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Analyzing the Effectiveness of Photogrammetry Software in Calculating Aerial Triangulation and in Spatial Data Production from Drone Images

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Drone, Commercial software, Orthophoto, Aerial triangulation, Point cloud, Accuracy.

Abstract: Drones are used by surveyors as an alternative to traditional methods of obtaining orthophoto maps and large-scale topographical maps, but several factors affect the accuracy of its data, one of them is software used in image processing. Because there are many types of software, choosing one of them is a real problem in survey projects using drones. Processing software is divided into commercial and open-source software. Commercial software is a black box situation, which highlights the challenge of isolating accurate sources of errors and judging the accuracy of processing products. In this research, the capabilities of the commercial software Pix4Dmapper, Agisoft Metashape, and 3DF Zephyr Aerial were compared in calculating the aerial triangulation of the image blocks taken by drones, with a comparison of the capabilities of this software in getting the most important spatial products for surveyors from these images (Digital Elevation Model and Orthophoto). The results showed that Pix4Dmapper was able to perform aerial triangulation more accurately than Agisoft Metashape and 3DF Zephyr Aerial, with great convergence between the results of Agisoft Metashape and 3DF Zephyr A. The results also showed that 3DF Zephyr Aerial had extracted the densest point cloud. Another finding is that Pix4Dmapper produced the most accurate orthophoto and took the shortest processing time, and that the Agisoft Metashape interface is more flexible and user-friendly than the rest of the tested software.

1. Introduction

Drones equipped with high-resolution cameras are a source of accurate data suitable for many photogrammetry tasks [1]. They have been used as an alternative solution to traditional survey methods in obtaining image maps and large-scale topographic maps in the fields of regional

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planning, real estate applications, monitoring slums, and creation of Digital Surface Models (DSM) [2] as well as in the mining industry for exploration, site safety management, monitoring and inspection, automated surveying, mapping, and stockpile management. For surveyors, the Digital Terrain Model (DEM) and orthophoto are the most important spatial products for using drones. DEM is used to cut out contour lines and Orthophoto is an image that is free from distortions resulting from camera inclination, lens distortions as well as relief displacement in the imaged scene. Thus, it can be used as an accurate image map [3] or as a base map to digitize the topographical features. The main input for the calculation of the DEM is the 3D point cloud resulting from image processing, while the data needed to produce the orthophoto are a vertical or near vertical aerial image and the parameters of the interior orientation and exterior orientation of the camera that took this image (camera position and orientation) and a Digital Terrain Model (DTM) (or DEM) of the area.

When using drones, the position and orientation of the camera is determined using the onboard Inertial Measurement Unit (IMU) and Global Positioning System (GPS). These parameters (images positions and orientations) are stored as EXIF metadata in the images. This data is later used in the image align process by applying what is known as Aerial triangulation (AT) [4]. When drones are used to get DEM and orthophoto, the procedures applied are very similar to those applied in traditional aerial photography in terms of flight planning, ground control work, image processing, and evaluation of the accuracy of aerial triangulation. Accordingly, many factors affect the spatial accuracy of drone images (dense point clouds, digital surface model, and orthophoto), including Factors affecting flight planning that help to get the desired accuracy [5], digital sensors used in image acquisition [6], control data used in calculating image blocks, and the software used in processing images and getting spatial products from them [7]. Due to a large number of these types of software, choosing one of them poses a real struggle in drone surveying projects. These software are based on the use of Structure from Motion (SfM) algorithms, which differ from traditional photogrammetry in that they automatically calculate the scene geometry, locations, and camera orientation. Here, the 3D coordinates of the points are determined synchronously by applying the iterative beam method which uses machine-truncated features from the set of highly overlapping images (up to 80%) [8].

SfM software are divided into two basic types: Commercial software and open-source software (OSS). Commercial SfM software has a relatively simple, standard workflow. However, they resemble a black box, i.e. users are not allowed to see what is going on inside them [9]. On the other hand, open-source SfM software has a generally complex workflow with the ability of the user to see their internal processes [10]. The black-box nature of commercial SfM packages highlights the challenge of isolating most sources of errors and judging the accuracy of processing products [11]. In these software, users find it difficult to determine the optimal settings due to the lack of comparative studies evaluating such software consistently [12].

In previous studies, comparisons between several commercial SfM software had been made. In reference [13], it was concluded that Smart3DCapture is the best when there is a large vertical movement during image capture and when the overlap between the images is little, while the researchers found that Pix4Dmapper is the most accurate when image overlap ratios are large with little vertical movement during image capture. In [14] a comparison between

Pix4Dmapper, PhotoScan, and Smart3Dcapture (in terms of accuracy with a focus on the effect of the number of control points and the pattern of their distribution on the results of the analysis) had been achieved. In [15], the researchers processed the images using Erdas-LPS, EyeDEA, PhotoScan, Pix4UAV, and PhotoModeler Scanner to evaluate their characteristics, capabilities, and weaknesses. The results showed that PhotoScan was the most reliable in terms of the accuracy of aerial triangulation, DSM, and Orthophoto. In addition to the above, the geometric accuracy of the DSM calculated by applying different scenarios of numbers of images and control points was compared in [16] using PhotoScan and MicMac developed at the French IGN National Geographic Institute, where in this research, both software gave satisfactory results, noting that PhotoScan provided better results (minor distortions in the DSM and better reconstruction). The results of this research also confirmed PhotoScan was more user-friendly and that MicMac was good for experimental users because of its flexibility. In this research, the accuracy of Aerial Triangulation AT was analyzed in some commercial photogrammetry software based on SfM algorithms in calculating image blocks captured by drones and in obtaining suitable spatial data for surveyors from them and analyzing their accuracy.

2. The importance and objectives of the research

The importance of the research comes in its emphasis on the importance of the computational capabilities of the processing software used in processing images captured by drones, the nature of spatial products, and their evaluation mechanisms at other factors include:

- Factors affecting the imaging planning process, which ensure the required accuracy.
- The nature of the digital sensors used in image cropping.
- The nature of the control data used in calculating the images.

This research aims to compare the capabilities of a group of commercial SfM software in calculating the aerial triangulation of the image blocks captured by drones. Besides, it aims to compare the capabilities of these software in getting the most important spatial products for surveyors from these images (DEM and orthophoto). The tested software was Pix4Dmapper, Agisoft Metashape, and 3DF Zephyr Aerial. The reason for choosing these software, in particular, is that they are the most popular commercial software today. The results of this comparison provide some useful guidance for surveyors who are not specialized in photogrammetry and who have started using drones in surveying work.

3. Methods and tools

3.1. Software tested in this research.

All SfM algorithms available in Drone-based photogrammetric software have compatible feature extraction in overlapping images and then connect them using feature matching. Thus, calculating the 3D location of each of them in the element coordinates by measuring the control points by applying aerial triangulation (AT). Besides, there are tools in the current software solutions that provide access to spatial data such as dense point clouds, digital surface models (DSMs), vertically referenced photos (orthophoto), grid models, real image models, texture models, and others [17]. These software differ from each other, as some have more options than others in terms of output formats, processing options, and the ease or difficulty of the software user interface. On the other hand, these software differ in terms of the flexibility of importing control points and measuring them, providing drawing capabilities on the resulting clouds to generate 3D models in vector format, as well as cloud editing tools and the contents of processing reports [13]. However, despite the existence of these differences, all these software have a common workflow that can be generalized to all SfM software dedicated to processing images captured by drones, as shown in Figure 1 [18].

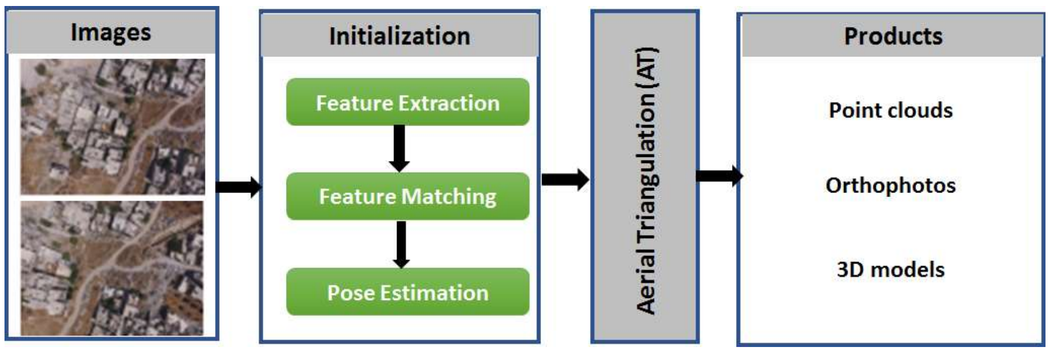

Fig. 1: General Workflow of SFM software.

3.1.1 Agisoft Metashape Software

This software was developed by the Russian company Agisoft LLC [19]. Its workflow starts with adding images and then performing Alignment, i.e. the approximate location and orientation of each image is determined, and tie-points are deducted in the form of a sparse point cloud by applying the SfM algorithms available in the software. Then the control points are measured on the images and then the dense point cloud and the 3D mesh model (representing the DSM) are generated and finally, the orthophoto is generated.

3.1.2 Pix4Dmapper

It is a Swiss software that was developed at the Federal Polytechnic School in Lausanne starting in 2011 [20]. Work begins in the software by adding images and then selecting the desired processing template. We then move on to Initial Processing, in which the SfM algorithms available in the software are applied to calculate image locations and their initial orientations using tie points. Then we move on to the stage of measuring the control points on the images, then generating the dense point cloud and the mesh model. Finally, the orthophoto and index are generated.

3.1.3 3DF Zephyr Aerial

It is an Italian software that provides a complete workflow for SfM photogrammetry and includes tools for post-processing, measurements, and automatic 3D modeling from still images or video recordings [21]. After importing the images into the software, the location of the images and their initial orientation are calculated using the tie points. Then the process of measuring the control points, generating a dense point cloud, the mesh model, and finally the orthophoto is generated.

3.2. Aerotriangulation and ground sampling distance

Aerotriangulation is the term used for the process of determining the ground coordinates of individual points using measurements of the photographic coordinates of these points. Phototriangulation may be the most general term since this process is also applied to ground photographs in addition to its application to aerial photographs. Bundle adjustment triangulation is the most widespread method, and it is based on a calculation that links the image coordinates to the body coordinates directly, without going through the stereoscopic coordinates [22]. It was called the Bundle method because there is a large number of light rays that pass through each location of the lens forming a bundle of rays. The principle of adjustment is to apply Xo, Yo, Zo and three rotations κ, ø, ω (the external orientation parameters) to each stereoscopic bundle until the rays intersect the tie points and match the control points. The external orientation parameters of these packages are determined simultaneously for all block images. As for the initial data, they are the image coordinates of the tie points (present in more than one image) and the control points, as well as the ground coordinates of the latter. The Ground Sampling Distance (GSD) Figure 2 expresses the ground length covered by one pixel in the image or is the distance between the centers of two pixels measured on the ground [23]. The larger value of the ground sampling distance means that there is less detail in the image. There is a positive correlation between the value of the ground sampling distance and the distance of the camera from the photographed object. i.e., the value of the ground sampling distance increases with the increase in the distance of the camera from the photographed object, and its value decreases with the decrease in this distance. The value of this distance is also affected by the focal length of the camera as well as by the dimensions of the pixels in the image.

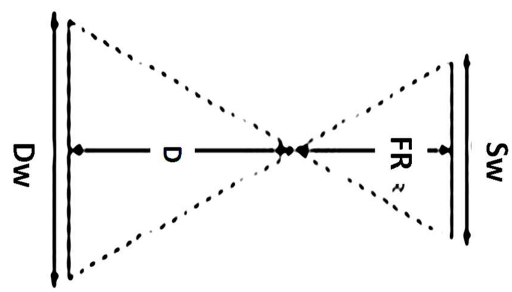

Fig. 2: Ground Sampling Distance.

From the previous figure, we find that:

$$\frac{D}{F_R} = \frac{Dw}{Sw} \quad (1)$$

$$D = \frac{Dw * F_R}{Sw} \quad (2)$$

Where: Sw is the real width of the sensor (given in millimeters), F_R is the real focal length (given in millimeters), D is the distance of the camera from the element (given in meters) and Dw is the distance covered by the image width on the element (given in meters). Dw can be calculated from the following relationship:

$$Dw = \frac{\mathrm{Im}_w}{100} * GSD \tag{3}$$

Where: Im_w is the image width in pixels. By merging relations (2) and (3), we find that:

$$GSD = \frac{D * Sw * 100}{\mathrm{Im}_w * F_R} \tag{4}$$

In [24], we find a relation to evaluating the theoretical accuracy of Aerial triangulation using ground sampling, which is:

$$\sigma = 4 \rightarrow 6 \times \mathrm{GSD} \tag{5}$$

which is the relation that we will approve in calculating the theoretical accuracy of aerial triangulation in our research.

3-3. Available Data

The available data are images of an airport in the United States of America. The total number of these images is 112, in addition to 17 GPS-measured control points given within the UTM projection system, zone 14N. The images were taken using the UAV Mapper drone, using a Sony Nex 5T camera with a Sony 16mm lens. The images covered an area of 11.39 hectares. Table 1 shows the GPS coordinates of these points while Figure 3 shows the location of these points

Table 1: UTM (Zone 14N) coordinates of control points

Point no.	X (m)	Y (m)	Z (m)
1	517565.154	3306582.028	448.491
2	517475.325	3306691.646	453.345
3	517544.813	3306690.468	452.264
4	517410.613	3306693.461	455.328
5	517558.396	3306402.737	444.821
6	517388.335	3306426.684	451.996
7	517396.273	3306535.12	454.481
8	517492.578	3306515.571	450.526
9	517418.151	3306460.581	452.045
10	517377.474	3306413.255	455.542
11	517404.826	3306698.291	449.299
12	517544.812	3306697.140	448.509
13	517558.577	3306394.823	449.436
14	517468.388	3306464.909	453.643
15	517493.506	3306485.995	454.278
16	517570.858	3306581.575	451.934
17	517388.696	3306536.853	450.152

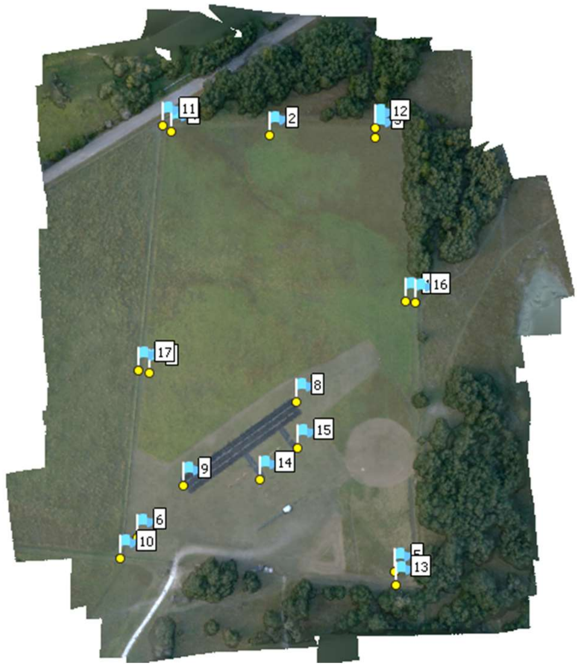

Fig. 3: Control points locations.

4- Results and Discussion

4-1 Setting the processing parameters in the tested software.

Before starting the comparison process, processing parameters must be set in the tested software so that we standardize the processing conditions for all software.

- As for the Agisoft Metashape software, the processing level (High accuracy) will be selected in the initial image orientation stage so that we ensure that tie points are extracted from the images with their full resolution. Besides, the parameter (Pair preselection) will be set as Generic (General) (assuming that there is no prior information about camera locations). The software will then perform the initial orientation with the support of the SfM algorithms. In the last stage, the control points will be measured on all available images, i.e. only the points that are visible on the images will be measured. Concerning generating the dense point cloud, the processing quality will be set as High, and the dense point cloud will be used as a source for building the grid model, which is the input to the digital model for elevations and orthophoto. It will also be left to the software to decide the accuracy of the resulting orthophoto recognition.
- As for Pix4Dmapper, the “Full” option will be selected when extracting the tie points, which means that the image will be used with its full resolution. As for the selection of matching image pairs, the “Aerial Grid or Corridor” option will be activated, which is equivalent to the “Generic” option in Agisoft Metashape. After implementing the initial orientation using only SfM algorithms, control points will be scaled on all available images as in the case of Agisoft Metashape. For the generation of a dense point cloud, the processing quality will be selected as “High”, and the dense point cloud will be used as a

source to build the digital model of the surface with the highest resolution available, and it will be left to the software to decide the resolution of the orthophoto.

- For 3DF Zephyr Aerial, the orientation type is set as "Aerial", the processing level is "Deep", and the tie point density is "High" (use the image at its full resolution). As for choosing the order of the images to be matched, the "Approximate grid" option is set, which is equivalent to the "generic" option in Agisoft Metashape. After performing the initial orientation using SfM algorithms only, the control points will be scaled on all available images as in the case of Agisoft Metashape. For the generation of the dense point cloud, the quality of processing has been chosen as "High details", and the point cloud will be used as a source to build the digital model of the surface (the mesh model), and we will let the software determine the accuracy of the orthophoto recognition.
-

4-2 Processing results and comparison methodology.

Image processing has been done using all the tested software and using the same computer (CPU): Intel(R) Core (TM) i5 CPU M 460 @ 2.53GHz, RAM: 4GB). Processing has gone through the following steps:

1. Calculating the initial orientation of the images takes into consider the previously described processing parameters.
2. Calculating the ground sampling distance (GSD) by knowing the average height of the camera and its specifications, to calculate the theoretical accuracy of aerial triangulation.
3. Dividing the control points into two Sets: One set of control points will be included in the calculation of aerial triangulation and the other set of control points will not be used in the calculation of aerial triangulation and will be used as check points for evaluating the accuracy of the vertically corrected image (orthophoto).
4. Carrying out aerial triangulation to calculate the elements of the external orientation of the camera (location and orientation) using the same control points and deducing the real accuracy values of the implemented triangulation using each of the tested software and comparing the values of this accuracy with the theoretical accuracy calculated in the previous step to judge the accuracy of the aerial triangulation.
5. Calculating dense point cloud taking into consideration the previously described processing parameters.
6. Calculating the mesh model (Digital Surface Model DSM) based on the previous cloud using all the studied software.
7. Calculating the digital elevation model (DEM) which represents the bare soil, by dividing the DSM semantic segmentation and subtracting the contour lines from it.
8. Calculating the corrected orthophoto using all the studied software and evaluating their accuracy.
9. Comparing the tested software products and overall processing times.

The previous steps have been applied using Pix4Dmapper as follows:

1. In the initial orientation stage, a scattered cloud of 25440 points was obtained, with the success of the software in processing all the images.
2. We calculated the ground sampling distance value as follows:

I. Calculating the average level of the control points from the reference surface, which in our case is approximately 451.53 m.
II. Calculating the average height of the camera from the reference surface, which in our case is equal to 543.76 m
III. Calculating the average distance between the camera and the photographed scene as the difference between the average height of the camera from the reference surface and the average level of the control points from the reference surface, so its value was equal to 92.23 m.
IV. The camera parameters we used are:
   a) Image width $S_w = 20.02\ mm$
   b) Focal length. $F_R = 16\ mm$
   c) Image width (pixels). $im_W = 4912$
   d) Image height (pixels) $im_H = 3264$
V. We applied the relation (4) and found that GSD = 2.3 cm/pixel and therefore the theoretical triangulation accuracy according to relation (5) ranges between 9.19 cm and 13.79 cm.

3. We divided the control points into two groups: The first group includes 9 points which will be used in calculating the aerial triangulation of the images, while the second group consists of 8 points, which are the check points that will be used later in evaluating the accuracy of the corrected orthophoto. The check points were selected so that they are distributed homogeneously in the edges and center of the photographed scene. Figure 4 shows the location of the check points.
4. Control points have been added and scaled on all images in which they appear. In Figure 5, we show the results of these stages, as we show in Table 2 the values of the mean squared errors on each control point and the total mean squared errors on these points

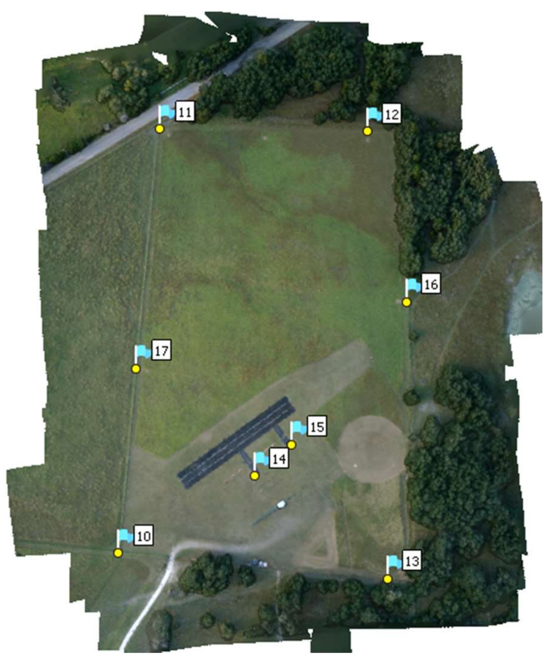

Fig. 4: Location of the check points.

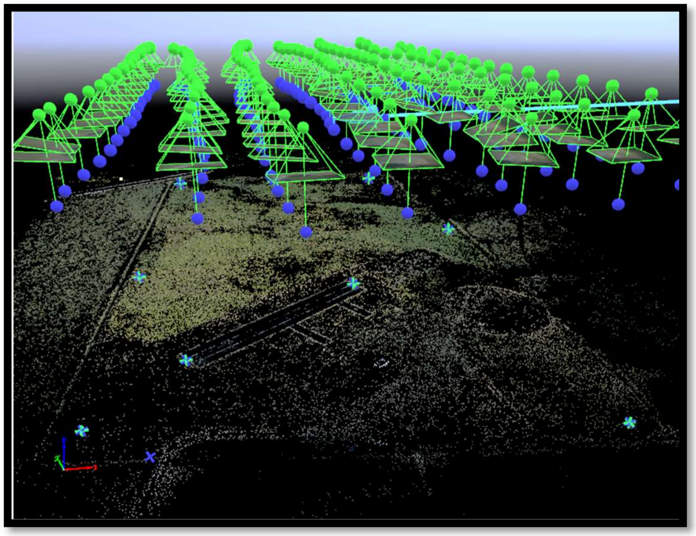

Fig. 5: Scattered point cloud with camera locations and control points.

Table 2: Statistical estimates of aerial triangulation of images.

Set Point	Error X [cm]	Error Y [cm]	Error Z [cm]	Total [cm]
1	1.9	-0.4	-3.7	4.2
2	0.3	-0.7	1.1	1.3
3	2.2	-0.3	-7.1	7.4
4	-1.8	-1.6	-3.2	4.0
5	0.3	-0.2	-3.2	3.2
6	2.2	-1.1	0.8	2.6
7	-3.0	1.1	0.0	3.2
8	-3.0	5.9	10.6	12.5
9	-3.3	-0.3	-4.9	5.9
RMS Error [m]	**2.26**	**2.11**	**4.97**	**5.8**

From Table 2, we note that the total mean squared error of the control points, or the practical triangulation accuracy is 5.8 cm, which is an acceptable value considering that the tolerance limit or the theoretical triangulation accuracy ranges between 9.19 cm and 13.79 cm.

5. The dense point cloud was built, totaling 795,865 points Figure 6, and from which the mesh model (Digital Surface Model) Figure 7 was created.
6. To calculate the contour lines, we semantically divided the dense point clouds into terrestrial and non-terrestrial points, and then the digital elevation model of the non-terrestrial points was generated. This model is the basis for generating contour lines. Figure 8 shows the results of the division process, and Figure 9 shows the results of generating contour lines with the spacing that the user selects.

Fig. 6: The resulting dense point cloud.

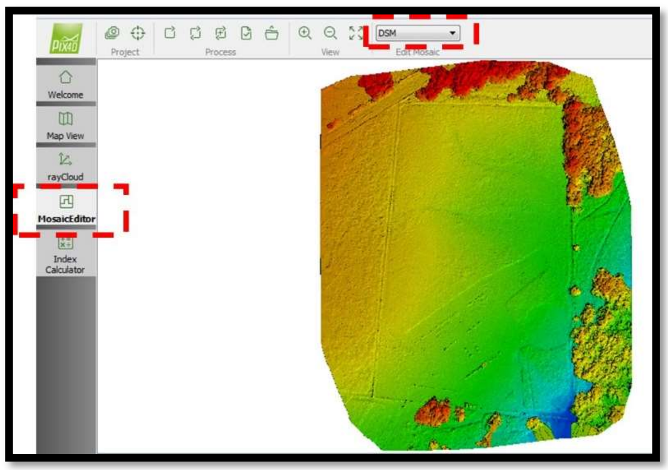

Fig. 7: Surface Digital Model.

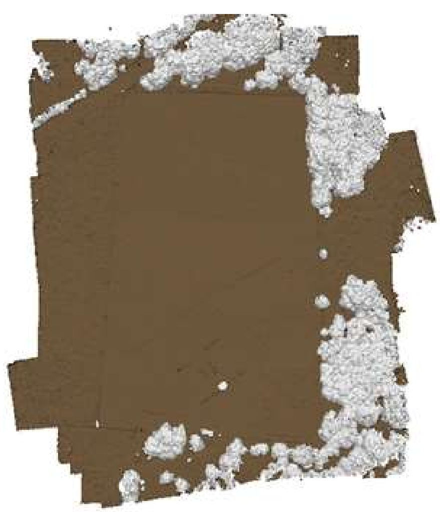

Fig. 8: Dividing the dense point cloud and isolating the bare ground.

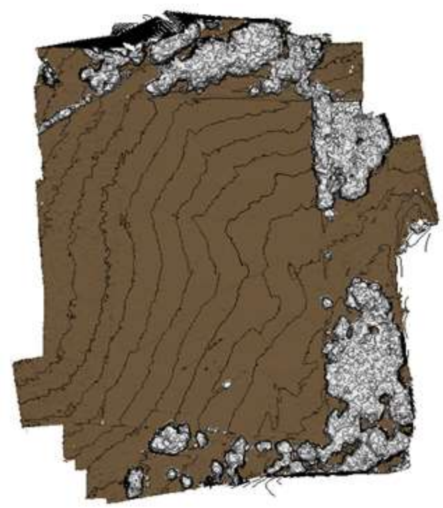

Fig. 9: Generating contours from bare ground

7. Finally, the orthophoto was generated Figure 10 with a resolution equal to the ground sampling distance, i.e. 2.3 cm/pixel .

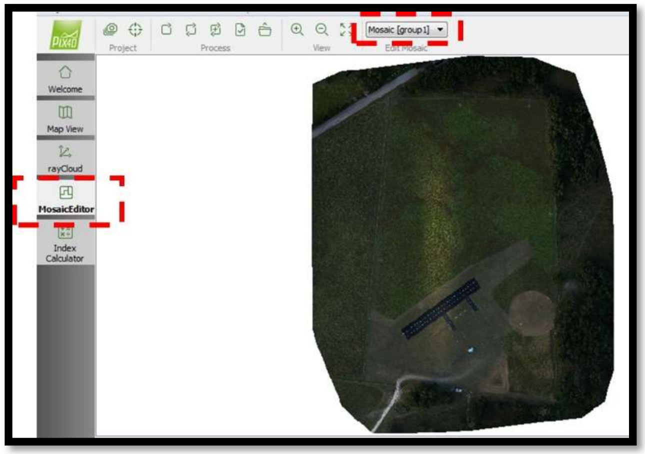

Fig. 10: The resulting orthophoto has a resolution of 2.3 cm/pixel.

1. To evaluate the horizontal accuracy of the corrected orthophoto, the eight check points which were not used in the calculation of this image were used. This evaluation is based on the concept of mean squared error over the horizontal location of the check points [25]. To calculate this error, we measured the coordinates of the check points on the corrected orthophoto and then calculated the differences between these coordinates X_O and Y_O and their coordinates measured using GPS X_{GPS} and Y_{GPS}. Based on the above differences, the following mean squared errors can be calculated :
   - The mean squared error in the X direction:

$$RMSE_X = \frac{\sum_{i=1}^{n}(X_O - X_{GPS})}{n} \tag{6}$$

   - The mean squared error in the Y direction:

$$RMSE_Y = \frac{\sum_{i=1}^{n}(Y_O - Y_{GPS})}{n} \tag{7}$$

   - The mean squared error on the horizontal location XY:

$$RMSE_{XY} = \sqrt{\frac{{RMSE_X}^2 + {RMSE_Y}^2}{n}} \tag{8}$$

Where: n: is the number of check points.

Table 3 shows the values of the differences at each check point.

Table 3: Processing results with Agisoft Metashape and 3DF Zephyr Aerial.

N	GPS-measured		Orthophoto-measured		Differences	
	X (m)	Y (m)	X (m)	Y (m)	dx (m)	dy (m)
10	517377.474	3306413.255	517377.446	3306413.280	0.028	-0.025
11	517404.826	3306698.291	517404.855	3306698.254	-0.029	0.037
12	517544.812	3306697.140	517544.829	3306697.119	-0.017	0.021
13	517558.577	3306394.823	517558.506	3306394.766	0.071	0.057
14	517468.388	3306464.909	517468.342	3306464.809	0.046	0.100
15	517493.506	3306485.995	517493.410	3306486.055	0.096	-0.060
16	517570.858	3306581.575	517570.796	3306581.531	0.063	0.044
17	517388.696	3306536.853	517388.667	3306536.875	0.029	-0.022

By applying relations (6), (7), and (8), we find that $RMSE_X = 0.054$ m ، $RMSE_Y = 0.052$ m and $RMSE_{XY} = 0.075$ m. The total processing time using Pix4Dmapper was 2.44 hours.
We repeated the previous processing steps in Agisoft Metashape and 3DF Zephyr Aerial, and we got the results shown in Table 4.

Table 4: Processing results with Agisoft Metashape and 3DF Zephyr Aerial.

Software	Agisoft Metashape	3DF Zephyr Aerial
Number of scattered cloud points	50225	57000
The total mean squared error of the control points, σ_{XYZ} (cm)	8.93	8.72
Number of dense cloud points	2880000	5176832
Generating DEM	Yes	Yes
Generating contour lines	Yes	Yes
Orthophoto accuracy from check points (m)	0.11	0.078
Total processing time (Hrs.)	6.49	10.30

To compare processing results, we adopted the following points:

1- The geometric accuracy of aerial triangulation.
2- The density of both scattered and dense point clouds.
3- The accuracy of the orthophoto images.
4- The processing time, flexibility, ease of use, and automatization level.

First: The geometric accuracy of aerial triangulation.

In the following chart Figure 11, we show the results related to the geometric accuracy of aerial triangulation for all the studied software.

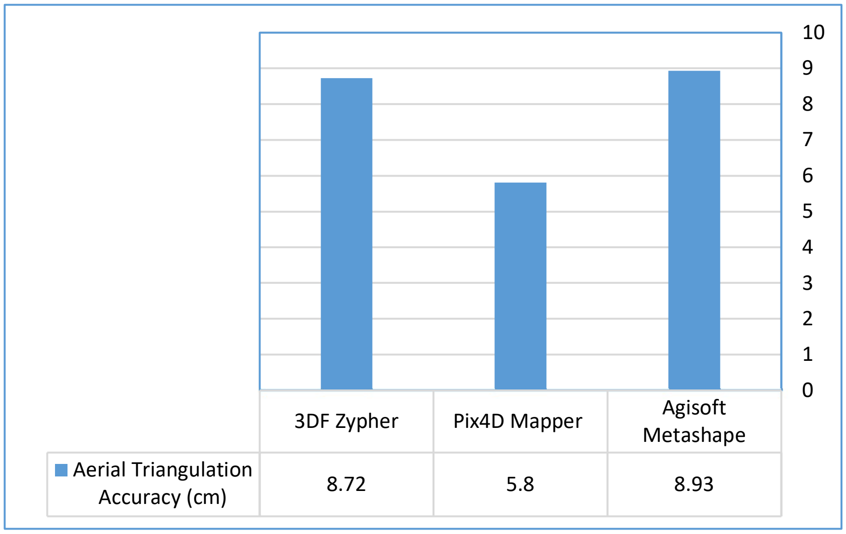

Fig. 11: The accuracy of aerial triangulation for all the studied software.

From Figure 11, we conclude that the triangulation algorithms applied in all software have achieved the required level of accuracy and have not exceeded the allowable error value (theoretical accuracy), whose value ranges between 9.19 cm and 13.79 cm, according to the relationship (5). On the other hand, we note that the accuracy of this orientation is close in both Agisoft Metashape and 3DF Zephyr, while it is better in the case of Pix4Dmapper. In our opinion, this difference is due to the difference in the accuracy of measuring the control points on the images.

Second: In terms of the density of the scattered and dense point clouds

The following chart Figure 12 shows the results related to the number of scattered cloud points and the number of dense cloud points resulting from all the studied software.

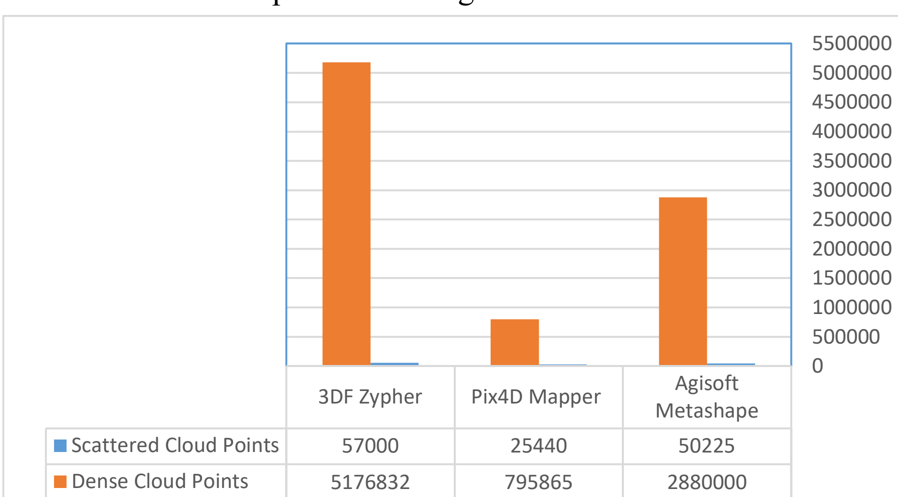

Fig. 12: The number of scattered and dense cloud points resulting from the tested software.

From Figure 12, we note that:

1. Using the same levels of processing, some software was able to extract a greater number of tie points (the case of 3DF Zephyr Aerial), and we also note that 3DF Zephyr Aerial has extracted the largest number of points of dense clouds as well. Thus, it can generate a surface digital model that has a higher definition accuracy, which confirms that the algorithms applied in this software are more advanced than the rest of the software.
2. All the tested software could generate dense point clouds and digital models of the surface that adequately reflect the geometry of the existing element. However, they differ in the number of points of these clouds and the accuracy of distinguishing digital models of the surface.

Third: The accuracy of the orthophoto using check points

The following chart Figure 13 shows the results related to the accuracy of aerial orthophoto for all studied software.

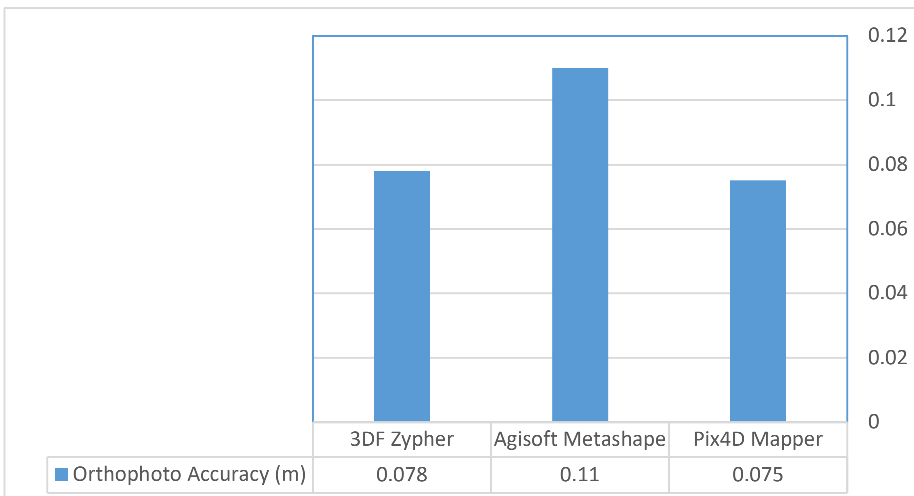

Fig. 13: The orthophoto accuracy of the studied software.

We conclude from Figure 13 the convergence of the results of the various software, noting that the best horizontal accuracy of the orthophoto was achieved by Pix4Dmapper, with a strong convergence with 3DF Zephyr.

Fourth: Comparison of processing times

The following chart Figure 14 shows the results related to the total image processing time and getting the required output by all the studied software. From this chart, we note that there is a significant difference in the processing time, despite the use of the same computer in all previous processors. In our opinion, this depends on the intelligence of the applied algorithms in managing the process of deducting, storing, and cleaning point clouds in the Pix4Dmapper software.

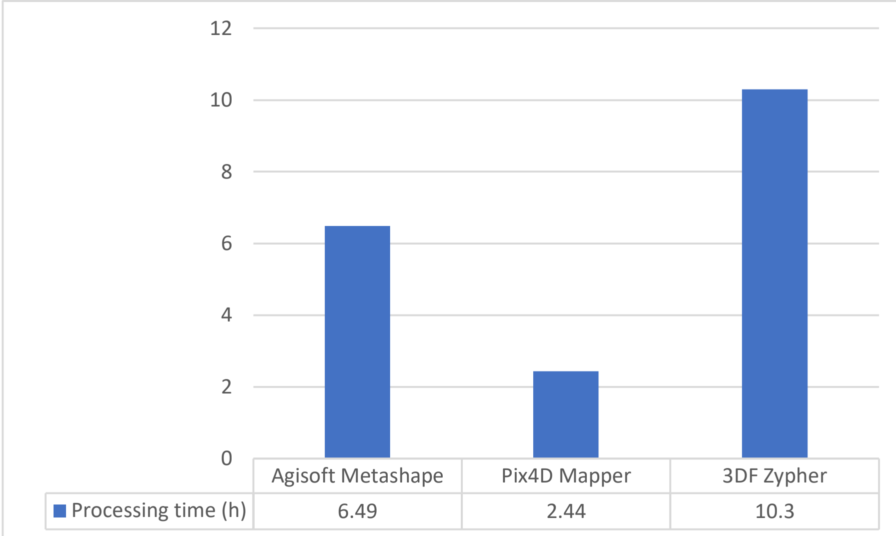

Fig. 14: The processing times to get the geometric output of the tested software.

Finally, we must point out that we have noticed through working on the software that some of them have relatively easy interfaces (the case of the software Agisoft Metashape) and others have more capabilities and tools to deal with control points and with modification in packages and with point clouds in terms of editing and exporting (the case of 3DF Zephyr Aerial). As for the processing reports, we found that Pix4Dmapper provides a useful visual assessment to verify the location of control points, which is not available in other software. On the other hand, both Agisoft Metashape and 3DF Zephyr Aerial can export spatial outputs using the main window of the software, while Pix4Dmapper does not have this capability, but rather stores these products in the project folder in the formats specified by the user when specifying the processing output options.

The results of our research are consistent with most previous research, but we point out that the 3DF Zephyr Aerial program was not included in this research in the comparison process, and this is a new point in our research. On the other hand, we tried to focus on the concept of GSD extensively in order to help non-photogrammetry specialists (traditional surveyors) adopt an effective standard for calculating the accuracy of theoretical aerial triangulation and evaluate the practical accuracy of this triangulation before continuing the processing chain.

5- Conclusions

Based on the theoretical study evaluating the effectiveness of some photogrammetry software in calculating the aerial triangulation of image blocks captured by drones and in generating spatial data, and the practical application of this study on a real case, we conclude the following:

2. The ground sampling distance (GSD) is an effective criterion for calculating theoretical aerial triangulation accuracy and for evaluating practical triangulation accuracy. Which can help surveyors to judge triangulation accuracy before proceeding with the processing series.

3. The experiment proved that Pix4Dmapper managed to perform aerial triangulation more accurately than Agisoft Metashape and 3DF Zephyr Aerial. The resulting accuracy when using Pix4Dmapper was 5.8 cm, while when using Agisoft Metashape and 3DF Zephyr Aerial it reached 8.93 cm and 8.72 cm. respectively. Noting that there is a great convergence between the results of Agisoft Metashape and 3DF Zephyr Aerial.
4. Despite adopting the same levels of processing in all the tested software, the 3DF Zephyr Aerial software extracted the densest point cloud compared to the rest of the software (5176832 points), which may confirm that the algorithms applied in this software are more advanced than the rest of the software.
5. The horizontal resolution of the orthophoto produced by the software Pix4Dmapper is the best; it reached 0.075 m, close to the results of the software 3DF Zephyr Aerial.
6. Pix4Dmapper took the shortest time to process images (2.44 hours) compared to the other software. This, in our opinion, depends on the intelligence of the applied algorithms in managing the process of cutting, storing, and cleaning point clouds in this software.
7. The user interface of Agisoft Metashape is more flexible and easier to use compared to the other

6- Recommendations

At the end of this research, we recommend the following:

1- Expanding the scope of the comparison so that we increase the number of tested software to reach more comprehensive conclusions.

2- Increasing the number of comparison criteria to include other factors such as image overlap ratios, image recognition accuracy, number and distribution of control points, camera calibration, and computer specifications used for the quality of software products.

3- Application of tested software on rigged terrain areas.

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تحليل فعالية برامج المسح التصويري في حساب التثليث الجوي وفي توليد البيانات المكانية من صور الدرونات

ملخّص

من الصحيح أن الدرونات صارت تستخدم من قبل المساحين كبديل عن الطرائق التقليدية في الحصول على الخرائط الصورية (الأورثوفوتو) والخرائط الطبوغرافية ذات المقاييس الكبيرة، ولكن هنالك عدة عوامل تؤثر على دقة هذه البيانات المكانية ومنها البرنامج المستخدم في معالجة الصور. وبسبب كثرة هذه الأنواع من البرامج، فإن اختيار أحدها يعتبر مشكلةً حقيقية في مشاريع المسح باستخدام الدرونات. في الواقع، تنقسم برامج المعالجة إلى برامج تجارية وبرامج مفتوحة المصدر، وتمثل البرامج التجارية حالة صندوق أسود وهذا ما يسلط الضوء على التحدي المتمثل في عزل المصادر الدقيقة للأخطاء والحكم على دقة منتجات المعالجة.

تم في هذا البحث مقارنة إمكانيات البرامج التجارية Pix4Dmapper و Agisoft Metashape و 3DF Zephyr Aerial في حساب التثليث الجوي لبلوكات الصور الملتقطة بواسطة الدرونات، مع مقارنة إمكانيات هذه البرامج في الحصول على المنتجات المكانية الأهم بالنسبة للمساحين من هذه الصور (النموذج الرقمي للارتفاعات والأورثوفوتو). بينت النتائج أن البرنامج Pix4Dmapper استطاع إنجاز التثليث الجوي بشكل أدق من البرنامجين Agisoft Metashape و 3DF Zephyr Aerial، مع وجود تقارب كبير بين نتائج البرنامجين Agisoft Metashape و 3DF Zephyr Aerial، وأن البرنامج 3DF Zephyr Aerial قد اقتطع الغمامة الأكثف من النقاط. من ناحية أخرى، أنتج البرنامج Pix4Dmapper الأورثوفوتو الأدق كما استغرق أقصر زمن في معالجة الصور وكانت واجهات البرنامج Agisoft Metashape مرنة وأسهل استخداماً أكبر مقارنة بباقي البرامج المختبرة.

كلمات مفتاحية: درون، برامج تجارية، أورثوفوتو، تثليث جوي، غمامة نقاط، دقة.