The impact of UAV flight planning parameters on topographic mapping quality control

H H Ali¹ and F M Abed¹
¹College of Engineering, University of Baghdad, Baghdad, Iraq

Abstract. There is a growing need for up-to-date data for rapid decision making in the modern digital age. Recently, the need for high-resolution topographic maps is highly demanding by most mapping clients. With the maturing automatic structure from mobile and multi-view stereoscopy software, small organizations and individuals now have the ability to make their own surveys based on mobile mapping devices. This study looks at how feasible using low-cost Unmanned Aerial Vehicle (UAV) as a mobile mapping device for photogrammetric topographical surveys. It is showing the impact of different UAV flight settings and parameters on the accuracy of mapping products. An automatic scenario for photogrammetric flight mission and its execution are proposed and described. The focus of this research is to generate 3D point clouds from digital imagery using low-cost UAV and showing the relationship between flight mission settings and the quality of the delivered 3D data. Automatic solution is presented and analysed, which automatically generate 3D point clouds from arbitrary image configurations. Results delivered within millimetres based on specific flight setting and optimal quality control considerations. Accuracy assessment and validation process was adopted based on statistical assessments according to ground truth 3D adjusted measurements to assure validity.

1. Overview
The term UAV is commonly used in the computer science, robotics and artificial intelligence, as well as photogrammetry and remote sensing communities. These vehicles could be drove or controlled remotely, semi-autonomous, autonomous, or have a mix between these capabilities. Mobile topographic mapping is known as the acquisition of spatiotemporal event by using a mobile multi-sensor platform such as UAV [1]. Maps and digital terrain models are kind of object information which derives structure from registered data, and this is the purpose of mobile topographic mapping. The process round of mobile topographic mapping consists of the following steps: mobilization of the platform and flight planning, data acquisition, data processing, extraction of object information, and allocation of object information to a user [2]. Each step takes long time to execute based on the used platform and the processing system. Many manufactures for several years offer multi-sensor platform. This platform is consisted of the following components: integrated navigation unit consisting of GNSS receivers (GPS) and this part provides the exposure station coordinates; the inertial measurement unit (IMU) and this optical part is named gimbal which control the rotation angels of the sensor; and the optical 3D measurements system mostly represented through one or several laser scanner sensors or cameras (Choi, Chan. 2015). However, this research is focusing on mobile topographic mapping-based UAV photogrammetry platform.
2. Flight planning

In the past a single-lens frame camera is the type most often used in metrical photogrammetry. These cameras expose the entire frame or format simultaneously through a lens held at a fixed distance from the focal plane [3]. They have a format size of 9*9 in. (23cm*23cm) and lenses with focal lengths of 6 in. (152.4 mm), although 3-1/2, 8-1/4, and 12 in. (90, 210, and 305 mm) focal lengths are also used. Certain factors, depending generally on the purpose of the photography, must be specified to guide a flight crew in executing its mission of taking aerial photos. Some of them are boundaries of the area to be covered, required scale of the photography, camera focal length and format size, and end-lap, and side-lap percentage. Once these elements have been fixed, it is possible to compute the entire flight plan and prepare a flight map on which the required flight lines have been delineated [4]. The pilot then flies the specified flight lines by choosing and correlating headings on existing natural features shown on the flight map. In the most modern systems, the flight planning is done using a computer and the coordinates of the flight lines are calculated.

The UAV is automatically guided by an on-board IMU-GNSS system along the planned flight lines. Also, the most important parameter that should be calculated when using UAV is the GSD (Ground Sampling Distant) [3]. The GSD defined as the distant on the ground between the centres of two neighbour pixels on the image. Certain factors should be known from the specification of the camera like sensor width (millimetre), focal length of the camera (millimetre), image width, and image height (pixel). When we assume the flying height in (meter) to calculate the GSD in (centimetre per pixel), the value can be delivered based on the following formula [5]:

\[ \text{GSD} = \frac{\text{Sensor width} \times \text{flying height} \times 100}{\text{focal length} \times \text{image width}} \]

A simple tool was established for this purpose, see figure 1 in below.

3. Targets design and distribution

For accurate final derivable in any photogrammetric project, it is highly recommended to use GCPs with a well distribution selection in the study area. In order to inspire and make control targets, it is important to know the resolution of the camera mounted on the UAV in the maximum flight plan altitude. In this research a low cost and feasible ground targets were designed and distributed in the study area in order to be recognized smoothly from the maximum flying altitude. These targets were made from hard plastic created by CNC machine with specific dimensions which was (1*1) meter and in the centre, there was a circle target with a radius of 25cm divided into 4 quarters and in the centre of this circle another circle with radius 1.8cm and as it described in figure 2. These targets were distributed to cover the entire study site which is selected to be inside the UOB campus (see figure 3) with two selected study areas (college of engineering and college of science).
Figure 2. Shows the dimensions of the designed GCP targets.

Figure 3. Shows the distribution of the designed GCP targets.

4. **GCP observation**

Photogrammetric control consists of any point whose position is known in an object space reference coordinate system and whose image can be positively identified in the photographs. In aerial photogrammetry, the object space is the ground surface, and various reference ground coordinate systems are used to describe control point positions. Photogrammetric control, or ground control as it is commonly called in aerial photogrammetry, provides the means for orienting or relating aerial photographs to the ground. Therefore, every phase of photogrammetric work requires some ground control [5]. There are many methods for establishing ground control points such as total station and GPS. A GPS method known as differential positioning can be used to determine locations of points with much greater accuracy than point positioning, see figure 4.

Figure 4. Shows the concept of differential GPS measurements.
In order to observe these GCPs, the DGPS type TOPCON GR5 was used in this research. Static mode was used in observing 4 GCPs for post-processing. However, 13 GCPs were observed with post-process Kinematic mode. To correct these GCPs online, OPUS website and TOPCON tool office software were utilized. GCP 01, 02, 06 and 10 are considered as base stations in the project and thus the other 14-point corrections depend on these base stations. Figure 5 shows the occupied duration for each GCP point, the horizontal and vertical precision, and standard deviation of the adjusted GCPs coordinates.

![Figure 5](image_url)

**Figure 5.** Shows the shows the occupied duration for the GCP points and their statistics after 3D adjustment in L.S.

### 5. Image acquisition

The flight was achieved in the manual, assisted or autonomous mode, relative to the mission specifications, platform’s type, and environmental conditions. The presence on board of GNSS/INS navigation devices is frequently exploited for the autonomous flight (take-off, navigation, and landing) and to guide the image acquisition process. The image network quality is strongly influenced by the typology of the performed flight in the manual mode. The image overlap and the geometry of capturing are usually very asymmetrical, although the presence of GNSS/INS devices, together with a navigation system, can guide and improve the acquisition process. During the flight, the autonomous platform is typically monitored with a Ground Control Station (GCS) which displays real-time flight data such as speed, attitude, position, distances, GNSS observations, battery or fuel status, rotor speed, etc. On the opposite, remotely controlled systems are steered by the operator from the ground station [6]. Thereafter, the system allows image data acquisition following the computed way-points, however low-cost systems acquire images with a scheduled interval. The used devices (platform, auto-pilot, and GCS) are fundamental for the quality and reliability of the final result: low-cost instruments can be sufficient for little extensions and low altitude flights, while more expensive devices must be used for long endurance flights over wide areas. Generally, in the case of light weight and low-cost platforms, a normal overlap in the image block cannot be confident as they are strongly influenced by the presence...
of wind, piloting capabilities and GNSS/INS quality, all randomly affecting the attitude and location of the platforms during the flight. Thus, higher overlaps, with respect to flights performed with manned vehicles or very expensive UAVs, are usually recommended to keep in count these problems.

In order to capture images to create the 3D model, a quad-copter DJI Phantom 4 pro was deployed for this purpose. This type of drones has a built-in camera with sensor (1 inches CMOS; effective pixels 20 megapixel) flying autonomously by applying GPS-IMU mounted on the drone. By using Pix4D capture software in the smartphone or iPad, the flight mission could be uploaded from the PC and then the drone.

There were five different altitude applied in this research (40, 60, 80, 100, and 120 meters). Also, two capturing angle position were used (Normal and oblique). Furthermore, two overlap percentages were adapted with single grid and double grid mission scenarios in both 100 and 120m altitude in normal case.

6. Data processing
There are many softwares to process the UAV images; however, Pix4D and Agisoft PhotoScan are the two most popular paid aerial imagery and photogrammetry processing choices. These softwares are with relatively simple user interfaces and comprehensible manuals, as well as an established track record of use for professional aerial mapping applications. Both programs are regularly updated and improved upon, as the demand for UAV mapping and the market for photogrammetry software expand. However, aid photogrammetry software is expensive and can require considerable processing power to operate, which should be factored into mapping budgets. While GCPs are useful for increasing the accuracy of georeferencing, most photogrammetry software packages, such as Agisoft PhotoScan and Pix4D, can function without them. Instead, they use GPS data collected by a GPS logger or by a GPS-enabled camera to create a reasonably geographically accurate image [7].

Pix4D Mapper was used in this research to process the data. It can process up to 10000 images, fully automated and with a high accuracy. A Geo-referenced orthomosaic and DSM can be obtained in principle without the need for GCPs. However, as shown here, more accurate geo-referencing does require GCPs and therefore was adopted in this research for validation and quality control purposes.

Six flight planning parameters have been reviewed in this research to determine the quality control and quality assurance of topographic mapping. These parameters were also analyzed to show their impact on accuracy requirements in a UAV photogrammetric mapping projects. These parameters are: flying altitude, gridding style, GCPs, photo orientation, image quality, and overlap percentage.

7. Accuracy assessment and analysis

7.1 GCP adoption
The first parameter to analyze was the GCP adoption in image triangulation process to show their impact on the accuracy of the 3D point cloud model. Three different flying heights were selected and in individual flying height, the images were processed once with GCP points and later without GCP point adoption. In all phases the camera Gimbal was set to normal to the flying direction. The RMSE values are shown in individual flying heights in figures (6, 7, and 8) respectively in both with and without GCP phases. The results show the highly positive impact of using GCPs in triangulation process as they significantly increase the 3D accuracy especially when the GCPs are selected to be far from buildings and formed a strong control figure in the study area.
**Figure 6.** Shows the RMSE of the triangulated point clouds with GCP adoption in 60 m. flying height.

**Figure 7.** Shows the RMSE of the triangulated point clouds with GCP adoption in 80 m. flying height.
7.2 Difference in Flying Height
Five different flying heights were tested and analyzed to show how height can affect accuracy when other parameters are fixed. In all cases the camera Gimbal was set to normal to the flying direction. Figure 9 is showing the RMSE results delivered from the selected flying heights. It is clear from the figure that the accuracy is decreased in the three directions whenever flying height is increased. However, some exceptions are highlighted in 100m flying height which needs further investigations.

7.3 Image orientation
The major benefit of this process is to compare between the oblique images and normal images and their impact on the calculated GSD when the area coverage and number of photos are dramatically changed. The oblique images were captured when the Gimbal of the camera was tilted 70 degree from the horizon which equals to 20 degree from the normality. Two study area were tested in this process, 100 meter flight plan was applied on the circle road bounded the science and engineering colleges, however 60 meter altitude was deployed over the college of engineering only. Figure 10 in below is showing how the image orientation can impact the GSD resolution and number of photos those extremely impact data processing time and the delivered accuracy.
### Difference in flying Height Processing

| Easting (m) | Northing (m) | Elevation (m) |
|-------------|--------------|--------------|
| 40m with GCPs | 0.019 | 0.014 | 0.028 |
| 60m with GCPs | 0.0225 | 0.0153 | 0.04 |
| 80m with GCPs | 0.0265 | 0.0155 | 0.17 |
| 100m with GCPs | 0.0195 | 0.02 | 0.14 |
| 120m with GCPs | 0.02 | 0.0295 | 0.167 |

*Figure 9.* Shows the RMSE of the triangulated point clouds delivered from different flying heights.

### Normal Vs Oblique process Data

| GSD (cm/pixel) | quantity of IMG | area coverage(sq.km) |
|----------------|----------------|----------------------|
| 100m nadir     | 2.7            | 508                  | 0.821                |
| 100m oblique   | 2.99           | 320                  | 1.05                 |
| 60m nadir      | 1.45           | 333                  | 0.323                |
| 60m oblique    | 1.7            | 198                  | 0.494                |

*Figure 10.* Shows the relationship between image orientation and GSD resolution, and number of images in UAV triangulation projects.
7.4 Overlap percentage
Small study area was elected to test the end-lap and side-lap impact on the calculated GSD and number of photos. Therefore, the building of the surveying engineering department and water resources department in addition to the building of the architecture department were selected to apply the flight mission. The flying height was selected to be 50 meter above these buildings. Two end-lap and side-lap values were selected in this mission as shown in figure 11 together with their results. The results show a bizarre relationship between overlap percentages with photo numbers which might be due to the selected values those seems to be close to each other’s to show a sensitive difference and therefore this flying mission parameter needs further investigations.

Figure 11. Shows the relationship between image overlap percentage and GSD resolution, and number of images in UAV triangulation projects.

7.5 Gridding
Gridding scenario in flight planning is a very important parameter that can affect the accuracy of the final product in topographic mapping projects. There are two main scenarios in this respect, single gridding and double gridding to cover the study area. Although double gridding should increase GSD resolution in typical conditions, it can increase the number of the processed images which deliver more error sources. In this research two different altitudes have been selected to analyse gridding scenario, 100 and 120m. In both altitudes when double gridding is applied, the grids were set perpendicular to each other’s. In figure 12 the results are demonstrated which show obvious draw back in horizontal and vertical accuracies when double gridding is applied. This can be due to the large amount of the delivered photos that inversely affect the 3D triangulated point clouds in horizontal and vertical directions.
Figure 12. Shows the impact of double gridding scenario in flight planning mission on the 3D point cloud accuracy.

7.6 Image quality processing:
This part of processing is analysing the quality of the processed image on the point cloud densification and accuracy using PIX4D image processing program. Small area was chosen in this test (51 m²) with 239 images set to 50-meter flying height. There are three kinds of point cloud densification options in this software; low, optimal and high quality modes. Figure 13 is showing the impact of the quality of the processed images on the density of the triangulated point clouds and thus objects resolution. It is obvious from the results that high quality mode is recommended for sites with dense details such as natural study sites.

8. Conclusions and outlooks
This paper is presented a practical methodology to use low-cost UAV for topographic mapping. The study looks at how feasible using low-cost UAVs for this particular application and showing the impact of different flight planning parameters on the accuracy of the mapping products. A statistical study was presented to show how difference in flying height can change the accuracy of the delivered 3D data. It also analyses the impact of GCPs adoption in triangulation process, gridding plan scenario, image quality of the processed images, image orientation, as well as overlap percentage on the resolution and densification of the triangulated points and also the accuracy of these points if compared with ground-truth targets. It was found that dramatic drop in accuracy could be delivered whenever flying height is increased; however, careful care should be adopted to keep other parameters fixed. It was also found that although oblique images can cover larger area on ground and reduce image number, it is recommended to use near nadir images if the ground accuracy is a priority for projects aiming for millimetre level accuracy. Further and from findings delivered in this two study areas, it is not recommended to use double gridding scenario in flight planning, because it increase the number of the processed images dramatically which deliver more error sources and reduce accuracy. It is also recommended to use high quality image mode when processing images in Pix4D software, however, a workstation is recommended to use to overcome system crashes. Finally, it is
recommended to do further processing and plan setting regarding overlap percentage to deliver a clear message about its impact on the data resolution and accuracy.

![Diagram showing the impact of image quality on 3D point cloud densification.](image.png)

**Figure 13.** Shows the impact of the image quality mode in Pix4D software on the 3D point clouds densification.

### References

[1] Neitzel F and Klonowski J 2012 Mobile 3D mapping with a low-cost UAV system *ISPRS - IAPRS XXXVIII* 39–44.

[2] Blyenburgh V P 1999 UAVs: An overview Vol. 1.

[3] Colomina I, Blázquez M, Molina P, Parés M and Wis M 2008 Towards a new paradigm for high-resolution low-cost photogrammetry and remote sensing *XXIst ISPRS Congress: Technical Commission I XXXVII* Par 1201.

[4] Ghilani C and Wolf P 2015 *Elementray surveying - Introduction to geomatics* Vol. 13.

[5] Chan C 2015 Low cost UAV photogrammetry accuracy assessment *J. Geodesy and Geomatics Engineering* 1–20.

[6] Francesco N and Remondino F 2014 UAV for 3D mapping applications: A review *J. Applied Geomatics* 6 1–15.

[7] Serge W 2015 Drones and Aerial Observation: New Technologies for Property Rights, Human Rights, and Global Development *J. New America* 63–71.