Determination of the optimum number and distribution of the ground control points in stereo imaging to achieve precise positions

A H Hilal\textsuperscript{1}, O Z Jasim\textsuperscript{1} and H S Ismael\textsuperscript{1}
\textsuperscript{1} Civil Engineering Department, University of Technology/Baghdad, Iraq

E-mail: bce.19.34@grade.uotechnology.edu.iq

Abstract. A precise location in aerial surveying can only be achieved using Ground Control Points GCPs. At least three point should be used and as the number increases the model will be more precise in X, Y and Z positions for a certain extent. The distribution of the GCPs also affect the precision of the 3D model resulted from the aerial imaging. This study aims to find the optimum number and distribution of the GCPs to achieve the minimal error in points location. 1.5 km\textsuperscript{2} of longitudinal area was imaged with a commercial UAV named DJI Mavic 2 pro with at nadir camera orientation at height of 100 m above the ground. A total of 1515 images were taken with average ground sampling distance (GSD) of 2.3 cm. Differential Global Positioning System DGPS Leica GS 15 receiver were used to observe the 62 ground control points with PPK fashion. The project area was divided into two regions the first region has a parallel distribution of GCPs and the second region has a zigzag distribution. The images were processed using Pix4Dmapper and Agisoft Metashape software by applying a bundle adjustment process with an incremental number of GCPs starting with 3 and finishes with 26 for each distribution pattern, the remaining points were used as a check points to determine the precision of the model at each trial. The resulted coordinates of check points were compared with the coordinates observed with the DGPS. The comparison depicts the optimum number of GCPs required for the best location precision and the best distribution pattern.

1. Introduction
Stereo imagery plays an important role in creating 3D models [1,4,5] of various objects and features using the basis of 3D photogrammetry, recently drone stereo imagery has gained a lot of attention regarding the engineering application such as Land Surveying, Remote Sensing and Geographic Information Systems [2,14]. Benefiting of its availability, cost, mobility and ease of use. Researchers around the globe have started investigating the abilities and advantages that these systems offers and a lot of discoveries has been achieved around this topic. One of the major problems arises from the use of the Drone mapping systems that they are requires a ground control points in order to achieve a high precision results [11] regarding positions of the features and objects being mapped so we can make a high precision measurement on the outputs of these systems such as the othromosics [12,3], the 3D point clouds and the DSMs [13]. The GCPs are used to reference the project to a known well defined coordinate system so that the measurements be as accurately as possible [6,9]. The precision of the results is highly influenced by the number and the distribution of these control points. Increasing the number of GCPs will lead to increase the precision of the resulted model [7]. How the GCPs distributed
throughout the project also affect the precision of the model [10]. There is some research investigated the optimum number of GCPs for the drone mapping systems [8]. Oniga et al. studied the optimum number of GCPs for UAS images but he did not take the effect of points distribution on the final results of the project into consideration and his project was limited to a small area. This study aims to identify the optimum number and distribution of GCPs that gives the most accurate positions for the 3D point cloud resulted from using a low-cost drone imaging system which consequently effects the accuracy of the other data types such as the orthomosaic and the DSM. The GCPs were measured using PPk DGPs with millimetres precision and used to georeference a block of 1515 overlapped nadir images taken with 100 m height above the ground, the GCPs distributed parallel in the first 3 km of the project and zigzag in the rest of the longitudinal project area. Two different software solutions were used to process the images i.e., Pix4D Mapper software by Pix4D and Metachape’s Agisoft software. The accuracy of the project was inspected by comparing the generated coordinates of the GCPs with the original coordinates measured by the DGPS. In this study an area of about 1.5 km2 imaged with a DJI Mavic 2 Pro Drone system at 100 m altitude above the ground and GSD of 2.3 cm, 62 control points were observed using leica GS15 DGPS and distributed in parallel and zigzag pattern.

2. Study area
The study area is the first 6 kilometers of the 25 km Army Canal Project which is a waterway connecting the Tigris river at the north of Baghdad City, Iraq with Diyala river in the south. The study area is a

Map 1. Study area (Army Canal) with GCPs distribution overlayed over satellite imagery.
longitudinal area covers the waterway and the two parks and roads on the sides with an average width of 250 m and long of 6.15 km (see map 1 and map 2).

3. Materials and methods

3.1. Measurement of ground control points (GCPs)

Measuring the geodetic coordinates of the ground control points is crucial for getting precise locations in aerial surveying and these GCPs should have a minimal error in order to achieve high accurate results. In this project a Leica GS 15 DGPS was used to identify the geodetic coordinates of the GCPs using Post Processing Kinematic PPK technique, the base station was used to observe one of the GCPs located in the center of the project, the observation period was 15.5 hours. The rover receiver was used to observe the other GCPs with observation period of 15 minute for each GCP. All the GCPs were marked with red dot of about 15 centimeters diameter and with a central white dot of about 5 centimeters diameter (Figure 1). The base station data processed using OPUS site after 14 days after the observation with RMS error equal to 1.5 mm in Longitude and 2 mm in the Latitude and 2 mm in the elevation. The other GCPs were processed with reference to the base station using Leica Geo Office software. The average RMS error for these GCPs was 1.8 mm in X coordinate and 1.3 mm in Y coordinate and 2 mm in Z coordinate. The project has 62 GCPs distributed along the waterway path in two different fashions, the first 3 km of the project has its GCPs distributed in parallel fashion with two aligned points every 100 m along the path of the waterway, the second 3 km of the project has its GCPs distributed in zigzag fashion with a point in one side of the canal and the subsequent point in the opposite side with gap distance of about 100 m (see figure 2, figure 3 and map 3).
3.2. Data capturing

The project was captured using DJI’s Mavic 2 Pro drone which is a commercial UAV for general use. The UAV has a built-in camera with 13.2 mm and 8.8 mm sensor width and height respectively and image size of 5472 px width and 3648 px height. The flight planning is done using DJI Pilot software (figure 3) using Linear Flight Mission feature with equal left and right extensions of 60 m and a band...
length of 2 km. The project area requires 9 bands to be completely mapped with side overlap of 80 percent and frontal overlap of 70 percent and single grid. All the images were taken at nadir with camera height of 100 m above the ground. The 1.5 km² project was imaged with 1515 images with an average GSD of 2.3 cm (see figure 3 and figure 4).

3.3. Data Processing
As noted earlier, the data processing was performed using two different software solutions so that we can get a general perspective of how each software works and which one is better. In both software the area is separated into two projects one for the parallel GCPs distribution and contains 31 GCP, the other is for the zigzag GCPs distribution with also 31 GCPs. The model is processed using and increasing number of GCPs starting with only 3 control points and the other 28 points were used as a check points and ending with using 26 control points and 5 check points. The accuracy of the model was represented by the amount of RMS error of the check points which refers to the relative distance between the calculated coordinates of the check points from the model and their accurate coordinates measured with DGPS.

3.3.1. Processing with Pix4D Mapper software
Pix4D mapper software performs processing as a set of steps the user can choose his own preferences and parameters for each processing step. First of all, the user has to create a new project and then import the images making up the survey model, in our case we have imported 1515 images for the entire project into the software, each image has it geotag attached with it so that, the initial position and orientation of the capture location is known to the software but these positions don’t have a high accuracy. After importing the images their geolocation (which includes the coordinate system by which image capture location was measured and the accuracy of these coordinates) have to be selected, as in our case WGS 1984 UTM zone 38N is selected as a horizontal coordinate system and the EGM 2008 as a vertical Datum. The output coordinate system is selected the same as the input coordinate system. Form the processing options template which is a pre-set template for different processing fashions we chose 3D map as we need to generate 3D map model. To start the image matching process, we used Geometrically verified matching as the matching strategy for the project. The interior camera parameters optimization set as all prior which will allow the software to calculate the interior camera parameters from the model itself. After running the initial processing step for the first time the GCPs added to the project as .csv file from the GCP/MTP Manger with each point has its horizontal and vertical accuracy set to 0.002 m.
Each GCP will then be marked carefully on the images to tie the model to its accurate position and the type of these GCPs will be changed to either a Control Point or a Checkpoint. Then we reoptimized the project for the second time to recalculate tie points locations relative to the newly added GCPs. The quality report generated from running the initial processing will be saved for each trial to compare the RMS error of the different number of GCPs/Checkpoints used (see figure 5 and figure 6).

3.3.2. Processing with Agisoft software
Agisoft performs the processing almost the same as the Pix4D Mapper with minor differences in the interface. The processing begins with creating a new project and importing the images from the workflow menu which contains all the required processing steps. After importing the images, we start aligning them and creating the tie points for the model by choosing align photos from the workflow menu and selecting high for the accuracy and checking the generic preselection and the reference preselection options and also checking the adaptive camera model fitting option in the advanced tab which will estimate the interior camera parameters from the model the key point and the tie point limits were set to 40,000 and 10,000 respectively. This will align the cameras in a way similar to the flight path and create the 3d tie points of the model. GCPs imported to project afterwards from a .csv file with each one has its own easting, northing and elevation coordinates and set the accuracy for each point as 0.002m. The process of marking GCPs on the images is very similar to way it’s done with the Pix4D software with each point being marked carefully on at least 5 images. The last step of georeferencing is done by optimizing the cameras with the newly added control points and choosing the point type either as a control point or as a check point and reoptimizing the project for every iteration of control point to check point used. For each iteration a report of the processing result is generated and saved for comparison.

4. Results

4.1. Results for parallel distribution
When Pix4D mapper software is used to perform the bundle adjustment of the model, 4.7 m RMSE was resulted from using the minimum number of GCPs which is 3 GCPs and measured from the remaining 28 check points, while the maximum number of GCPs which is 26 GCPs resulted a RMSE of 0.047 m measured for the 5 remaining check points, however the RMSE was dropped rapidly to 0.5 m after
Adding 7 more GCPs and making the total number 10 GCPs. After adding more GCPs, the RMSE becomes less than 10 cm when 15 GCPs used to reference the project. The amount of RMSE still decreasing as we add more GCPs, however the difference between the consecutive trials is decreases also until reaching about 2-5 mm (see Table 1 and chart 1).

When Agisoft software is used to perform the bundle adjustment, 6 m RMSE was resulted from using the minimum number of GCPs which is 3 GCPs and measured from the remaining 28 check points, while the maximum number of GCPs which is 26 GCPs resulted a RMSE of 0.051 m measured for the 5 remaining check points, however the RMSE was dropped to 0.2 m after adding 7 more GCPs and making the total number 10 GCPs. After adding more GCPs the RMSE becomes less than 10 cm when 15 GCPs used to reference the project. The amount of RMSE still decreasing as we add more GCPs, however the difference between the consecutive trials is decreases also until reaching about 4-8 mm (see Table 1 and chart 2).

**Table 1.** Full bundle adjustment processing results for parallel GCPs distribution using Pix4DMapper and Agisoft software.

| No. of GCPs | No. of CKPs | Pix4D mapper | Agisoft | RMSE diff. |
|-------------|-------------|--------------|---------|------------|
|             |             | X       | Y       | Z       | RMSE | X | Y | Z | RMSE |
| 3           | 28          | 2.066   | 2.347   | 3.519   | 4.707 | 2.153 | 2.269 | 5.117 | 5.997 | -1.290 |
| 4           | 27          | 1.291   | 1.513   | 2.264   | 3.014 | 1.530 | 1.746 | 1.355 | 3.917 | -0.904 |
| 5           | 26          | 1.007   | 0.891   | 1.117   | 1.748 | 1.123 | 1.006 | 1.537 | 2.153 | -0.405 |
| 6           | 25          | 0.889   | 0.760   | 0.964   | 1.516 | 0.901 | 0.791 | 0.998 | 1.560 | -0.044 |
| 7           | 24          | 0.461   | 0.473   | 0.811   | 1.046 | 0.631 | 0.555 | 0.807 | 1.165 | -0.119 |
| 8           | 23          | 0.302   | 0.296   | 0.662   | 0.786 | 0.571 | 0.277 | 0.710 | 0.952 | -0.167 |
| 9           | 22          | 0.258   | 0.266   | 0.561   | 0.672 | 0.293 | 0.197 | 0.653 | 0.742 | -0.070 |
| 10          | 21          | 0.198   | 0.221   | 0.448   | 0.537 | 0.209 | 0.183 | 0.436 | 0.517 | 0.020 |
| 11          | 20          | 0.183   | 0.207   | 0.381   | 0.471 | 0.189 | 0.177 | 0.401 | 0.477 | -0.007 |
| 12          | 19          | 0.177   | 0.171   | 0.344   | 0.423 | 0.163 | 0.158 | 0.309 | 0.383 | 0.040 |
| 13          | 18          | 0.144   | 0.153   | 0.297   | 0.364 | 0.142 | 0.147 | 0.288 | 0.353 | 0.011 |
| 14          | 17          | 0.118   | 0.148   | 0.255   | 0.318 | 0.139 | 0.143 | 0.260 | 0.328 | -0.010 |
| 15          | 16          | 0.083   | 0.098   | 0.226   | 0.360 | 0.130 | 0.121 | 0.241 | 0.299 | -0.039 |
| 16          | 15          | 0.064   | 0.089   | 0.210   | 0.237 | 0.097 | 0.101 | 0.195 | 0.240 | -0.003 |
| 17          | 14          | 0.062   | 0.071   | 0.184   | 0.207 | 0.074 | 0.083 | 0.183 | 0.214 | -0.007 |
| 18          | 13          | 0.059   | 0.063   | 0.160   | 0.182 | 0.066 | 0.070 | 0.158 | 0.185 | -0.003 |
| 19          | 12          | 0.044   | 0.048   | 0.124   | 0.140 | 0.051 | 0.047 | 0.146 | 0.162 | -0.022 |
| 20          | 11          | 0.041   | 0.035   | 0.092   | 0.107 | 0.043 | 0.042 | 0.133 | 0.146 | -0.039 |
| 21          | 10          | 0.037   | 0.033   | 0.073   | 0.088 | 0.041 | 0.038 | 0.103 | 0.117 | -0.029 |
| 22          | 9           | 0.033   | 0.029   | 0.053   | 0.069 | 0.038 | 0.036 | 0.089 | 0.103 | -0.034 |
| 23          | 8           | 0.031   | 0.023   | 0.045   | 0.059 | 0.036 | 0.033 | 0.057 | 0.075 | -0.016 |
| 24          | 7           | 0.029   | 0.021   | 0.040   | 0.054 | 0.030 | 0.028 | 0.046 | 0.062 | -0.008 |
| 25          | 6           | 0.027   | 0.018   | 0.037   | 0.049 | 0.028 | 0.023 | 0.041 | 0.055 | -0.006 |
| 26          | 5           | 0.025   | 0.018   | 0.036   | 0.047 | 0.027 | 0.020 | 0.038 | 0.051 | -0.003 |
4.2. Results for zigzag distribution

When Pix4D mapper software is used to perform the bundle adjustment of the model, 2.9 m RMSE was resulted from using the minimum number of GCPs which is 3 GCPs and measured from the remaining 28 check points, while the maximum number of GCPs which is 26 GCPs resulted a RMSE of 0.035 m measured for the 5 remaining check points, however the RMSE was dropped rapidly to 0.5 m after adding 7 more GCPs and making the total number 10 GCPs. After adding more GCPs the RMSE becomes less than 10 cm when 15 GCPs used to reference the project. The amount of RMSE still decreasing as we add more GCPs, however the difference between the consecutive trials is decreases also until reaching about 2-5 mm (see table 2 and chart 3).

When Agisoft software is used to perform the bundle adjustment, 3.6 m RMSE was resulted from using the minimum number of GCPs which is 3 GCPs and measured from the remaining 28 check points, while the maximum number of GCPs which is 26 GCPs resulted a RMSE of 0.039 m measured for the 5 remaining check points, however the RMSE was dropped to 0.2 m after adding 8 more GCPs and

Chart 1. Pix4D Mapper adjustment for parallel GCP distribution.

Chart 2. Agisoft adjustment for parallel GCP distribution.
making the total number 10 GCPs. After adding more GCPs the RMSE becomes less than 10 cm when 15 GCPs used to reference the project. RMSE still decreasing as adding more GCPs, but the difference between the consecutive trials is decreases also until it reaches 4-8 mm (see table 2 and chart 4).

Table 2. Full bundle adjustment processing results for zigzag GCPs distribution using Pix4DMapper and Agisoft software.

| No. of GCPs | No. of CKPs | Pix4D mapper | Agisoft | RMSE diff. |
|-------------|-------------|--------------|---------|------------|
|             |             | X    | Y    | Z    | RMSE | X    | Y    | Z    | RMSE |         |
| 3           | 28          | 1.531| 1.23 | 2.117| 2.888| 1.854| 1.461| 2.691| 3.580| -0.692|
| 4           | 27          | 1.266| 0.992| 1.193| 2.003| 0.993| 1.008| 1.571| 2.114| -0.112|
| 5           | 26          | 0.994| 0.711| 0.973| 1.562| 0.866| 0.875| 0.993| 1.582| -0.020|
| 6           | 25          | 0.786| 0.401| 0.838| 1.217| 0.774| 0.619| 0.884| 1.328| -0.111|
| 7           | 24          | 0.541| 0.307| 0.773| 0.992| 0.509| 0.526| 0.805| 1.088| -0.096|
| 8           | 23          | 0.433| 0.289| 0.579| 0.779| 0.394| 0.487| 0.74 | 0.970| -0.191|
| 9           | 22          | 0.259| 0.251| 0.486| 0.605| 0.246| 0.318| 0.691| 0.799| -0.194|
| 10          | 21          | 0.175| 0.202| 0.394| 0.476| 0.168| 0.279| 0.583| 0.668| -0.192|
| 11          | 20          | 0.127| 0.193| 0.363| 0.430| 0.157| 0.197| 0.461| 0.525| -0.095|
| 12          | 19          | 0.099| 0.153| 0.332| 0.379| 0.108| 0.147| 0.389| 0.430| -0.051|
| 13          | 18          | 0.088| 0.111| 0.261| 0.297| 0.087| 0.124| 0.306| 0.341| -0.044|
| 14          | 17          | 0.074| 0.096| 0.226| 0.256| 0.079| 0.099| 0.248| 0.278| -0.022|
| 15          | 16          | 0.068| 0.088| 0.196| 0.225| 0.071| 0.083| 0.202| 0.230| -0.004|
| 16          | 15          | 0.052| 0.074| 0.173| 0.195| 0.055| 0.076| 0.198| 0.219| -0.024|
| 17          | 14          | 0.031| 0.061| 0.141| 0.157| 0.041| 0.06 | 0.176| 0.190| -0.034|
| 18          | 13          | 0.028| 0.056| 0.091| 0.110| 0.036| 0.042| 0.097| 0.112| -0.001|
| 19          | 12          | 0.027| 0.033| 0.079| 0.090| 0.033| 0.038| 0.083| 0.097| -0.007|
| 20          | 11          | 0.024| 0.029| 0.068| 0.078| 0.03 | 0.035| 0.056| 0.073| 0.005 |
| 21          | 10          | 0.021| 0.028| 0.051| 0.062| 0.024| 0.031| 0.048| 0.062| 0.000 |
| 22          | 9           | 0.02 | 0.025| 0.049| 0.059| 0.021| 0.022| 0.039| 0.049| 0.009 |
| 23          | 8           | 0.018| 0.022| 0.037| 0.047| 0.017| 0.019| 0.036| 0.044| 0.003 |
| 24          | 7           | 0.015| 0.017| 0.034| 0.041| 0.015| 0.018| 0.035| 0.042| -0.001|
| 25          | 6           | 0.013| 0.015| 0.031| 0.037| 0.015| 0.017| 0.034| 0.041| -0.004|
| 26          | 5           | 0.012| 0.014| 0.03 | 0.035| 0.014| 0.017| 0.032| 0.039| -0.004|
5. Discussion

The data resulted from the bundle adjustment of each project gives us an indication of the various factors that affect the accuracy of the point cloud positions. As the project is longitudinal the referencing process is different than that used for the wide area projects, since the area changes rapidly in the long direction than the short one the GCPs must be distributed in a way that covers that extra area. The two distributions used are the most logical distributions that guarantees a full coverage for the whole project area. Each point distribution type was processed separately in a different project to assess the quality of each distribution. The results shows that the zigzag pattern is more efficient, since its gives better results than the parallel pattern, with the parallel pattern the minimum RMSE obtained is 0.047 m using Pix4D Mapper software and 0.051 m using Agisoft software, while with the zigzag pattern the minimum RMSE obtained is 0.035 m using Pix4D Mapper software and 0.039 m using Agisoft software. This difference is mainly because the zigzag pattern offers a better coverage for the project area, so that each point cloud will have more near GCPs that can reference their positions with. For the optimum number of GCPs
problem we can see that the amount of RMSE is decreases every time we add a new GCPs as a control points but this amount start getting smaller after the 20 control point, but the best results is achieved with the maximum number of GCPs with RMSE equal to 0.035 m. this is due to the fact that longitudinal project requires more control points with more length added to the surveying area unlike the wide area project limited number of GCPs will be sufficient. Pix4D Mapper software gives slightly more accurate results for the bundle adjustment than Agisoft software with a difference ranging between 0.7 m with the minimum number of GCPs and 4 mm with the maximum number of GCPs. This leads to the result that Pix4D Mapper is handling bundle adjustment better than the way Agisoft does.

6. Conclusion
This study discussed the effects of adding more Ground Control Points (GCPs) to georeference the 3D point cloud model of a drone surveying using low-cost commercial drone named DJI mavic 2 pro, using two different software solutions to process the images and generate the 3D model, the Orthomosaic, and the DSM after georeferencing the model by adjusting the camera positions and orientations using full bundle adjustment method. The software used were Pix4D Mapper and Agisoft. The GCPs distributed differently throughout the project area to quantify the effect of each distribution pattern on the accuracy. We found that using zigzag pattern is better for getting small amount of RMSE for the check points than using parallel pattern. The optimum number of GCPs is directly related to the area of the longitudinal project with RMSE almost identical for GCPs above 23. We conclude from this study that in order to obtain highly accurate results in low-cost drone mapping the minimum distance between two GCPs should be no more than 100 m.

7. References
[1] Gindraux S, Boesch R and Farinotti D 2017 Remote Sens. 9 186.
[2] Oniga V E, Breaban A I and Statescu F 2018 Proceedings 2 352.
[3] Jasim O Z, Hassoon K I and Sadiqe N E 2019 Eng. &Tech.Journal 37 140–7.
[4] Mohammed A A, Haifaa N H and Noor H H 2020 Eng. &Tech.Journal 73 012234.
[5] Khalf A Z, Alwan I A K and Jameel A 2013 Eng. &Tech.Journal 31 1601–11.
[6] Khalf A Z, Alwan I A K and Jameel A 2013 Eng. &Tech.Journal 31 1753–64.
[7] Khalf A Z and Al-Saedi A S J 2016 Eng. &Tech.Journal 34 2140–51.
[8] Khalf A Z, Mohammed N S and Al-hasoon F S 2016 Eng. &Tech.Journal 34 2739–53.
[9] Khalf A Z and Salwan S 2016 Eng. &Tech.Journal 34 1605–14.
[10] Khalf A Z, Alwan I A K and Hameed N H 2014 Eng. &Tech.Journal 32 2020–29.
[11] Khalf A Z and Haidir M K 2012 Eng. &Tech.Journal 30 2522–35.
[12] Jasim O Z, Hameed N and Abdulgabar T 2018 MATEC Web Conf. 162 03021.
[13] Jasim O Z 2019 Period. Eng. Nat. Sci. 7 1710-21.
[14] Khalf A Z, Hamodi H and Riyadh M 2015 Eng. &Tech.Journal 33 431-9.