Accuracy assessment on low altitude UAV-borne photogrammetry outputs influenced by ground control point at different altitude

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Abstract. Unmanned Aerial Vehicles (UAV) photogrammetry is as precise as conventional survey which able to produce centimetre accuracy. It is considerably quicker and gives brief portrayal of geography. Given ideal regulatory conditions this innovation will supersede current techniques for most mapping and studying applications. UAV can be an important technology to extract useful information of the earth surface in short period of time for example Digital Surface Models (DSM) and other information. The final products are highly dependent on the choice of values on various parameter for the flight planning, and for the processing of the data. The aim of this research is to study the effect of Ground Control Point (GCP) influence on the final accuracy of the output with difference flying altitude. All photogrammetric procedure was applied using Agisoft PhotoScan a Structure from motion (Sfm) software from aligning photos to build Digital Elevation Model (DEM) and georeferenced orthophoto. In this research, we have used total of 16 GCP’s where the coordinates measured with L1 RTK GPS receiver. Analysis was carried out to show the importance of GCP for mapping using low cost UAV. The analysis of both qualitative and quantitative were carried out to verify that the use of GCP is essential to produce a centimetre accuracy photogrammetric output. Utilization of GCP in mapping is significant because the output obtained from photogrammetry comes with actual measurements of the model that we have mapped.

Keywords: Unmanned aerial vehicle (UAV), ground control point (GCP), accuracy, photogrammetry

1. Introduction

UAV innovation is turning into more enthusiastically used by the way of land surveyors for many applications. Recently, drones have become a low-cost, a handy gear which may be used to carry out measurements from the air. Current enhancement in sensors and flying systems has substantially broadened the use of UAV consisting scope of calculations, developing orthomosaic map, producing 3D models, acquiring facts for Geographic Information System (GIS), overseeing extraction in open mining, carrying out construction monitoring and inspections, and basic mapping of terrain and other earth surface. UAV shorten the time of performing surveys from several days to few hours, that need to be spent in a field. New output can be created that visually and graphically improve the report preparation process with high resolution map and detailed CAD models of buildings to be incorporated
in Building Information Modelling (BIM) application. Besides that, if nicely utilize, UAV can increase the safety of people conducting measurements, because an operator can stay away from any dangerous area [1], [2], [3].

UAV are increasingly more used as important tool for generation of useful records of the earth for example DSM and OrthophoMap. The final output is incredibly depending on the choice of numerous parameters for the flight mission, and for the processing of the data obtained. Conducting a good flight mission with desired accuracy calls for know-how of different flight setting depends on site condition, weather and available lightings. Many elements ought to be taken into attention when capturing data with UAV and the most crucial are: the flying altitude, percentage of overlapping both front and side pictures and also the speed of the aircraft while taking photos. Moreover, oblique geo-referencing is crucial in bundle block adjustment, considering that reliability of camera calibration is primarily based on accuracy GCP. Therefore, distribution and wide range of GCP numbers is important [4], [5], [6], [7].

UAV which are commercially affordable do not directly possess the capability as immediate substitute for survey grade accuracy output. The information at first gathered by the UAV must be corrected using GCP. These ground control points are initially taken from survey grade instruments such as DGPS and RTK-GPS. Mapping project ended up being the most precise become the one utilizing the use of ground points to do the levelling, which remained as far as possibly permitted and the accuracy of the orthomosaic became 0.132 m. The project that didn’t utilize ground control points had the accuracy of 0.417 m. A decent distribution of GCPs isn’t just needed to tackle absolute orientation of the image block in the coveted coordinate outlined, yet additionally to mitigate block deformation effects which are basically from remaining systematic errors in the camera calibration and alignment. GCPs has the advantage over the conventional forward intersection in location accuracy, and it can achieve the approximation to the precision of conventional block adjustment with GCPs, which broadens past research on accuracy improvement. The GCP is used to produce photogrammetric output while the control point (CP) is used for accuracy assessment. UAV system can be used for small-scale mapping and other diversified applications, especially for small areas, which involves a limited budget and time constraints. The main objective of this research is to consider ground control point influence on the final accuracy of the products, when a low-cost UAV equipment is used [8], [9], [10].

2. Study Area

The study area is at Universiti Sains Malaysia, Penang near the football field where the sites have differential terrain profile. The site is free from any distraction on the air for the UAV to move around without any obstacles to obtain the data. The study area covered was 2.43 hectare as shown in Figure 1. The exact location of the study area is at latitude of 6.428794 and longitude of 100.143884.

![Figure 1. Location of study area (latitude, longitude: 6.428794, 100.143884) (Google Map)](image)
3. Methodology of research

3.1. Material
This research utilizes a low altitude UAV which is the DJI Phantom 4 Professional drone mounted with 20 Megapixel with 1” CMOS sensor as shown in Figure 2(a) and Table 1 shows the camera specification which can produce a high-resolution product. Besides, the GPS equipment that were used are Leica Viva UNO CS10 with External Antenna AS05 as shown in Figure 2(b). Data processing was done by using the Structure for Motion (SFM) software which is Agisoft Photoscan Professional version 1.2.6.

| Camera Model | Resolution | Focal Length | Pixel Size | Precalibrated |
|--------------|------------|--------------|------------|---------------|
| FC 6310      | 5472 x 3648 | 8.8 mm       | 2.41 x 2.41 µm | No            |

Figure 2. DJI Phantom 4 Pro (a) Leica Viva UNO CS10 GPS-RTK equipment (b)

3.2. Distribution and Establishment of GCP
GCPs are used to rotate, scale and orientate the project to a real-world location and in some cases a local coordinate system. GCP are typically statically placed on the outside edge and several on the interior of the project area. Checks points were used for independent verification of the project accuracy and points are randomly spaced throughout the project. Total of 18 Ground control points were established for this research. There are two types of GCP marker we used which is the mat and temporary marker (spray) white crosses were painted which enclosed the study area as shown in Figure 3 (a) and (b). All the GCP were distributed throughout the study area as shown in Figure 4 (a). Total 12 points used as control points and total of 4 points used as check point for GCP accuracy checking out of 16 points measured.

The reason why we choose to use 16 GCP is to study the effectiveness of number of GCP to accuracy of mapping. Rule of thumb to set number of GCP is 10 because many researcher and photogrammetry software manual highly recommended to add 8-10 GCPs in projects to make the 3D model more stable and accurate. For example, based on his research K.N. Tahar suggested to use more than 8 GCP because its recorded good results for RMSE vector of Easting and Northing coordinate with +0.5 meters [11]. To measure the GPS coordinates at the center of each GCP, we need either a Real Time Kinematic (RTK) or Post Processing Kinematic (PPK) GPS receiver. The coordinates of all GCP measured with the UNO CS10 GPS using Real Time Kinematic method were shown in Table 2. The equipment was set up as shown in Figure 4(b).
3.3. Flight Planning and data acquisition
Flight planning was done with the aid of an open source software called DJI Ground Station Pro for data acquisition. With the mission planner, the many parameter can be adjusted to allow the UAV to capture images to cover the area with good Ground Sampling Distance (GSD) for high resolution output. All the parameter for flight planning as shown in Table 3 is kept constant throughout the mission. The example of flying path for 60 m altitude form the starting point was shown in Figure 5.

Table 2. GCP’s Coordinates from the GPS equipment.

| GCP  | X (m)      | Y (m)      | Z (m)  | GCP  | X (m)      | Y (m)      | Z (m)  |
|------|------------|------------|--------|------|------------|------------|--------|
| Point 1 | 100.3090  | 5.361794   | 2.4981 | Point 9 | 100.3081  | 5.362101  | 17.6515|
| Point 2 | 100.3087  | 5.361453   | 3.0666 | Point 11 | 100.3080  | 5.361885  | 18.7456|
| Point 3 | 100.3083  | 5.361267   | 9.3624 | Point 12 | 100.3079  | 5.361427  | 21.0252|
| Point 4 | 100.3082  | 5.361323   | 12.2802| Point 13 | 100.3079  | 5.361657  | 21.0656|
| Point 5 | 100.3086  | 5.361771   | 6.8458 | Point 15 | 100.3082  | 5.361864  | 12.8003|
| Point 6 | 100.3080  | 5.361396   | 17.9836| Point 16 | 100.3082  | 5.361467  | 12.3663|
| Point 7 | 100.3085  | 5.362202   | 9.1804 | Point 17 | 100.3081  | 5.361482  | 16.5218|
| Point 8 | 100.3083  | 5.362229   | 12.6819| Point 18 | 100.3081  | 5.361867  | 16.4450|
Table 3. Flight planning parameter

| Mode            | Parameter               | Mode          | Parameter       |
|-----------------|-------------------------|---------------|-----------------|
| Shooting angle  | Parallel to Main Path   | Front Overlap Ratio | 75%             |
| Capture mode    | Hover & Capture at Point| Side Overlap Ratio | 70%             |
| Speed           | 5.0 m/s                 | Course Angle  | 0°              |
| Altitude        | 50,60,70,80,100         | Gimbal Pitch  | -90° (Downwards)|

Figure 5. Flying path for 60 m altitude

3.4. Photogrammetric data processing

Digital photogrammetry software was used to perform data processing, generating DSM and producing orthophoto of the study area. Agisoft Photoscan Professional version 1.2.6 was used for processing following the parameter kept constant as shown in Table 4. The GCPs were used to perform the aerial triangulation to produce 3D stereoscopic model. GCPs were also used to georeference images to the local coordinate system. The step is continued by generating DEM and orthophoto of the digital aerial imagery as shown in Figure 6. The generated output from the drone images is DSM, because the photogrammetry technics take into consideration of the surface texture to perform triangulation process. The generated orthophoto was used for accuracy assessment and visualization.

Figure 6. Flow of photogrammetry data processing

Table 4. Data Processing Parameter

| Software Version | Coordinate system | Camera Optimization parameters | Camera Alignment parameters | DEM Reconstruction parameters |
|------------------|-------------------|--------------------------------|-----------------------------|------------------------------|
| 1.2.6 build 2834 | WGS 84 (EPSG:4326) | f, b1, b2, cx, cy, k1-k4, p1-p4 | Accuracy-High Pair preselection - Reference | Source data-Dense cloud Interpolation-Enabled |
4. Results and Discussion

In this research, two photogrammetric output were generated such as digital elevation model and digital orthophoto by processing the data obtained from UAV for with GCP and without GCP based on variation in flying altitude using the low-cost UAV. To assess both approaches, data process is done with and without GCP to different altitude which is for 50 m, 60 m, 70 m, 80 m, and 100 m using the same waypoints. The effectiveness of GCP number to mapping accuracy also were analysed based on number of 4, 6, 8, 10, 12, and 16. Results of the analysis were shown in the table and figure below. Two methods of analysis were carried out for accuracy assessment which qualitative and quantitative analysis. Qualitative analysis was done by analysing the quality of the generated orthomosaic map and DSM. Besides, the quantitative analysis is done by using Root Mean Square Error (RMSE) comparation with both sets of data. Check points derived using the GPS equipment were compared with control points error and the total error of control points should be less than the error of check point. This is crucial to produce a photogrammetric output with good accuracy.

4.1. Qualitative Analysis

Based on the generated orthophoto and DSM of five different flying altitudes, we can say the output with GCP were relatively in good accuracy. When overlaid the orthophoto of the both condition in Google Earth file (KMZ), we can conclude that the one with GCP can tie up nicely to the coordinate system as shown in Figure 7 below. This is because GCP coordinates was used for bundle adjustment and to tie the orthophoto to the exact reference point. GCP can integrate data collection as well as dramatically improving your UAV mapping accuracy.

![Figure 7. Alignment of orthophoto in Google Earth for 50 m altitude for Without GCP (a) and with GCP (b)](image)

Furthermore, there is difference in DSM produced when using GCP and without GCP in processing the data obtained from the drone. When we compare the accuracy of DSM obtained, we can say that the output georeferenced with GCP can produce a good DSM. Based on the DSM for 50 m altitude as shown in Figure 8, the lower ground altitude is 0.454 m for with GCP compared to without GCP which is 42.7 m. We can conclude that GCP is necessary to produce photogrammetric output that have a good accuracy in height variation for further analysis of the site. Normally, it is enough to use from 5 to 10 ground control points even for large areas of the field. Many points do not significantly contribute to a higher accuracy but for different terrain variation, the higher number of ground control points are necessary to achieve the desired accuracy.
Figure 8. Output DSM for both with GCP (A) and without GCP (B)

4.2. Quantitative Analysis
The RMSE of both control points and check point was checked to show that the output of the both data sets with different altitude have difference in total error as shown in Table 5. The control points error should be less error compared to check points to state that the output of photogrammetric product with GCP is good in accuracy. When we compare the total error with GCP and without GCP, we can conclude that the error for without GCP is higher, but the percentage is very low. This is because the software can align the camera according to the built in GCP which is not very accurate to produce an output for further analysis. The output with GCP can correctly geolocate the site being surveyed, accurately scale the project in all three axes and allow the user to make an accurate dimensional measurement.

| Flying Altitude | Count | X error (cm) | Y error (cm) | Z error (cm) | XY error (cm) | Total (cm) |
|-----------------|-------|--------------|--------------|--------------|---------------|------------|
| 50              | 4     | 6.1436       | 21.5321      | 32.2627      | 22.3914       | 39.2716    |
| 60              | 4     | 8.51959      | 25.3507      | 36.7458      | 26.7440       | 45.4477    |
| 70              | 4     | 5.54228      | 20.699       | 33.494       | 21.4281       | 39.7619    |
| 80              | 4     | 6.94968      | 19.9826      | 31.2954      | 21.1567       | 37.7758    |
| 100             | 4     | 7.53276      | 19.861       | 31.4474      | 21.2416       | 37.9126    |

(B) Check points RMSE for with GCP

| Flying Altitude | Count | X error (cm) | Y error (cm) | Z error (cm) | XY error (cm) | Total (cm) |
|-----------------|-------|--------------|--------------|--------------|---------------|------------|
| 50              | 12    | 10.1175      | 9.71998      | 30.8882      | 14.03         | 33.9252    |
| 60              | 12    | 15.2688      | 18.8708      | 29.9404      | 24.2743       | 38.5444    |
| 70              | 12    | 10.0901      | 10.2131      | 31.3416      | 14.3568       | 34.4734    |
| 80              | 12    | 10.1719      | 10.1113      | 31.0228      | 14.3425       | 34.1778    |
| 100             | 12    | 10.0328      | 10.1439      | 31.4297      | 14.2673       | 34.5164    |
Table 6. Total Average error for output without GCP

| Flying Altitude | X error (cm) | Y error (cm) | Z error (cm) | XY error (cm) | Total (cm) |
|-----------------|-------------|-------------|-------------|--------------|-----------|
| 50              | 49.1324     | 34.1228     | 43.5112     | 59.8194      | 73.9702   |
| 60              | 40.8823     | 35.9328     | 68.9821     | 54.4292      | 87.8696   |
| 70              | 38.9209     | 30.1707     | 58.2878     | 49.2454      | 76.3058   |
| 80              | 21.5566     | 26.3666     | 35.0791     | 34.0571      | 48.892    |
| 100             | 24.9255     | 25.3111     | 42.8238     | 35.5237      | 55.64     |

Besides that, we also can conclude that height variation can affect the resolution of map produced from the photogrammetric process. The higher the altitude, the lower the resolution per cm/pixel as shown in Table 7. So, the Ground Sampling Distance (GSD) play an important part to produce a high-resolution map. We should consider that the altitude for capturing the data should have a minimum GSD but factor of area to be covered also must be considered. Some project client may set requirement on the resolution of the map to be produced, therefore GSD is very important so that we can able to produce the required output as per the request. This is mainly to save time and numerous data used for processing which sometimes takes days to finish.

Table 7. Resolution of Outputs

| Altitude | Resolution With GCP (cm/pix) | Without GCP (cm/pix) |
|----------|-----------------------------|----------------------|
| 50       | 6.9                         | 6.68                 |
| 60       | 7.99                        | 7.86                 |
| 70       | 9.09                        | 9.00                 |
| 80       | 10                          | 9.88                 |
| 100      | 12.4                        | 12.1                 |

Furthermore, the effective number of GCP also were analysed based on 4, 6, 8, 10, 12, and 16 GCP numbers. Based on the analysis as shown in Table 8, we can say that the optimum number of GCP is in the range of 8-10 where the RMSE is very low and optimum to obtain high accuracy photogrammetric output. The number of GCP more than 8 is required for huge study area with differential elevation profile because the coordinates of well distributed GCP is important to map the area with accurate elevation measurement.

Table 8. Error for effective number of GCP

| Number of GCP | X error (cm) | Y error (cm) | Z error (cm) | XY error (cm) | Total (cm) |
|---------------|--------------|--------------|--------------|---------------|------------|
| 4             | 60.1575      | 59.4198      | 80.4802      | 50.0123       | 80.5112    |
| 6             | 35.5628      | 38.7728      | 60.7414      | 34.0143       | 62.5004    |
| 8             | 15.0001      | 11.0101      | 51.6016      | 24.3508       | 50.0734    |
| 10            | 10.1719      | 10.1113      | 33.0021      | 14.1025       | 43.1277    |
| 12            | 10.4398      | 10.6479      | 28.0207      | 12.0643       | 40.6214    |
| 16            | 10.0014      | 10.1113      | 26.0008      | 12.1455       | 40.0081    |

5. Conclusion

Based on this study, the digital aerial imagery of low altitude UAV can be used for large scale mapping with the aid of GCP. Without GCP, the accuracy of the output is normally in the range of 10 to 40 m or more off from the original position. But once ground control has been implemented to the image processing, the accuracy improves to 0.2 to 1 meters or better accuracy. GCP must be distributed well in the study area and more number of points does not replicate higher accuracy products. The number of 8-10 GCP is sufficient to produce a reliable photogrammetric output. Area’s
with differential terrain profile needs more number of GCP to measure the elevation of each point accurately to produce accurate model. Data processed with GCPs will render better results which are reliable with the least errors compared to data processed without GCPs. The sub-meter accuracy can have produced with the UAV applications with low cost expenditure and less workforce which is the main plus point. For future works, difference in accuracy respects to GSD’s should be tested out to obtain the optimal GSD for mapping and number of GCP’s for study area consists of differential elevation profile.

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