Systemic Approach to Elevation Data Acquisition for Geophysical Survey Alignments in Hilly Terrains Using UAVs

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Abstract. This study is about systematic approach to photogrammetric survey that is applicable in the extraction of elevation data for geophysical surveys in hilly terrains using Unmanned Aerial Vehicles (UAVs). The outcome will be to acquire high-quality geophysical data from areas where elevations vary by locating the best survey lines. The study area is located at the proposed construction site for the development of a water reservoir and related infrastructure in Kampus Pauh Putra, Universiti Malaysia Perlis. Seismic refraction surveys were carried out for the modelling of the subsurface for detailed site investigations. Study were carried out to identify the accuracy of the digital elevation model (DEM) produced from an UAV. At 100 m altitude (flying height), over 135 overlapping images were acquired using a DJI Phantom 3 quadcopter. All acquired images were processed for automatic 3D photo-reconstruction using Agisoft PhotoScan digital photogrammetric software, which was applied to all photogrammetric stages. The products generated included a 3D model, dense point cloud, mesh surface, digital orthophoto, and DEM. In validating the accuracy of the produced DEM, the coordinates of the selected ground control point (GCP) of the survey line in the imaging area were extracted from the generated DEM with the aid of Global Mapper software. These coordinates were compared with the GCPs obtained using a real-time kinematic global positioning system. The maximum percentage of difference between GCP’s and photogrammetry survey is 13.3 %. UAVs are suitable for acquiring elevation data for geophysical surveys which can save time and cost.

1. Introduction
Geophysical surveys in mountainous and natural terrains are normally challenging because of the site conditions, which may affect the quality of data acquisition. Subsurface characterization of terrains requires accurate elevation data to produce good subsurface models of survey lines. During geophysical survey operations, various challenges emerge due to several factors such as the use of dynamite as an energy source, reserve forests, presence of wildlife, and highly undulating terrain conditions. These factors call for the implementation of stringent safety standards while ensuring the quality of the data acquired within the study period in the most cost-effective manner. This study introduces a new technique in data acquisition to elevate ground surfaces using unmanned aerial vehicles (UAVs). UAVs promise low-cost data acquisition and highly accurate data. UAVs are also one of the fastest platforms for acquiring target data. Drone mapping is already bringing enormous insights and efficiency gains to a variety of industries and has become increasingly popular in recent years. Obtaining an overhead view of a site in the quickest way possible is extremely useful for site planning and communication across many industries, particularly construction and mining. Using
drones to understand elevation data is particularly valuable. The use of drone imagery is also highly useful in disaster risk reduction [1],[2],[3],[4],[5],[6].

The main photogrammetric procedures include aerial triangulation, image orientation, model definition, creation of surface models, orthophoto generation, and vector data collection for geographic information systems (GIS) or cartographic requirements. Digital elevation models (DEMs) can be improved using a certain number of ground control points (GCPs), and their coordinates are determined by geodetic measurements. GCPs are usually measured using real-time kinematic global positioning system (RTK-GPS). In the direct method, the 3D georeferenced point cloud can be generated directly after adjustment of the GPS time and camera inertial time. In the indirect method, the GCP is measured before flight via RTK-GPS surveying [7], [8], [9], [10], [11].

2. Materials and Methods

2.1 Drone flight phase

In this research, a UAV fly path was designed to cover the study area completely with two sets of fly paths in the vertical and horizontal phases. Figure 1 shows the flight line at the study area. The current waypoint file specifies the global position, flying altitude above ground, heading, speed, and external control for pitch and triggering of the camera. A user can generate the waypoints automatically according to pre-defined settings, such as those for flying an UAV in a circle or other complex patterns. The time a quadcopter spends at a waypoint location and the required accuracy before the camera takes a photo can also be specified.

Figure 1. Example of flight pathway for data acquisition using Dji Phantom 3.
2.2 Image Acquisition phase
An autonomous flight mission was initiated to capture aerial images of the study area. The drone captured 135 images covering the entire study area. The flight took about 25 minutes to complete the two sets of flight phases. This method made it possible to acquire high-resolution imagery, which was crucial in generating the orthophoto and DEM. Details of the drone flight phase are shown in Table 1.

The following flight processes was developed:

![Image](image_url)

Figure 2. Flight Processes for Image Acquisition.

Table 1. Details of drone flight phase.

| Date and time       | Sunday, 19 March 2017, 5:59:41 PM |
|---------------------|-----------------------------------|
| Area covered        | 422100 m²                         |
| Distance covered    | 11.44 km                          |
| Altitude            | 100 m                             |
| Resolution          | 4.3 cm/px                         |

2.3 Ground Control Point
GCPs are physically marked locations with a fixed position and precise coordinates. GCPs increase the accuracy in the X, Y, and Z axes (commonly known as; northing, easting, elevation; and latitude, longitude, and altitude). Fixed points in the study area were used to adjust the project physically in three dimensions to align it with the GCPs and create global and local accuracies. GCP are essential in ensuring highly accurate image processing. If the navigation positioning system cannot be used directly (even for autonomous flight) because the signal is strongly degraded or not available, the orientation phase must rely only on a pure image-based approach, which requires GCPs for scaling and geo-referencing. Six GCPs were imported in the bundle adjustment solution and treated as weighted observations inside the least squares minimization, as shown in Figure 3 and Table 2.
2.4 Image processing phase

The Agisoft PhotoScan Professional 1.2.6 software was used to process the imagery. Photogrammetric data processing is needed to generate a georeferenced 3D point cloud from the unordered, overlapping, and airborne image collection of the surface. After the acquisitions, images can be used in the photogrammetric process. Camera calibration and image triangulation were initially performed to generate a digital surface model or digital terrain model successively. These products could finally be used in the production of ortho-images, 3D modelling applications, or the extraction of further metric information. Camera calibration and image orientation tasks required the extraction of common features visible in as many images as possible (tie points) followed by bundle adjustment. After the orientation of a set of images, the following steps in the 3D reconstruction and modelling workflow were performed: surface measurement, orthophoto creation, and feature extraction. Starting from the known camera orientation parameters, a scene could be reconstructed digitally by means of interactive procedures or automated dense image matching techniques. The output was normally a sparse or a dense point cloud. Dense image matching algorithms should be able to extract dense point clouds to define an object’s surface and its main geometric discontinuities. Figure 4 shows the procedure in processing the aerial images to produce digital orthophotos and DEM.

Table 2. Coordinates and elevation of GCPs.

| GCP | Latitude (m) | Longitude (m) | Height (m) |
|-----|-------------|---------------|------------|
| 1   | 6.465182303 | 100.3500048   | 84.410     |
| 2   | 6.464993975 | 100.3498294   | 90.842     |
| 3   | 6.465888486 | 100.3499698   | 74.762     |
| 4   | 6.465800961 | 100.3496002   | 71.237     |
| 5   | 6.463826653 | 100.3488958   | 50.984     |
| 6   | 6.463929842 | 100.3484779   | 51.849     |

Figure 3. Location of GCPs in the study area.
Figure 4. Analysis process of a drone image in Agisoft Photoscan software.
2.5 Verification of Digital Elevation Model

The surface model acquired from drone mapping together with photogrammetry processing was compared with GCPs. The coordinates of each GCP were plotted on the global mapper software to compare the validity and accuracy of the terrain model. Accuracy is an important factor in the mapping and surveying of an area. The comparison was performed by plotting the elevation of each GCP in the point and line graph. The orthophoto and DEM were exported to the global mapper software to generate a contour of the study area. The GCP was marked to extract elevation data from the software. Elevation data were used to compare the GCP elevation taken by the surveyor using RTK. The location of the GCPs on each seismic survey line was marked by the surveyor, as shown in Figure 5. Twelve seismic lines were plotted in the as-built drawing of the study area. Figure 6 shows the flowchart of the procedure to generate the contour and plot the GCP.

![Figure 5. Location of GCPs on the seismic survey line at the study area.](image)

![Figure 6. Analysis processes in Global Mapper software.](image)
3. Results and Discussion

The results of this research include a DEM, digital orthophoto, digital orthophoto with contour line, and contour map. The global mapper software was used to help locate the survey line on the basis of the coordinate. In this way, the surveyor could mark the survey line according to the selected coordinate after considering the topography of the study area. This step ensured that no wrong judgment was made in picking the survey line for the sub-surface survey works. Then, the best fit line for seismic data acquisition was determined with consideration of the factor of slope elevation and site accessibility. Geophysical survey work was carried out efficiently, thereby reducing the risk of changing the survey line alignment on the day of the event. The 2D and 3D models were used to analyse the study area by covering a large, inaccessible area. Figure 7 shows the digital Elevation model and digital orthophoto produced from UAV images and photogrammetry processing.

![Digital Elevation Model](image1)

![Digital Orthophoto](image2)

**Figure 7.** Primary data: (a) Digital orthophoto and (b) Digital Elevation Model.

Data processing in Agisoft PhotoScan and global mapper software produced secondary data based on the DEM of the study area. Figure 8 shows the digital surface model, orthophoto with contour, and panoramic view of the slope model.

![Digital Surface Model](image3)

![Orthophoto with Contour](image4)

**Figure 8.** Secondary data: (a) Digital surface model and (b) Orthophoto with contour.
Figure 8. (a) Digital Surface Model, (b) Digital orthophoto with contour and (c) Panorama view of the slope mode.

Comparison was made by plotting the two graphs and identifying the differences between elevations. The global mapper was found to be capable of producing an elevation line with coordinates and elevation of the survey line with maximum difference of 13.5% in comparison with the GCP data. Differences were calculated for all survey lines with the start and end point elevations and the elevation from the global mapper based on the DEM obtained from photogrammetry process. The photogrammetry survey was compared with GCP’s conventional data collection which shows the difference in error between 4% - 14%. The graph plot between the GCP’s manual elevation and elevation from photogrammetry survey is shown in Figure 9.

Figure 9. Example of GCP and the elevation for seismic line H extracted from software.

Acquiring the elevation on site involves certain disadvantages, including human error, equipment error, and incorrect positioning of handheld GPS. The elevation for the survey line is important in the tomography analysis for seismic refraction. The tomography model should represent the exact surface elevation of the survey line so better illustrate the difference in velocity by depth. The model also presents the slope cross section in which seismic refraction survey is carried out. All generated results based on UAVs can be used for planning preliminary tasks, such as excavation and slope stability analysis. This approach can be cost effective and avoid errors in acquiring elevation data during geophysical survey acquisition. Therefore, this research provides solutions to researchers, consultants, and practitioners in acquiring elevation data with minimal cost, time, and labour requirements.
Table 3. GCP 1 and Photogrammetry Survey. Comparison comparison

| Line | GCP 1 (m) | Photogrammetry Survey (m) | Error % |
|------|-----------|--------------------------|---------|
| A    | 60.32     | 68.02                    | 12.77   |
| B    | 50.23     | 54.25                    | 8.00    |
| C    | 48.02     | 53.14                    | 10.66   |
| D    | 34.25     | 38.92                    | 13.64   |
| E    | 53.58     | 59.65                    | 11.33   |
| F    | 76.28     | 80.25                    | 5.20    |
| G    | 69.47     | 74.69                    | 7.51    |
| H    | 73.12     | 78.14                    | 6.87    |
| I    | 80.24     | 86.17                    | 7.39    |
| J    | 54.36     | 57.34                    | 5.48    |
| K    | 59.41     | 67.34                    | 13.35   |

Table 4. GCP 2 and Photogrammetry Survey.

| Line | GCP 2 (m) | Photogrammetry Survey (m) | Error % |
|------|-----------|--------------------------|---------|
| A    | 45.32     | 48.02                    | 5.96    |
| B    | 50.23     | 54.47                    | 8.44    |
| C    | 67        | 69.87                    | 4.28    |
| D    | 45.78     | 49.45                    | 8.02    |
| E    | 61.25     | 69.54                    | 13.53   |
| F    | 47.25     | 49.97                    | 5.76    |
| G    | 54.25     | 58.79                    | 8.37    |
| H    | 64.54     | 68.46                    | 6.07    |
| I    | 78        | 81.35                    | 4.29    |
| J    | 65.49     | 72.15                    | 10.17   |
| K    | 54        | 59.47                    | 10.13   |

Table 5. GCP 3 and Photogrammetry Survey comparison.

| Line | GCP 3 (m) | Photogrammetry Survey (m) | Error % |
|------|-----------|--------------------------|---------|
| A    | 47.56     | 50.23                    | 5.61    |
| B    | 65.24     | 69.47                    | 6.48    |
| C    | 75.68     | 79.15                    | 4.59    |
| D    | 68.49     | 73.15                    | 6.80    |
| E    | 70.25     | 76.48                    | 8.87    |
| F    | 80.56     | 89.45                    | 11.04   |
| G    | 76        | 79.87                    | 5.09    |
| H    | 64.52     | 69.87                    | 8.29    |
| I    | 80.24     | 86.17                    | 7.39    |
| J    | 63.54     | 69.56                    | 9.47    |
| K    | 55.46     | 59.48                    | 7.25    |

4. Conclusion
This successfully proves the reliability of using UAVs to acquire elevation data for geophysical survey work. This technique can be adopted as a systemic approach to acquire site elevation data in short periods and at low operation cost. Highly accurate data with respect to rules, techniques, and limitations can also be obtained. The quality of the results depends on the number and quality of input images and processing, as well the adequate number of GCPs covering the entire site. The use of UAVs obviously offers many potential applications, including slope monitoring, construction project progress, and determination of excavation.
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