Generation of digital elevation model through aerial technique

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Abstract. Unmanned Aerial Vehicle (UAV) system, nowadays, is highly utilized to solve problems in various applications across different fields due to its low-cost, safety, and its low flying altitude. With photogrammetric techniques and latest available aerial technology, it is possible to utilize UAV for generation of Digital Elevation Model (DEM) and subsequently, determination of elevation on various geomorphology. Previously, this is only possible through deployment of manned aircraft and metric camera which requires monumental cost. This paper reviews the applications and developments of DEM generation. Three main components are presented in this review: (a) a summary of conventional surveying methods to determine elevation, subsequently generate a DEM, (b) a summary of remote sensing methods to generate DEM; namely satellites, and airborne platforms, and (c) findings and future possibilities for further studies. The review reveals that traditionally, DEM is produced through ground surveying methods, traditional photogrammetry methods, and derivation of contours and elevation points from hardcopy topographic maps. The chapters discuss each of the methods and common DEM products derived from them. Most of the studies reviewed herein articulate the mechanism of triangulation which is a method to rectify the DEM to its local geographical and elevation coordinates. So far, only a relatively small number of detailed studies have been conducted on the DEM produced by UAV. From the findings of flying the UAV at 4 different altitudes of 50 m, 80 m, 110 m and 140 m; much more research on the identification of elevation through UAV-based imagery is required from different altitude of flight. Hence, it is possible to use UAV to identify elevation in small areas which has limited project budget and time constraints.

1. Introduction

In recent years, Unmanned Aerial Vehicle (UAV) is proven to becoming more effective and highly utilized to solve problems in various applications across different fields. It is potentially applicable in many fields such as remote sensing, disaster mapping, search and rescue, aerial surveillance, atmospheric survey and others [1]. Among the applications of UAV is aerial photogrammetry which is the art, science and technology to obtain data and information about an environment through a process of recording, measuring and interpreting photographic images [2]. Photogrammetry utilizes overlapping photographs to measure coordinates and determine elevation. Subsequently, these overlapped photographs are used to prepare planimetric or topographic mapping at specified accuracy. From the high-resolution photographs, we can generate high density coloured point clouds by using the recent photogrammetry methodology which is based on Structure from Motion (SfM) algorithm and Multi View Stereo (MVS) that integrates the feature of Computer Vision into classical 3D
photogrammetry technique [3]. From the point clouds, we are able to generate Digital Elevation Model (DEM) which can be used to obtain information regarding elevation on a desired position.

Traditionally, DEM are produced through aerial photogrammetry which involves standardized photogrammetric workflow by obtaining the aerial photographs using a manned aircraft and metric camera which involves monumental cost [4]. However, with recent development in surveying and remote sensing technology, there are different data sources and method for DEM which will be discussed further in this paper. The data sources and method to produce DEM will be focused on the traditional ground surveying, topographic maps, remote sensing, and UAV. In this paper, by using photogrammetric technique through UAV, we observe its capability in generating DEM consequently, determining height in a study and provide an insight of the possible research in future. UAV is predicted to be utilisable in completing a surveying works, such as levelling, with reduced time, cost and manpower [5]. Therefore, the aim of this study is to study the DEM generated from low cost UAV from the altitude.

2. Literature Review

DEM is a quantitative representation of the Earth terrain which gives basic information about its relief and elevations [6]. The model is made up of an array representation of squared cells (pixels) with value of elevation associated to each pixel [7]. The values of cells in the model are interpolated to establish values for entire terrain model. In recent development involving geomorphologies, it is essential to know the terrain prior to any decision making. The process of making decision is enhanced with the availability of 3D geographically-referenced DEM as they provide efficacious visualization.

There are many uses of DEM which greatly facilitate in understanding our environment towards establishing a more sustainable management of our environmental resources. For example, DEMs play an important role in hydrological modeling, geological studies, disaster analysis, agriculture applications, and so on. DEM is generated through ground surveying, digitizing topographic maps, remote sensing, and photogrammetry.

2.1. Ground Surveying

According to a study [8] to assess ground survey methods and airborne laser scanning for digital terrain modelling (DTM), three different methods were used for ground surveying which are tachymetry, real time kinematic global positioning system (RTK-GPS), and terrestrial laser scanning (TLS). Firstly, the tachymetry method involves the deployment of total station and prism. This method is known to produce the highest of accuracy for (X, Y, Z) but it requires at least 2 manpower, consumes a lot of time and requires lengthy starting workflow from determination of datum. Secondly, the RTK-GPS method is the simplest as it only involves one instrument which is the GPS itself and can be operated with one manpower and able to produce high accuracy of (X, Y, Z). Thirdly, the TLS uses the principles of the Light Detection and Ranging (LiDAR). It can produce millimeter-order accuracy and operable with 2 manpower. From the study, he also found that the total standard deviation of measurement (SDM) error for tachymetry to be the highest of below 5 mm, followed by GPS at 6.5 mm and TLS at 10 mm. With regards to tachymetry for RMSE in DTM elevation, they found that the GPS has RMSE of 0.168 m and the TLS has RMSE of 0.511 m. This result is supported by a study [9] where she also found that the DEM produced by tachymetry has the highest accuracy, followed by RTK-GPS and TLS.

2.2. Remote Sensing

There are various satellites offered to generate DEM from their sensors but mainly they are divided into commercial and open source satellite. A study to evaluate vertical accuracy of open source DEM used Cartosat-1 DEM, ASTER GDEM Version 2 and SRTM. In this study, the DEM is georeferenced to the GCP which is observed using Global Positioning System (GPS). It is found that when georeferenced to Ground Control Point (GCP) and compared to EGM96 geoid model, the Root Mean Square Error (RMSE) for Cartosat DEM is 4.83m, ASTER is 6.08m and SRTM is 9.2m [10].
2.3. Airborne Platform

The airborne platform utilizes an aerial platform, a high-resolution camera, and GCP to georeference its images to the local geographical coordinates. There are a number of research that studies the accuracy of DJI Phantom generated DEM. A study [11] found that when flown at altitude of 50m with 17 GCP, they are able to generate DEM with vertical accuracy of 0.1151m. Another study found that when flown at altitude of 50m with 4 GCP at Modry Kamen, they are able to achieve vertical accuracy of 0.023m [12]. Although all the studies apply the principles of georeferencing of the photographs to GCP, the differences of the products in these studies shows that there is a need for a detailed study on the DEM produced by UAV. Hence, 4 different altitude is selected in this study to investigate the DEM generation through aerial technique which are determined at 50m, 80m, 110m and 140m. The 50m altitude is chosen based on previous studies conducted as a benchmark to compare this study. The other 3 altitudes are chosen to investigate the accuracy of DEM at a higher altitude of data acquisition and subsequently, deduce a better altitude alternative so that wider area of study can be acquired since UAV is known for its limited flight duration.

3. Study Methodology

![Flow Chart for Study Methodology](image)

Figure 1. Flow Chart for Study Methodology
The study is split into 4 phases; namely Phase 1 on Preliminary Study, Phase 2 on Data Acquisition, Phase 3 on Data Processing, and Phase 4 on Data Analysis. Figure 1 shows the flow of methodology to be conducted in the pilot study. The study area is chosen at Pantai Kelanang and the flight path is set near to the beach to as it has different terrain morphology and features. The image was taken automatically using a dedicated photogrammetry mapping app, Map Pilot, with 60% side lap and 30% end lap. 3 GCPs were placed near to the beach to tie the images using an RTK-GPS with 3D coordinates (x, y, z) observed.

The data is collected by using a low-cost UAV, DJI Phantom 3 Professional with 35mm fixed lens camera. The flight path is generated using Map Pilot with the flying height and flying speed fixed at constant rate. Only the flight altitude is changed at 4 different sets, which is 50m, 80m, 110m, and 140m.

The acquired images is processed using a dedicated digital photogrammetric software, Agisoft Photoscan, to generate DEM and orthophoto of the beach. The GCP placed earlier is used for aero triangulation of the images so that it will result in stereoscopic images with coordinates. The process is done by producing DEM, orthophoto and RMSE result.

Lastly, a qualitative and quantitative analysis is done on the DEM and orthophoto produced from different altitude. The qualitative part is conducted by analysing the quality of the DEM and orthophoto produced. Meanwhile, the quantitative part is conducted by performing the RMSE calculation over the GCP obtained by RTK-GPS and differentiated by equal point position estimated by the photogrammetry-generated result. The equation for Root Mean Square Error (RMSE) is shown in Equation 1.

\[
RMSE = \pm \sqrt{\frac{\sum(n_1-n_2)^2}{N-1}}
\]  

whereby;

\(n_1\) = difference in value of two parameters  
\(n_2\) = mean of differentiation  
N = sum of points

4. Results and Analysis

Digital Elevation Model (DEM) is a raster data that can be generated solely from the aerial images themselves, however, to produce a higher accuracy product, it is important to place Ground Control Point (GCP) with accurate coordinates. This DEM is generated by using module functions in PhotoScan Pro which must follow the procedure as specified in its manual.

![Figure 2. DEM generated by Phantom 3 at 50m altitude](image1)  
![Figure 3. Orthophoto generated by Phantom 3 at 50m altitude](image2)
Figure 4. DEM generated by Phantom 3 at 80m altitude

Figure 5. Orthophoto generated by Phantom 3 at 80m altitude

Figure 6. DEM generated by Phantom 3 at 110m altitude

Figure 7. Orthophoto generated by Phantom 3 at 110m altitude

Figure 8. DEM generated by Phantom 3 at 140m altitude

Figure 9. Orthophoto generated by Phantom 3 at 140m altitude

For qualitative analysis, based on Figure 3, Figure 5, Figure 7 and Figure 9, it can be seen that all 4 images exhibit the same feature whereby the water is located on the left side and the beach on the right side. The flow of the beach from the sand to water is continuous in all 4 orthophotos. Beach must form continuous flow from sand to water and exhibit no jumps between the original aerial photograph edges. However, huge differences in DEM is seen in Figure 8, compared to Figure 2, Figure 4 and Figure 6. Figure 2, Figure 4 and Figure 6 shows an almost uniform normal elevation pattern from the water to the beach, but in Figure 8 the elevation pattern shows a major difference whereas it seems that the beach is at the same level with the water.
After that, it can be seen that different altitude results in different elevation range. Figure 2, Figure 4 and Figure 6 shows an almost near lowest elevation range which is between -24.7849m to -22.5365m. In Figure 8, the lowest elevation is recorded at 28.1207m which is a huge difference compared to others.

For quantitative analysis, the RMSE is compared between the 3D coordinates obtained from GPS-RTK and the 3D coordinates obtained from estimation by photogrammetric-generated result. Generally, smaller RMSE values indicates higher accuracy of the result. The following Table 1 shows the tabulation of RMSE results.

| Flying Altitude (m) | Aerial Triangulation | RMSE (m) |
|---------------------|----------------------|----------|
|                     |                      | X        | Y        | Z        | Mean     |
| 50                  | 3                    | ±0.043   | ±0.009   | ±0.009   | ±0.044   |
| 80                  | 3                    | ±0.135   | ±0.176   | ±0.135   | ±0.863   |
| 110                 | 3                    | ±0.031   | ±0.008   | ±0.013   | ±0.034   |
| 140                 | 3                    | ±0.048   | ±0.024   | ±0.004   | ±0.054   |

Based on Table 1, it can be seen that the difference of mean RMSE between the minimum and maximum flying altitude differs by ±0.010 m. The best result is obtained when flying at 110m which shows mean RMSE of ±0.034 m.

Nevertheless, it must be noted that the results of this study might be influenced by possible multiple errors. The environmental conditions which is the strong monsoon wind from the coastal area constitutes a challenge in flying the UAV [13]. This is because the wind interferes heavily during the image acquisition on the flight path which may affect the resultant image and subsequently affecting the DEM produced based on the UAV imageries. This is evident during the flight at 80m altitude where the mean RMSE shows a huge difference compared to other 3 altitudes.

5. Conclusion

Based on this study, it can be concluded that the UAV system can be used to produce DEM with sub-meter accuracy. Although other methods such as traditional ground surveying can be used for higher accuracy and remote sensing can be used for larger area. If the project requires sub-meter accuracy within a limited timeframe over a small area, the UAV system is applicable. Hence, based on this study, the recommended altitude for DEM generation from UAV imagery is 110m at most, or below. Generating DEM from UAV images flown at 140m altitude is not recommended as the resulting model shows a vast difference from the original value.

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