

Automatic Slope Modelling Accuracy Assessment Using Point Cloud Data from Unmanned Aerial Vehicle

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Abstract. Military commanders often determine appropriate routes for combat mobility from source to destination based on a prior understanding of the operating region's important topographic features and environmental factors. With advances in military technology, the types of maps needed for military operations have changed. The computer-based geographic information system (GIS) is an essential technology to replace current topographic surveys. Obtaining survey data with the current method is costly and creates hazardous working conditions, especially on steep slopes or remote areas. Unmanned Aerial Vehicle (UAV) technical capabilities performance has improved yearly. In photogrammetry, this advancement presents broader opportunities to obtain digital images to create large-scale maps. This technology can overcome hazards while reducing the time and cost of obtaining site data at the slope area. In this study, the Digital Surface Model (DSM) and UAV-derived path profiles of various heights are compared, and the accuracy of the data with and without using Ground Control Points (GCP) is examined. A total of seven GCPs and ten control points (CPs) were established in the study area. The study area is located within the National Defence University of Malaysia campus. DJI Phantom 4 captured aerial images from three different altitudes, namely 60m, 80m and 100m. All acquired images were processed using Pix4Dmapper software, and the products produced included digital orthophoto and DSM. Invalidating the accuracy of the produced DSM, the coordinates of the GCP of the survey line in the imaging area were extracted from the generated DSM using Global Mapper software. Compared to 0.43m for 100m without GCP, the average Root Mean Square (RMS) for 100m with GCP is 0.02m. Many inaccuracies are reduced by the GCP 100m altitudes. In conclusion, using GCP can deliver greater accuracy and attain the precision required for surveying. The 100m altitude point cloud data is suitable for mapping and modelling the slope or hilly area with reliable accuracy.

Keywords: Unmanned aerial vehicle; point cloud data; UAVs; terrain analysis; military operation.

1. Introduction

The commander and his team must know how to get closer to the target or enemy location in a military operation or conflict area. Spatial data is required to locate these target or enemy locations. Among analyses done using the spatial information are Slope Analysis, Contour Line Construction, Sight Line Analysis, Visibility Map, Hill Shade Analysis, Route Length and Specific Point of Height (FM 100-5, 1982). Accurate topographic maps were necessary because of the increased lethality and range of firearms in the 21st century. Fields of fire for direct fire (line-of-sight) weapons, cover and camouflage from enemy fire and observation, the simplicity of off-road movement for tactical vehicles, and markers for helicopter routes and landing zones are all critical considerations (FM5-105, 1985). At the divisional or lower levels, tactical decisions call for more accurate and current topographical data.

Military commanders often determine appropriate routes for combat mobility from source to destination based on a prior understanding of the operating region's important topographic features and environmental factors. The crucial ones are soil properties, types of dominant vegetation cover, surface configuration, and surface roughness (US Army, 1990). However, this method is typically fairly time-consuming because most working processes must be completed manually. In those conditions, some analytical tools to support this work are necessary. With advances in military technology, the types of maps needed for combat have changed. The computer-based geographic information system (GIS) is an essential technology to replace the conventional topographic survey. The broad scope of GIS applications in military work is reviewed in (Wilson and Gallant, 2000; Satyanarayana and Yogandron, 2012; and Baijal, Arora and Ghosh, 2012).

Obtaining survey data with the current method is costly, consumes time and exposes to hazardous working conditions, especially on steep slopes or remote areas. As (Tahar, 2015) stated, slope areas are complex and diverse, and many slope areas have different slope angles and heights. Spatial information such as the heights and surface properties of the surrounding area were gathered during topographic surveying. Due to this, the working conditions gathering survey data with the current method are considered hazardous. Compared to physical data collection utilising surveying tools, aerial images provide the best accurate spatial data for mapping. It shows photographs of the actual condition and easily understandable local facts. Traditional aerial photography or pictures are previously taken from an aircraft. However, aircraft require tremendous costs, human resources, and time (Room et al., 2019). Many studies have focused on employing Unmanned Aerial Vehicles (UAVs) as field data acquisition tools for collecting three-dimensional (3D) mapping data and 3D modelling. The primary motivation is to reduce the time to obtain data and avoid hazardous working conditions.

UAV technical capabilities performance has improved tremendously. UAVs can be used as a surveying technology for acquiring spatial data to improve the efficiency of topographical modelling. It is possible to get high-density, high-accuracy data for orthophotos, 3D models, and point clouds. This development in photogrammetry opens up more options for obtaining the digital images needed to produce large-scale maps. UAVs can also take precise, high-resolution pictures when planes or satellites cannot see because clouds block the view from high altitudes. Now that UAV is integrated with the Global Positioning System Real-Time Kinematics (GPS RTK) system, it is possible to create highly accurate topographic maps (Room et al., 2019; Neza et al., 2020). However, the cost of a UAV with GPS RTK is high. Low-cost UAVs are a potential mapping option by employing ground control points (GCPs) and control points (CPs) for georeferencing. With a ground control point (GCP) placed on the ground, UAV data can be used to build a precise topographic map.

A study by (Turner et al., 2014) compared the results of their UAV mapping to those produced using traditional aerial or satellite platforms. It was concluded that UAV-acquired datasets have better resolutions in both temporal and spatial aspects. In comparison, researchers such as (Remondino, 2011) concluded that by employing UAV platforms, 3D outputs such as Digital Surface Modeling (DSM)/Digital Terrain Modeling (DTM), contour lines, textures, and 3D models, and vector data might be created with acceptable accuracy. (Siebert and Teizer, 2014) developed a UAV system to quickly

and autonomously collect mobile 3D mapping data. As a result, new technology, like a UAV, can be investigated to produce effective and quick slope map data (Giordan et al., 2020; Azmi et al., 2014; Ekaso et al., 2020; and Fuad et al., 2018). The accuracy of the map produced from UAV data needs to be scrutinised by comparing it with the accuracies of the traditional surveys. According to (Nagendran et al., 2018; Handayani et al., 2017; and Ismail et al., 2018), GCPs can produce photogrammetric output with reasonable accuracy at different altitudes. Thus, we used GCPs to acquire the highest possible precision in this study. This study evaluates the accuracy of GCPs data in the slope area/hilly area. To achieve the aim of this study, two objectives have been identified as follows:

- a. To compare the Digital Surface Model (DSM) and path profile of different altitudes derived by UAV.
- b. To analyse the accuracy between data with and without using GCP.

2. Methodology

2.1. Study Area

The study area is located within the National Defence University Malaysia (NDUM) campus, which is at the peak of Puncak Gemilang, as in Figure 1. This study collects conventional surveying data using GNSS equipment and UAV for photogrammetry images. The selection of site studies is very fitting and systematic for doing the work as a drone needs to fly in a clear area. Figure 1 shows the configuration of the Ground Control Point (GCP) and Control Point (CP) on the site area of this study. There are seven GCPs, and ten CPs planned to be used and established on-site. Seven GCPs were placed in order to obtain good accuracy. The yellow colour represents the GCPs; meanwhile, the red colour represents the CPs.



Fig. 1 Location of the study area in NDUM

2.2. Field Data Collection and Analysis

The usage of GCP considerably improves the drone maps' overall accuracy. Every point on the map must match its latitude and longitude, partly to GCP. As a result, this study assesses the inaccuracy at various flight altitudes without employing GCP. Figure 2 elaborates on the methodology used in this study. During the first stage, a fixed-wing DJI Phantom 4 was used to capture all of the photographs.

Phase 2 comprises preparation and planning, including site selection, equipment, flight planning, software, and GCP location. Phase 3 data collecting will include two rounds of field data collection. Phase 4 of the data processing utilising Pix4Dmapper software has begun. Global Mapper was employed for data analysis even though Pix4Dmapper is used for image processing. Phase 5 concludes with data analysis using Global Mapper software and a qualitative study.

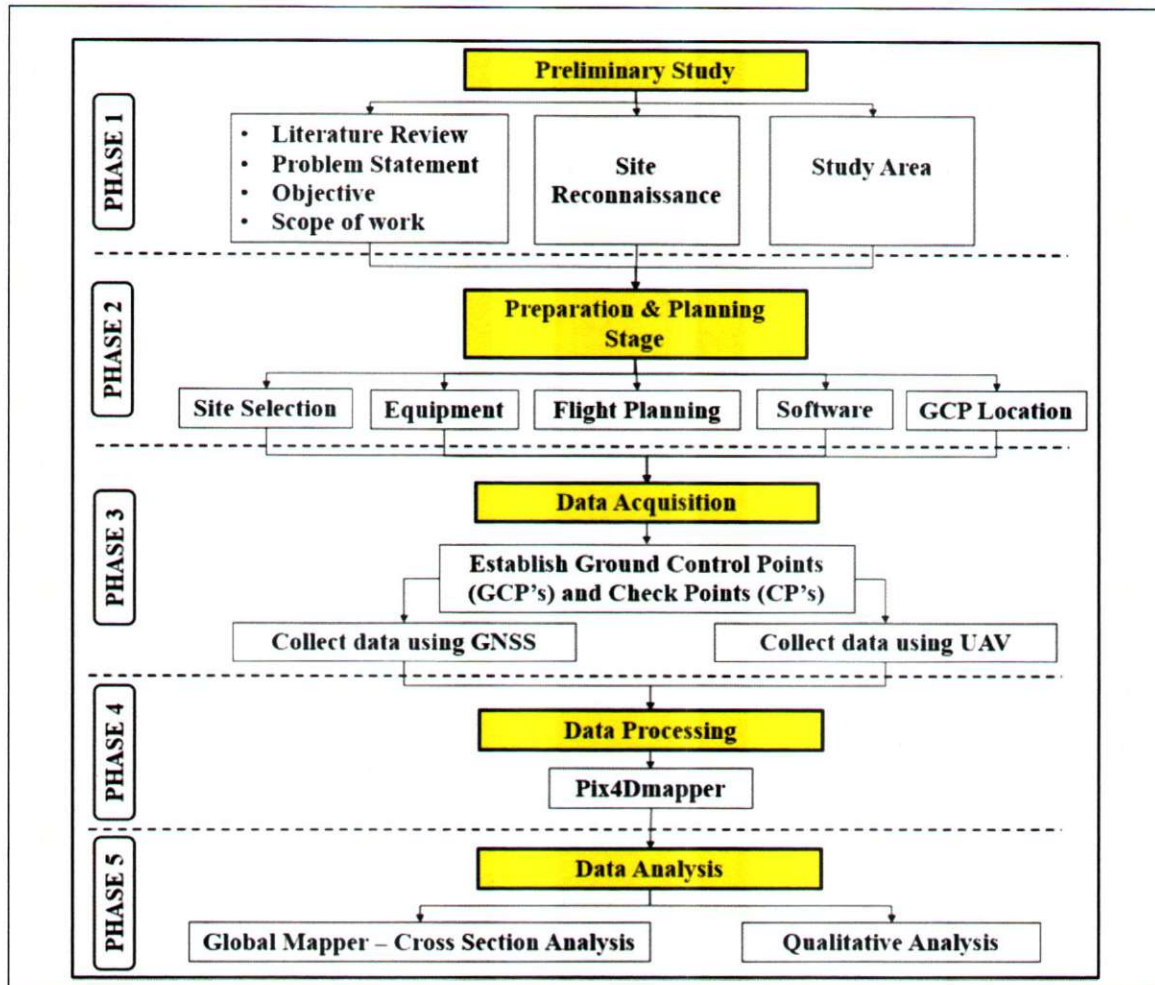


Fig. 2 Methodology of the study

3. Results and Discussion

3.1. Overlapping of images and root mean square error (RMSE)

Pix4Dmapper and Global Mapper are used to do the analysis. Based on the information obtained from the UAV, the Pix4Dmapper programme generated an orthophoto picture and a DSM. An important factor in determining the overall quality is the overlap. Low overlap might result in poor 3D reconstruction in the red sections, demonstrating low overlap. The overlap must be green for accurate 3D modelling and mapping applications. Figure 3 below compares the overlapping images for GCP and without GCP. In Figure 3, low overlapping only happened at the perimeter of the study area without GCP output (a). Most of the study area is covered in green because of the use of GCP. Green areas

denote pixel-by-pixel overlaps of more than five photos. It is noted that high-quality results are produced because these locations have an adequate number of keypoint matches. By using GCPs, we may develop precise 3D modelling in mapping applications. Because images need to be georeferenced to depict the physical world adequately, georeferencing is a crucial issue in the DSM creation.

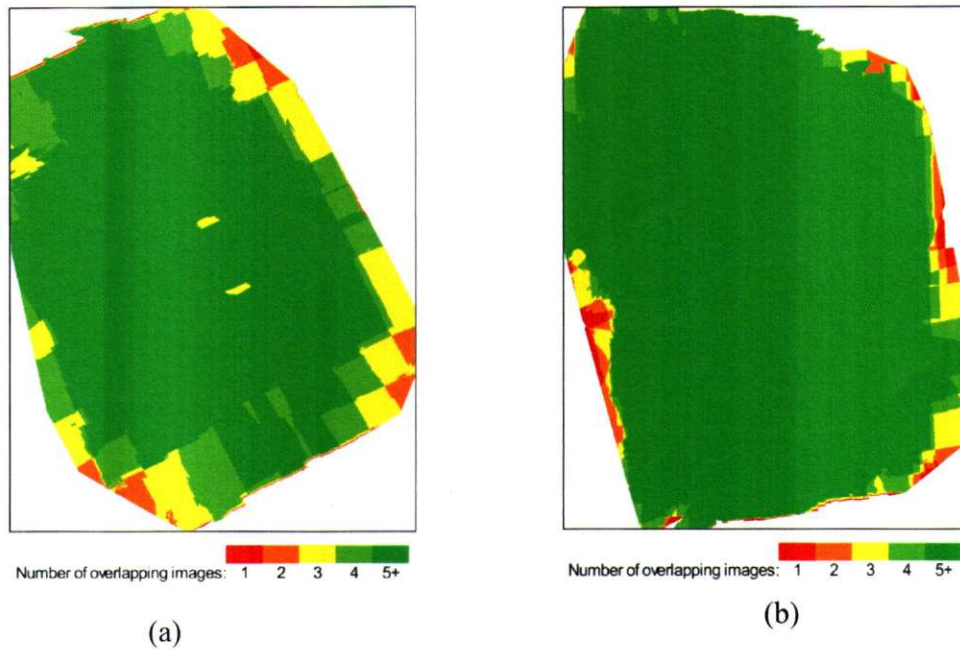


Fig. 3 Overlapping images (a) 100m without GCP and (b) 100m with GCP

Table 1. RSME errors from data processing during Pix4mapper software

| Altitude (m) | Error in X (m) | Error in Y (m) | Error in Z (m) |
|--------------|----------------|----------------|----------------|
| 60 | 2.92 | 1.44 | 0.28 |
| 80 | 0.76 | 0.34 | 0.33 |
| 100 | 0.52 | 0.36 | 0.40 |
| 100* | 0.01 | 0.02 | 0.02 |

*Denote georeferencing with GCP.

The Root Mean Square Error (RMSE) from the Pix4Dmapper software's quality report was also computed for this analysis. Table 1 displays the RMSE values for flying altitude with and without GCP to assess their accuracy. We can observe that compared to 60m altitude, there is not much difference between 100m and 80m elevations at x, y, and z coordinates. While the error is significant at the x and y coordinates for an altitude of 60 metres, it is relatively consistent at 80 and 100 metres without GCP. The low altitude will affect the x and y coordinates but not the z coordinates for slope areas. At 60 metres, the average RMSE is 1.54 metres; at 80 metres, 0.47 metres, and 100 metres without GCP, 0.43 metres. Here, we may state that the RSME decreases with increasing altitude. In contrast, the RSME value increases with decreasing altitude.

For the RSME between GCP use and without GCP, a flying altitude of 100m was used as a comparison. In comparison to 0.43m for 100m without GCP, the average RSME for 100m with GCP is 0.02m. Therefore, it may conclude that there is a considerable difference between GCP and without GCP. Implementing the 100m altitudes with GCP has improved engineering data collection precision. The 100m altitude consistently results in a steep slope or hilly area. Calculatedly, there is a 0.41m difference between these two.

3.2. Path Profile Analysis

The DSM produced by Pix4Dmapper is used with the Global Mapper programme version 22.1. Figure 4 illustrates a DSM example created using a flying altitude of 100m. For each altitude, sections A-A, B-B, and C-C indicate three cross-sections with various berm heights for comparison. Figure 5 is an example of the output of the path profile. Figure 6 depicts the cross-section at various flying altitudes of 60, 80, and 100 metres: A-A, B-B, and C-C sections. Figure 6(a) depicts section A-A without the use of GCP; the ground level at flying altitudes of 60m, 80m, and 100m is 155.35m, 154.6m, and 162.53m, respectively. Figure 6(b) depicts section B-B without using GCP; the current ground level at flying altitudes of 60m, 80m, and 100m is 163.33m, 163.98m, and 170.39m, respectively. Section C-C for the current ground level for flying altitudes of 60, 80, and 100 metres is shown in Figure 6(c) and is equal to 170.96, 171.57, and 177.7 metres. According to the results, for all cross-sections, the difference between 60m and 80m heights is slightly similar in the slope area but different in the flat area (road).

The cross-section of 100m elevations for Sections A-A, B-B, and C-C is depicted in Figure 7. For each cross-section created, an interval of 1m is used. According to the cross-section in Figure 7(a), the present ground level at sections A-A utilising GCP is 174.87m, while the level without GCP is 162.53m. Figure 7(b) illustrates that the current ground level at sections B-B using GCP is 183.92m, while the level without GCP is 170.39m. According to Figure 7(c), the present ground level at Sections C-C with GCP is 190.9 m, while 177.7 m without GCP. According to the observations, there is a considerable difference between utilising and not using GCP, and the error grows with height. Therefore, we can conclude that employing GCP allows us to produce more accurate findings than those obtained without it. Since accuracy is a concern, it is advised that GCP be mandated when conducting surveys, monitoring, mapping, inspections, and many other applications.

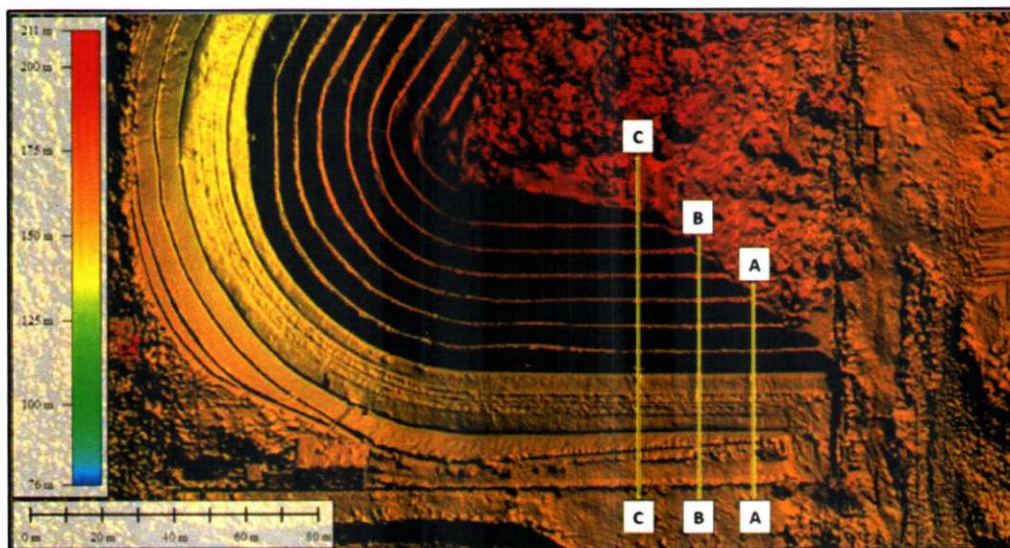


Fig. 4 Output using Global Mapper creating cross-section at A-A, B-B and C-C for a flight altitude of 100m

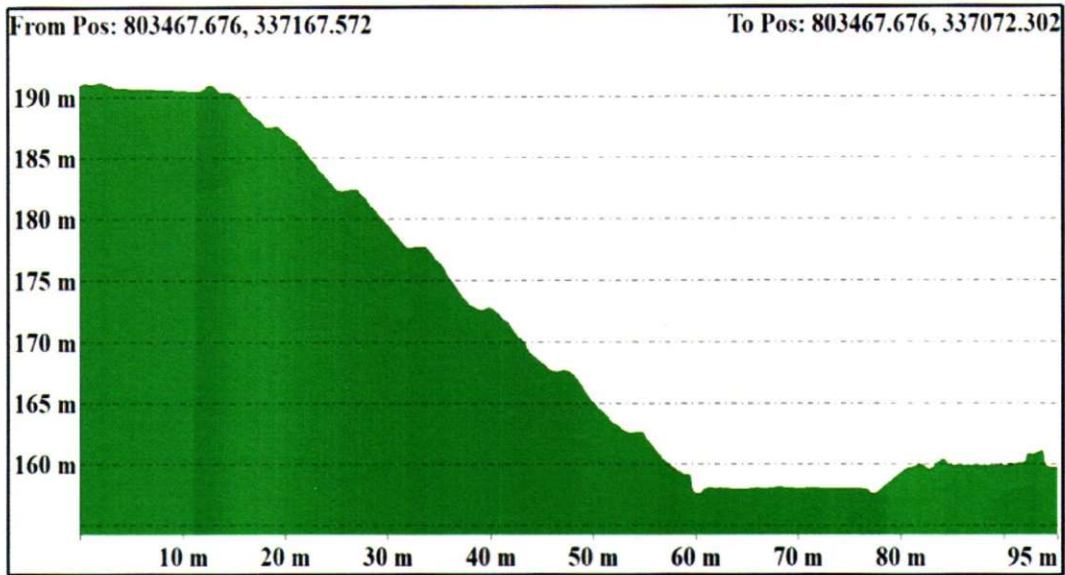
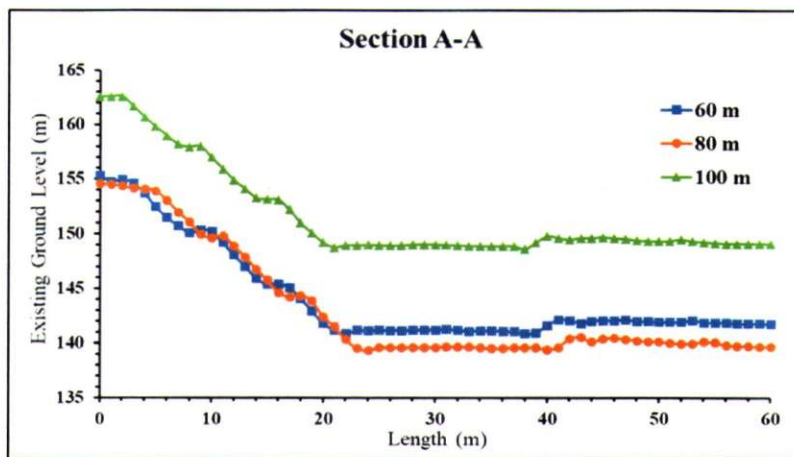
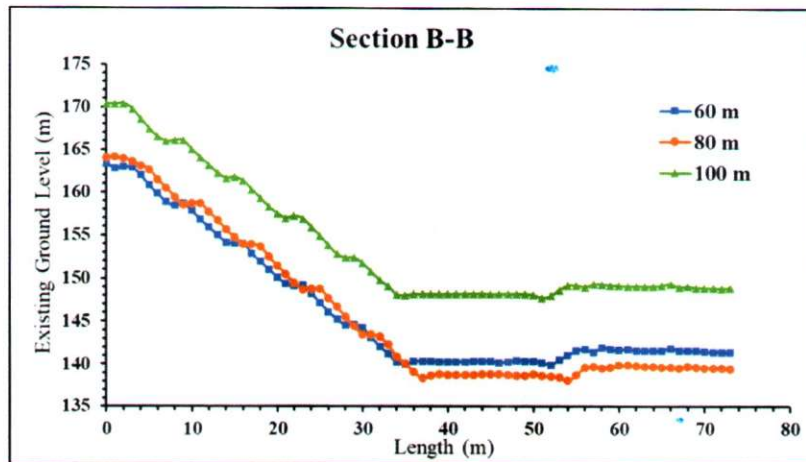


Fig. 5 Path Profile with 7 berms height at cross-section C-C for a flight altitude of 100m

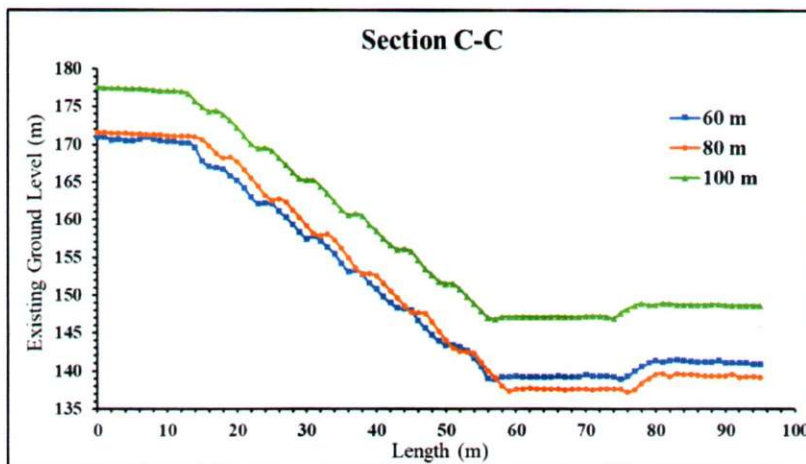
The output of the average error using GCP and without GCP at the slope and flat areas is tabulated in Table 2 above. Sections A and A had average errors at the slope and flat sections of 12.06 metres, 12.42 metres, and 12.71 metres, respectively. As can be seen, section A-A, which has three berms, had a lower inaccuracy than sections B-B, which has five berms, and section C-C, which has seven berms. The dimensional aspects cause the mistakes to grow as the height does. The pixels blur as the flight altitude height increases, making it impossible to see the feature's edges. Without GCP, it has been found that the data obtained has a sizable inaccuracy.



(a)



(b)

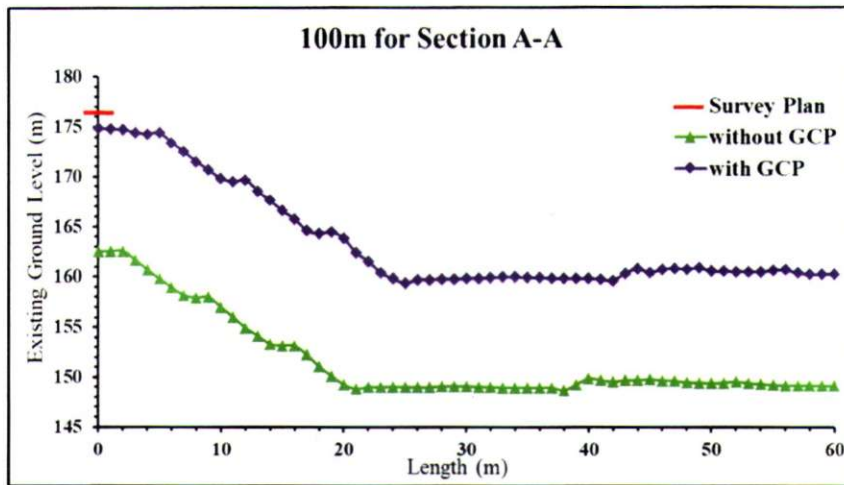


(c)

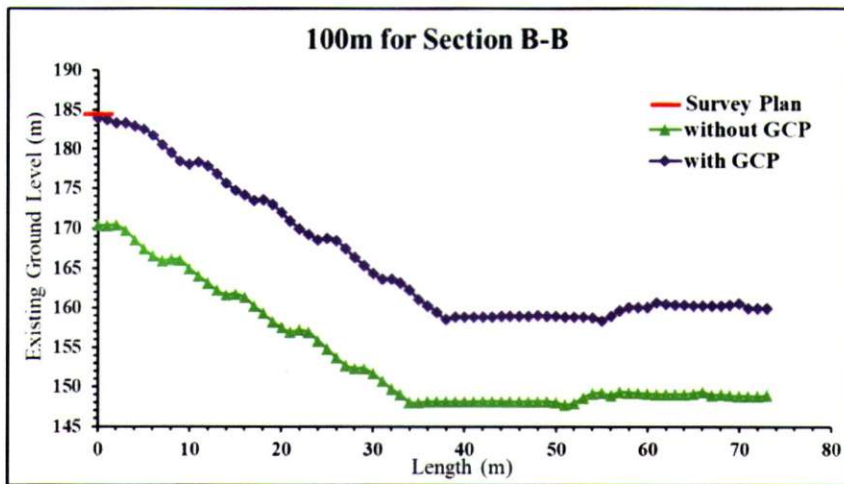
Fig. 6 Cross-section of different flight altitudes of 60m, 80m and 100m (a) Section A-A (b) Section B-B and (c) Section C-C

The output of the average error using GCP and without GCP at the slope and flat areas is tabulated in Table 2 below. Sections A-A, B-B and C-C had average errors at the slope and flat sections of 12.06 metres, 12.42 metres, and 12.71 metres, respectively. As can be seen, section A-A, which has three berms, had a lower inaccuracy than sections B-B, which has five berms, and section C-C, which has seven berms. The dimensional aspects cause the mistakes to grow as the height does. The pixels blur as the flight altitude height increases, making it impossible to see the feature's edges. Without GCP, it has been found that the data obtained has a sizable inaccuracy. To get an exact survey result, it is advised to employ GCP.

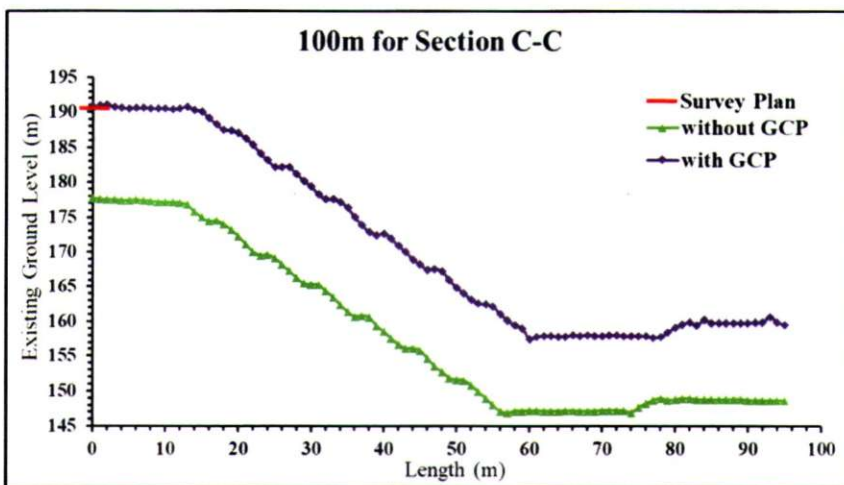
When comparing the survey plan with UAV data, output from 100m altitudes with GCP is used. It has been noted that the UAV's elevations and the site's present ground level are practically the same. The UAV's plant height measurement caused the disparity to be roughly 1 metre. In light of this, data collected from an area with various berms with a fixed height of 100 metres will be impacted. Figure 7 above compares the output from 100m altitudes using GCP between data from the survey plan and UAV.



(a)



(b)



(c)

Fig. 7 Cross-section of flight altitude for 100m; (a) Section A-A (b) Section B-B and (c) Section C-C compared with actual survey data

Table 2 The average errors obtained from 100m altitudes on sloping areas in the use of GCP and without GCP

| Section | Error (m) |
|---------|-----------|
| A-A | 12.06 |
| B-B | 12.42 |
| C-C | 12.71 |

Table 3 Comparison output from 100m altitudes with GCP and actual survey plan

| Section | Survey data (m) | UAV* (m) | Error (m) |
|---------|-----------------|----------|-----------|
| A-A | 175.80 | 174.87 | 0.93 |
| B-B | 184.65 | 183.92 | 0.73 |
| C-C | 190.06 | 190.90 | -0.84 |

**Flight altitude 100m with GCP*

4. Conclusion

For this study, obtaining UAV data is more efficient in time, human resources, and cost than conventional methods. UAVs also can reduce hazards during site data collection. They can be used as preliminary site data with an accepted error range. It can be concluded that using GCP can provide higher accuracy and achieve the precision needed for surveying. UAV is also suited for mapping the slope area with reliable accuracy. If a UAV system is utilised for surveying, GPS control points must be set up to ensure high-precision data collection. These control points are produced for establishing a geographic coordinate system and are manually specified before the UAV flies. They are utilised to make image orientation corrections.

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