto mosaic image was analyzed, and positional data were obtained with a mean squared error of ±19.37 cm from orthophoto mosaic obtained from digital aerial images taken with 7 cm GSD, ±19.43 cm from orthophoto mosaic obtained from digital aerial images taken with 15 cm GSD, and ±19.61 cm from orthophoto mosaic obtained from digital aerial images taken with 25 cm GSD.

Considering the horizontal accuracy standards for digital orthophotos given in Table 1 and the orthophoto image accuracies found in the study, it is recommended that the point accuracies obtained at the end of photogrammetric triangulation should be 10 cm or less in order to produce orthophotos with an accuracy of 20 cm. This condition is met for all three orthophoto mosaic images.

Although the type of the study and the accuracy expected from the result vary in the studies, it is seen that the location accuracy obtained from orthophoto images produced with 7 cm, 15 cm, and 25 cm GSD is suitable for use except for studies requiring very high accuracy (Class-I) and these digital orthophotos can be used as a base.

In addition, if the location accuracies of orthophoto mosaic images obtained from digital aerial images taken at all three ground sampling distances are also compared, in some projects, ±1m accuracy is sufficient. The production and use of digital orthophotos in projects where the accuracy of meters and above is sufficient will provide more advantages to users (Mutluoğlu and Ceylan, 2005). The location accuracies of the digital orthophoto maps produced at 7, 15, and 25 cm ground sampling distances were below 20 cm. In projects where 20 cm and above accuracy is expected, these orthophoto maps can be used. This situation provides great convenience to users in terms of advantages, costs, and production speed.

Acknowledgement

This article is produced from Aydan YAMAN's Ph.D. thesis work.

Author Contributions

Aydan Yaman: Conceptualization, Data curation, Methodology, Software, Writing-Original draft preparation. **Hacı Murat Yımaz:** Supervision, Methodology, Reviewing and Editing

Conflicts of Interest

The authors declare no conflict of interest.

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