Assessment of Photogrammetric Mapping Accuracy in Slope Area with Different Flight Altitude Using Unmanned Aerial Vehicle (UAV)

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Abstract. Nowadays, UAV is preferred by experts since it is more affordable with reliable accuracy. However, debates on its accuracy draw worldwide attention in order to maintain the output’s quality. Flight altitude is one of the most debated issues of UAV employment due to various ground conditions. Thus, this study intends to investigate the effects of flight altitude towards the final output accuracy. In this study, three different flight altitudes (60m, 80m and 100m) were used to test the outputs accuracy within selected sites in UPNM campus by employing DJI Phantom 4 Pro V2.0 drone. Orthophotos and Digital Surface Model (DSM) of the selected sites were then generated using Pix4DMapper Software. On-screen measurements of selected features within the selected sites were taken and compared with the actual measurements obtained on grounds. Later, these outputs were used to generate contours using ArcGIS software. The generated contours were compared with available as-built plan. The results were examined qualitatively and quantitatively. From this study, it is found that the mean variance values on flat surface using different flight elevation were 0.86m, 0.99m and 1.16m for 60m, 80m and 100m respectively. Whereas, the mean variance values on hilly surface were 6.95m, 4.35m and 4.3m for 60m, 80m and 100m. On flat surfaces, 60m flight altitude was the best height to be used for UAV mapping. However, for hilly surfaces, 100m flight altitude was the best height to be used. This contrast may due to the lower overlapping images in 60m flight altitude image capture. From the study also, it is found that the accuracy of UAV mapping on hilly surfaces tends to be lower than flat surfaces. This called for further studies to identify the best measures to reduce the errors resulted by extreme ground characteristics.

1. Introduction
Growing interest on the application of UAV as a replacement for satellite imagery and manned aircraft is skyrocketed. This may due to several critical factors such as low cost, fast speed, high maneuverability and enhances the safety of UAV system. Data acquisition is the most expensive stage in most civil engineering project mapping, inspection, and research [1]. It promises an acceptable cost for data acquisition with acceptable accuracy. According to Raczynski [2], the most sophisticated UAV aircraft
technology is being driven by UAV operators for various applications. Over the years, drones have become cheap and handy. New developments in sensors and fly platforms have expanded the applications enormously including volume calculations, producing orthophoto maps, generate 3D models, obtaining Geographic Information System (GIS) data, monitor open-pit mines production, conducting construction checks, general mapping of terrain and more [3 - 7]. The UAV shortens the length of inquiry from several days to several hours to spend on the field [8]. They also, if used correctly, improve the safety of the person who performs the measurements, as the operator may live in a dangerous zone [8]. The low-cost drones are found to produce an accurate product if used appropriately, but then, there is a question on how to conduct the photogrammetric missions to achieve the highest possible accuracy required. Raczyński [2] mentions the adoption of new innovative technologies, particularly in mapping and surveys, are based on product enhancements offered in terms of accuracy and reliability and the effectiveness of time and money spent on measurement.

Many factors must be considered when capturing data and the most important factor is the setting of flight mission parameters such as height altitude on which UAV is flying, percentage of which adjacent images are overlapping and speed of the aircraft while taking photos, as a sensor used for acquiring images are rolling a shutter camera [9]. Moreover, site condition also influences the data captured. Indirect geo- referencing (geometric correction) plays an important role in bundle block adjustment since the reliability of camera calibration is based on the accuracy of Ground Control Points (GCP) [10]. However, no GCP is used in this study where the direct geo-referencing is used from the UAV-GNSS onboard measurement. Hence, the altitude of flying in flight mission is the focus on this study which can influence the accuracy assessment of the final product obtained.

Photogrammetry is the science of making measurements from photographs. From the overlapping images, finding a position of 3D points of a scene is the key problem. Thereby, it can be processed later based on collinearity condition. It is a process where a line originates from central projection of a camera and goes through a point in sensor plane (on the image) to the point of the object in the ground coordinate system. The three-dimensional points of a scene location are determined by the intersection of many lines. To reconstruct metric model from images, the orientation of image and calibration of camera are essential. These two approaches enable it to be achieved which are by classical photogrammetric workflow or computer vision (VC) technique. Known camera positions are something that makes the former depend on as well as with triangulation, the model can be resolved. There is a solution if the positions of the cameras are unknown which is by placing a set of reference markers with 3D coordinates that is known, manually identified in the images and to get the camera positions by using resection [8].

2. Study Area

![Image](image1.png)

Figure 1. Study Area
This study was conducted in Universiti Pertahanan Nasional Malaysia (UPNM) campus. A site within the campus was selected due to minimal signal interference and obstructions for UAV mapping applications. This site is located within a road construction project which has flat surfaces as well as hilly slopes which is very suitable to test the study assumptions; the lower the altitude, the higher the accuracy of the mapping for both surface characteristics. Figure 1 shows the site selected during this study. Figure 1(a) shows the satellite imagery obtained from Google Earth whereas Figure 1(b) shows the as-built plan of the same site with contour interval of 1m.

3. Methodology

As shown in Figure 2, this study was divided into four main phases. Phase 1 involves the gap study and reviews, preliminary study and site reconnaissance. In Phase 2, flight planning and data acquisition were conducted using DJI Phantom 4 drone. Phase 3 revolves within data processing using Pix4D Mapper and ArcGIS Desktop 10.5 software. In this phase, Pix4D Mapper was used to produce orthophotos and digital surface model (DSM) whereas ArcGIS Desktop 10.5 was employed to generate contours with 1m interval from the data obtained. In the last phase (Phase 4), data analyses were conducted qualitatively and quantitatively. Qualitative analysis was conducted through visual comparisons whereas, quantitative analysis was conducted using statistical calculation to identify which flight altitude (60m, 80m or 100m) is the best to be used for UAV mapping. The mean variance was calculated based on the measured distances of selected features on the site.

**Figure 2. Methodology of the Study**
This study was carried out without using ground control points (GCP) embedded within the UAV system due to the limitation of this study in obtaining the GCP data. Even though this is the case, the UAV system was designed to be able to align the camera with the build in GCP. Although this may reduce the product’s accuracy, the percentage of the error resulted is low [8].

In this study, the accuracy of the outputs was examined using mean of variance of the measured distances of selected features on the study area. Higher variance depicts higher errors resulted during the data acquisition. Equation 1 shows the formula to calculate variance and Equation 2 shows the calculation of mean.

\[
\sigma^2 = \frac{\sum(x_i - \bar{x})^2}{n-1} \quad (1)
\]

\[
mean \ of \ variance = \frac{\sigma^2}{n} \quad (2)
\]

4. Results and Discussion
The result and discussions were conducted in two different ways; qualitatively and quantitatively. The results and findings of this study are as follows:

4.1 Qualitative Analysis
Visual interpretations and comparisons conducted in this study show that the images captured using the three different altitudes produced a close resemblance. This means that, similar images of DSM were produced although three different flight altitude were used during data captures. Figure 3 shows the DSM layer produced. For the flight altitude of 60m, the highest peak is 171.836m, and the lowest value is 81.8828m. The highest and lowest value for the flight altitude of 80m is 178.057m and 70.694m respectively. For the flight altitude of 100m, the highest value is 183.097m and the lowest value is 86.173m.

The contours generated using ArcGIS Desktop 10.5 software were also examined. In Figure 4, it is shown that the patterns of the generated contours were also similar for 60m, 80m and 100m flight altitude except for some differences at the top of the hill. From the figure, it is found that the highest peak in the contours generated with flight altitude of 60m is missing as compared to the contours generated with the flight altitude of 80m and 100m. This may due to the lack of overlapping images during the data captures using flight altitude of 60m. This calls for further studies to identify the relationship between number of overlapping images and flight altitude to improve the product accuracy.

In order to identify which contour layer is the best in resembling the actual ground condition, comparison with the available as-built plan was conducted. It is found that the close resemblance was identified in the contours generated using 80m and 100m flight altitude. However, the overall visual interpretations shows that all three generated contour layers can reconstruct similar road design, slope patterns and alignments.
Figure 3. Digital Surface Model (DSM) in Different Altitudes; a) 60m, b) 80m, c) 100m
4.2 Quantitative Analysis

Figure 5 and Figure 6 shows the variance values of each selected feature on the studied site. On flat surfaces, it is found that Feature 1 has the lowest variance values for every flight altitude as compared to Feature 2 and Feature 3. A little contrast was found for hilly surfaces where Feature 1 has the lowest variance values for 80m and 100m flight altitude but not for 60m altitude. In both surfaces, Feature 2 has the lowest accuracy as depicted by higher variance values for each flight planning. This may due to different characteristics of each feature selected in term of its size, colour and the pixel size of the outputs which affect the on-screen measurements taken in this study. Thus, the inconsistencies in the results should be scrutinized further in future studies.

**Figure 4.** Contour Lines of Different Altitudes; a)60m, b)80m, c)100m

**Figure 5.** Variance values on flat surface
Figure 6. Variance values on hilly surface

Table 1 and Table 2 shows the mean variance of each observations. From the table, it is identified that the output generated using 60m flight altitude on flat surfaces has the lowest mean variances with the value of 0.86m, indicating higher accuracy as compared to the other two flight altitudes. On the other hand, the output generated using 100m flight planning on hilly surface shows the highest accuracy as compared to 60m and 80m flight planning as depicted by lowest mean variance calculated (4.3m).

Despite the contrast in the mean variance value for both surfaces, the study has found that the difference between each flight altitude were different. Larger differences were identified in the output generated using 60m flight altitude as compared to 80m and 100m flight altitudes. The differences of variance values in 80m and 100m were relatively small and consistent as compared to 60m flight altitude. This might due to the lack of overlapping images as stated before. Thus, it can be said that the errors resulted from 80m and 100m altitude become more stable.

Table 1. Mean variance for each flight altitude on flat surface

| Feature | Flight Altitude | 60m | 80m | 100m |
|---------|----------------|-----|-----|------|
| Feature 1 | 60m | 0.25 | 0.18 | 0.14 |
| Feature 1 | 80m | 1.51 | 1.67 | 1.86 |
| Feature 1 | 100m | 0.81 | 1.12 | 1.49 |
| Mean Variance | 60m | 0.86 | 0.99 | 1.16 |

Table 2. Mean variance for each flight altitude on hilly surface

| Feature | Flight Altitude | 60m | 80m | 100m |
|---------|----------------|-----|-----|------|
| Feature 1 | 60m | 7.23 | 3.19 | 2.77 |
| Feature 1 | 80m | 10.57 | 6.22 | 6.09 |
| Feature 1 | 100m | 3.04 | 3.64 | 4.04 |
| Mean Variance | 60m | 6.95 | 4.35 | 4.30 |
5. Conclusion
Based on this study, the accuracy assessment made on the selected features are related to the number of overlapping images due to different flight altitudes. In qualitative analysis, the lowest flight altitude at 60m produced a low overlapping images that resulted to the missing peak at the top of the hill on generated contour lines and this was opposed to 80m and 100m of flight altitudes. However, there are no differences were detected on the alignment of road and slope location at all flying altitudes.

Meanwhile, in quantitative analysis, it is shown that different altitudes may resulted different accuracy on variance values between flat and slope terrains. For both terrains, the altitude at 60m gave poor accuracy due to insufficient overlapping image as compared to 80m and 100m flying altitudes. However, some factors like feature size dimension and colour, plus the pixel size of the outputs must be considered due the different flight altitudes that lead to the variation on Ground Sampling Distance (GSD). At the end, the decision on applying lower or higher flight altitude should be reviewed in all aspects to achieve the required accuracy, thus getting UAV as an assistive tool in surveying and mapping activities.

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Acknowledgement
The authors would like to express their gratitude to Universiti Pertahanan Nasional Malaysia for the financial support for this work (UPNM/2019/GPJP/TK/6).