TERRAIN MAPPING FROM UNMANNED AERIAL VEHICLES

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ABSTRACT: In land surveying, digital terrain model (DTM) and digital surface model (DSM) have long been benefitted in many applications related to terrain mapping. Conventional methods of generating DTM and DSM have limitations in terms of practicality, time consumption and costing. The problems are much more serious for tropical regions where clouds are persistence and tend to affect the accuracy of most of these devices. This study aims to propose a novel way of generating DTM and DSM by utilising unmanned aerial vehicle (UAV) for different land covers including forest, plantation and developed areas in the tropical region of Malaysia. The aerial images obtained from non-matrix digital compact camera payload on UAV were processed photogrammetrically to produce terrain mapping products including DTM, DSM and orthophoto. A detailed survey is also conducted at these areas to produce contour map as benchmark data in which is less being practiced by UAV mappers. To determine the accuracy, quantitative and qualitative analysis were carried out by means of root mean square error (RMSE) and visual inspection. The results show that the RMSE of DTM for forest, plantation and developed area are ± 1.806m, ± 0.938m and ± 0.549m, respectively while for DSM are ± 3.143m, ± 0.637m and ± 0.276m respectively. This study has determined that, the development area gives the highest accuracy compared to the plantation and forested area in which for developed and plantation area the DSM is better than DTM while vice-versa for forested area. It can be concluded that the complexity if terrain is found to be one of the key factors that influences the accuracy of the generated DSM and DTM.

KEYWORDS: *Terrain Mapping; Land Cover; Unmanned Aerial Vehicle*

1.0 INTRODUCTION

In land surveying, a number of conventional devices have been used in producing terrain mapping particularly DTM and DSM. There are such as total station [1], global positioning system (GPS) [2], light detection ranging radar (LiDAR) [3-4], manned aircraft [5-6], terrestrial laser scanning (TLS) [7] and remote sensing [8-9]. However, despite have been benefitted many, these approaches suffer from certain limitations particularly in terms of time consumption, usage and costing. The issue is much more serious in the tropical regions which are known persistently covered with clouds especially during monsoon seasons, making it difficult to capture high-quality images even by using remote sensing satellite technology. Meanwhile, GPS survey requires a lot of time to establish high-density points in the study area. This is because GPS survey method measures discrete point on the surface. Therefore, this method is not practical for projects allocated with limited budget and time [3]. Terrain mapping using LiDAR and manned aircraft are very costly but has low ground resolution and limited time frame hence, rather impractical to be used for low altitude and small area surveying. Recently, UAV has been given a great attention in many applications including terrestrial terrain mapping, mainly, due to its low cost and practicality [10-11]. A UAV is commonly integrated with autopilot technology that enables semi or full autonomous navigation and image acquisition capabilities [1].

The image acquisition capabilities enable Earth terrain to be mapped and modelled to produce orthophoto. Orthophoto is an aerial photograph that has been geometrically rectified with appropriate scale and curvature, which has been considered as a vital element in the field of photogrammetry. Besides orthophoto, images acquired from UAV can also be used to generate Digital Terrain Model (DTM), which is the spatial terrain elevations of bare-earth, DTM can be utilized for road planning, forest inventory, land use classification and flood risk analysis. Besides that, DTM is also used to generate Digital Surface Model (DSM), which is a spatial reflectance of the Earth surface detected by aerial sensors in which may contain bare ground or surface features such as trees and built-up structures that can provide essential knowledge regarding natural and man-made objects on earth which can be used for 3D modelling. DTM and DSM can be generated from aerial imageries acquired from the camera mounted on a UAV [12]. This is done by overlapping stereo images wherein the accuracy of the final product is evaluated by means of root-mean-square error (RMSE) due to its practicality and simplicity [12-14].

Stereo images are two or more images of an area or object taken from different angles. Based on these models, users are able to use them for various applications particularly natural resources and environmental management. Furthermore, the use of UAV able to support real-time Digital Elevation Model (DEM) for large scale area under different types of land cover.

Presently, many researches and UAV mappers show successfully outcomes in generating DTM and DSM using UAV imageries under a particular land cover. Nevertheless, not much effort has emphasised on analysing the range of accuracy of the final output over different land covers [15-20]. Thus, the primary objectives of this study are to propose a novel way of generating DTM and DSM by utilising UAV and evaluate the accuracy of DTM and DSM for different land covers include forest, plantation and developed areas in the tropical region of Malaysia by means of root mean square error (RMSE). In doing so, ground surveying is conducted to produce base contour map to these land covers. It is hoped that this study will become a benchmark for terrain mapping especially for real-time low altitude semi-aerial photogrammetry.

2.0 METHODOLOGY

This study consists of five phases which are data acquisition, pre-processing, processing, output and analysis. Figure 1 shows the flowchart of the study.

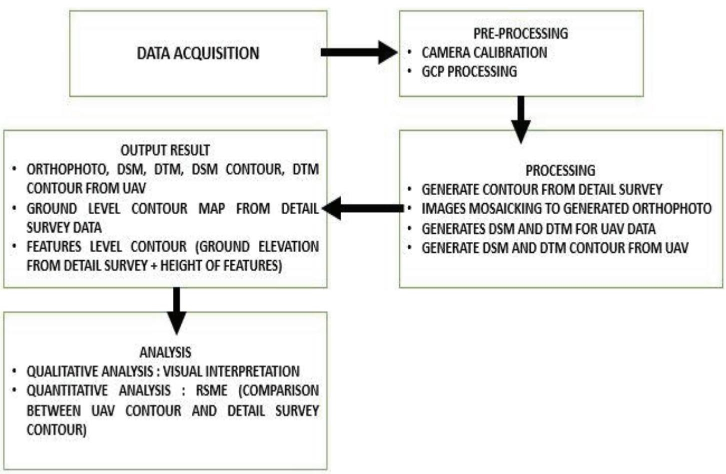


Figure 1: The research flowchart

The study used two sources of data which were UAV imagery as the primary data and detail ground survey as the secondary data. The detail ground survey data were used as the base-map for determining the accuracy of three UAV terrain products. Three different study areas (with different land covers) were selected in this study which are (a) Sg. Papan, Royal Belum Forest Reserve, Perak (forest area), (b) Rubber Plantation, Lembaga Getah Malaysia (LGM), Kota Tinggi (plantation area) and (c) Universiti Teknologi Malaysia, Johor Bahru (developed area). Figure 2 shows the location of the study area.

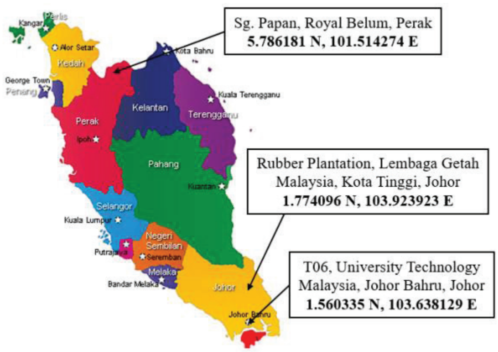


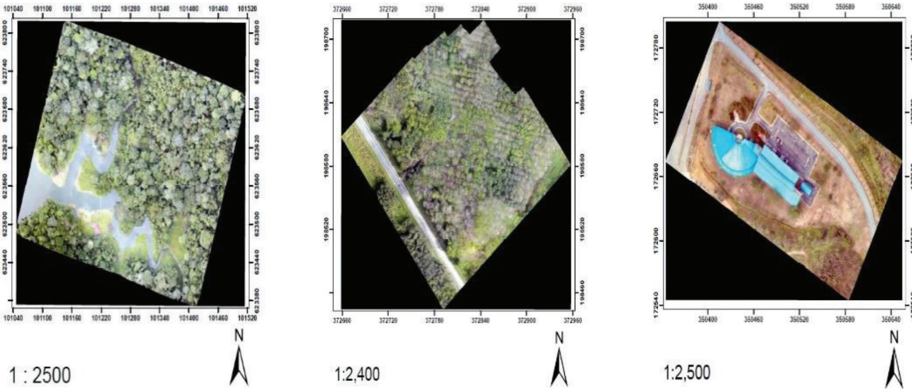
Figure 2: Location of the study area

Sg. Papan, Royal Belum Forest Reserve, Perak (longitude 5.786181N, latitude 101.514274E) is mainly a forest area with high density tree canopies. It is a hilly area with a somewhat complex terrain pattern. The high density of canopy of the forest is expected to affect the DTM to be generated due to the fact that some sun rays are unable to penetrate below the canopy. The study plot for this area is 100 m x 100 m with 250 m height above the mean sea level (MSL). For the second study area at Lembaga Getah Malaysia (longitude 5.786181 N, latitude 101.514274E), Kota Tinggi, Johor, the land cover is fairly uniform rubber trees with not very dense canopy compared to the forest. The selected study plot for this area is 120 m x 120 m with 17 m height above MSL. The third area is block T06, Universiti Teknologi Malaysia, Johor Bahru (longitude 1.560335N, latitude 103.638129E) which is a built-up area with buildings and other university infrastructures. The terrain is nearly flat with almost no tree canopy. The study plot is 140 m x 100 m with 17 m height above MSL. A detail survey was carried out where the outcome is to be used as the base-map and benchmark to the UAV images. For the forest area, a 100 m x 100 m grid was created to demarcate the ground points located at each intersection between X and Y directions. The intersection points were marked by pole to create 20 m x 20 m quadrants. The exact position of all the intersection points were measured and recorded by using a total station. For the plantation area and developed area, it was necessary to carry out random ground point survey because of not having serious obstructions due to trees. The survey was carried out using Topcon total station ES105. The data were then processed to produce contour maps for the study areas. Forestry Pro and Distometer were used to determine the height of ground objects such as trees and buildings within the study areas. The combination of ground object heights and measurements from the detail survey were used as the benchmark data. These data were compared to the DSM contours that were generated from the UAV images. For the developed area, the quadrant was divided into 4 sub-quadrants with 10 m x 10 m area each. This was to allow object height to be collected according to the sub-quadrant and the position of object can be estimated using a compass and measuring tape from any intersection point. Subsequently, the objects (including trees and buildings) were marked and their heights were recorded. Ground control points (GCP) were established for the whole study area to geometrically tie the UAV with real earth. Topcon Tools software was used where WGS84 system was adopted for the purpose of our study.

For UAV data acquisition, initially setting up of UAV system is carried out where all the UAV components such as digital camera, radio controller, software and battery were first prepared. Next, mission planning was established using Mission Planner Software to determine the waypoints for controlling the pathway and altitude of the UAV. There were two main phases of processing involved in this study, the first processing was the generation of orthophoto, DSM and DTM from raw UAV images and the second processing was to generate contour from DSM and DTM obtained from the UAV output as well as from the ground survey. Eventually, the accuracy of the generated DTM and DSM was computed by making use of root-mean-square error (RMSE) where the accuracy of the UAV terrain product was computed relative to the ground survey data.

3.0 RESULTS AND DISCUSSION

The output generated from processing of UAV images were orthophoto, DSM, DTM and contour maps. Universal Traverse Mercator (UTM) zone 48 N was used as the map projection coordinate system for the UAV image together with the WGS84 3D geodetic system. Figures 3 (a)-(c) show the orthophotos for the three different types of land cover namely forest, plantation and developed area, respectively. It is obvious that the forest area is nearby to a watery area, the plantation area contains rubber trees and located besides a straight road while the developed area contains a building surrounded by a tidy landscape.

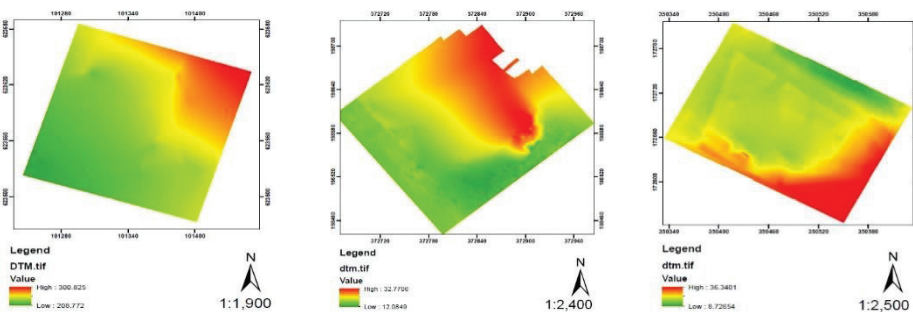


(a) (b) (c)

Figure 3: The orthophoto for (a) forest, (b) rubber and (c) developed area

3.1 Analysis of DTM from UAV Images

After filtration process that involved classification of ground and non-ground point cloud, DTM processing was initiated where the pattern of ground surface height for the study area was generated. Figures 4 (a)-(c) show the DTM from the forest, plantation and developed area, respectively. The colours which are green, yellow and red indicate the changes of elevation from low to the highest elevation for each land cover. For forest, the DTM ranges from 209 m to 301 m, 12 m to 33 m for plantation and 9 m to 36 m for development area. As expected, forest shows the highest average terrain elevation followed by plantation and development area [3, 15, 18].

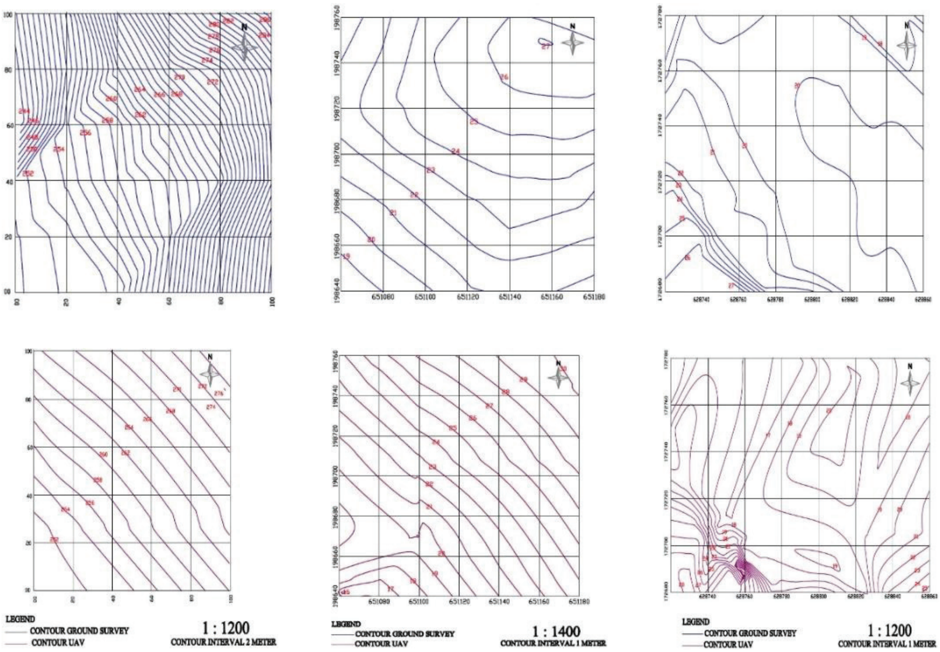


(a) (b) (c)

Figure 4: DTM for (a) forest, (b) rubber and (c) developed area

The generated DTM which was in raster form and was converted to contour map which was in vector form which was later used as one of RMSE parameter. The contour map was next imported to CAD (Computer-aided design) software for coordinate conversion. The UTM zone 48N coordinate was converted to the national RSO geocentric so that it had the same coordinate system as the ground survey data. For verification purpose, 20 sample points were selected from the contour map and detail survey where accuracy assessment was carried out for height at all corresponding X and Y coordinates. The patterns of the contour generated from the three study areas were identified and analysed. As expected, there was an obvious discrepancy between the patterns of the generated contour from UAV and detail survey for all the areas. This was due to the fact that the UAV-generated contour was produced based on the interpolation of point cloud generated using overlapping of image while ground survey-generated contour was produced from the interpolation between spot heights collected using the total station. Subsequently, the pattern of deviation between two sets of elevation data were statistically analyzed for standard statistical parameters such as standard deviation, mean and variance so that the data properties can be understood [20-21].

For DTM accuracy evaluation, RMSE is determined; this technique measures the dispersion of deviation between the original elevation data and the DTM data [22-23]. It was found that the RMSE values were ± 1.80 m, ± 0.938 m and ± 0.549 m for the forest area, plantation area and developed area respectively. The developed area shows the highest accuracy followed by the plantation and forest area. We now attempt to discuss this issue further. In principle, the accuracy of DTM depends on the generated point clouds at ground surface based on the conditions of the land cover within the area. The forest area has the lowest accuracy compared to the other land covers due to the obstruction that prevents point clouds to be generated. The obstruction is due to the tree canopies that prevent rays from reaching the ground surface. This leads to the less amount of point cloud compared to the plantation and developed area that have more point clouds due to the less obstruction. The low amount of point cloud for the forest area subsequently affects the generation of Mesh model. Consequently, this causes the low accuracy of DTM generated from forest compared to the plantation and developed area. Figures 5 (a)-(c) show the patterns of the contour generated from UAV and ground level contour for forest, plantation and developed area respectively. The height intervals are 2 m for forest and 1 m for plantation and development area. Due to the nature of surveying approach, the ground survey shows a more detail terrain pattern compared to plantation and developed area however with a somewhat consistent trend between the both [3, 15, 18].

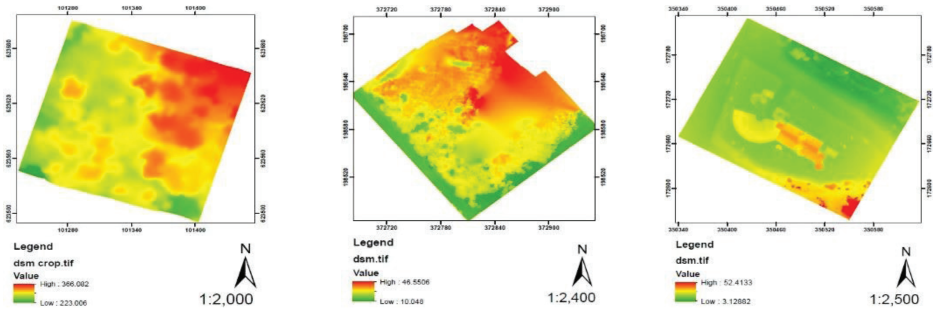


(a) (b) (c)

Figure 5: Contour generated from UAV (top) and ground level contour (bottom) for (a) forest, (b) rubber and (c) developed area

3.2 Analysis of DSM Generated from UAV Images

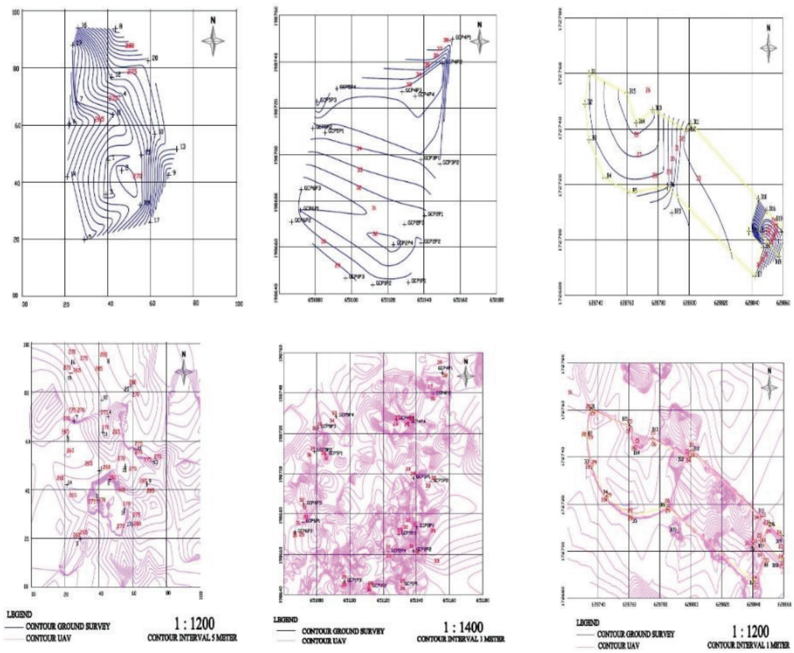
Figures 6 (a)-(c) show the result of DSM for forest, plantation and developed area, respectively. The elevations for the three different types of land cover are highlighted where the green, yellow and red indicate the changes of elevation from lowest to the highest elevation for each of the land covers. For forest the DSM ranges from 223 m to 366 m, 10 m to 47 m for plantation and 3 m to 52 m for development area. As expected, forest shows the highest average surface elevation followed by plantation and development area [3, 15, 18].



(a) (b) (c)

Figure 6: DSM for the (a) forest, (b) plantation and (c) developed area

For DSM, the method of analysis used was similar with the analysis of DTM. The only differences that the benchmark data were generated using the combination of ground height from the detail survey contour and the height of objects within the area that were measured using distometer and Forestry Pro range finder device. The interpolation methods were applied to the ground survey measurement and integrated with the heights object within the area. Subsequently, the contour map for the area was generated and this contour map is regarded to be the benchmark for the DSM generated from UAV in calculating the RMSE for determining the accuracy. Based on the analysis, the values of RMSE for UAV-generated DSM were± 3.143 m, ± 0.637 m and ± 0.276 m for the forest area, plantation area and developed area, respectively. Similar to DTM, the forest area gives the lowest accuracy of DSM compared to the plantation and developed area. This possibly due to the uncertainty in tree height collected using Forestry Pro range finder device. Somehow, the constraints experienced during the measurements were the dense tree canopy that prevents the peak point of trees be determined accurately. Figures 7 (a)-(c) show the pattern of the DSM contour generated from UAV and ground height integrated with object height contour for forest, plantation and urban area, respectively. From visual analysis, it can be seen that there is a somewhat consistent trend between both contour types for forest, plantation and developed area [3, 15, 18].



(a) (b) (c)

Figure 7: DSM contour for (a) forest, (b) plantation and (c) developed area generated from UAV (top) and ground height integrated with object height contour (bottom)

Table 1 shows the comparison of the accuracy of DTM data obtained by different techniques. The RMSE values that have been obtained in this study can be used as a reference benchmark for the implementation of UAV in producing DTM or DSM especially for plantation and developed area. The RMSE values produced for forest area were relatively high compared to plantation and developed area due to the physical characteristic of trees within forest area.

Table 1: Comparison of the accuracy of DTM data obtained using different techniques

Methods of data acquisition	Accuracy of data
Ground measurement	1 - 10 cm
Digitized contour data	About 1/3 of contour interval
Laser altimetry	0.5 – 2 m
Radargrammetry	10 - 100 m
Aerial photogrammetry	0.1 – 1 m
SAR interfereometry	5 – 20 m

3.3 Discussion

Alganci et al. [24] noted that the DTM and DSM posting shall be at the minimum as allowed by the data and shall not exceed 1 meter as a Journal of Advanced Manufacturing Technology (JAMT) standard performance. In addition, the American Society Photogrammetry and Remote Sensing has specified on the vertical accuracy of digital elevation data with 1 m contour interval for vegetated terrain such as forested and plantation area and nonvegetated terrain such as development area are below 5 m and 0.653 m respectively [25]. The development area gives the best accuracy for DTM and DSM compared to plantation and forest area with an accuracy of less than 1 m in which is at par with the ground surveying approach. Thus, the use of UAV for obtaining DSM and DTM for forest, plantation and developed area as proposed in this study can be seen as a promising alternative over the conventional ground surveying approach. The usefulness of the approach is beneficial particularly for remote areas that are difficult to access through ground surveying approach due to its ability to generate sufficient image overlapping for point cloud formation in producing the DTM and DSM. Furthermore, the use of UAV can tackle the problem that arise from the cloud cover or haze [31] because image capturing from UAV is taking place at low altitude for instance less than 500 m. In addition, geometric error that occurred at the image can be reduced by using sufficient Ground control point. Hence, will produced DSM and DTM with very high accuracy. Nevertheless, several weaknesses have been identified when using the proposed approach in which are controlling/tracking signal lost, battery duration and whether dependent.

Signal lost can be solved by enhancing the controlling/tracking hardwares and softwares by means of suitable optimized approaches 0. Battery duration can be prolonged by replacement with more durable batteries or changing to fuel cells. Since the proposed approach offer full autonomy to users, data acquisition can take place at any time during suitable whether condition. In this study, the factors identified able to affect the accuracy of DSM and DTM are (i) dense tree canopy cover and fluctuation of tree height in tropical rain forest which lead to undeliverable bundles of ray required to generate point clouds on ground surface; and (ii) the distribution of GCPs of the study area. These factors also have contributed to inaccuracy in determination of object heights within the areas of interest that experience the different conditions that include high-density non disturbed canopy (forested area), well cultivation (plantation area) and open area (developed area), respectively 0. This study has demonstrated that the proposed approach gives the highest accuracy for developed area due to its low tree obstruction and well distribution of GCPs [29-30].

4.0 CONCLUSION

In this study, DSM and DTM has been successfully generated from UAV imagery for different land covers namely forested, plantation and developed area. The accuracy of DTM and DSM has been then compared to the contour obtained from ground survey data. The outcomes show different pattern between contour maps obtained from UAV platform and ground survey data for the three land covers. This is due to the different complexity levels of terrain and surface properties from the three land covers [32-35]. The RMSE results for DTM are ± 1.806 m, ± 0.938 m and ± 0.549 m while DSM are ± 3.143 m, ± 0.637 m and ± 0.276 m for forest, plantation and developed area respectively. The results of this study shows that the terrain mapping using UAV platform is able to provide reliable data at sub-meter level accuracy as required in surveying and engineering projects. However, for the cadaster applications such as multipurpose cadaster, a proper data collection and processing is required to achieve standard cadaster accuracy. Nevertheless, for the proposed approach to be used towards the development of surveying policy in Malaysia, future improvements required include extensive consistency testings on a wider variety of land cover with different levels of terrain complexity.

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