Accuracy evaluation of digital terrain model based on different flying altitudes and conditional of terrain using UAV LiDAR technology

N A Fuad, Z Ismail, Z Majid, N Darwin, M F M Ariff, K M Idris and A R Yusoff
Geospatial Imaging and Information Research Group, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia.

nursyahiraaf@gmail.com, zamriismail@utm.my, zulkeplimajid@utm.my & norhadija2@utm.my

Abstract. Unmanned Aerial Vehicle (UAV) with Light Detecting Radar (LiDAR) sensor can be used to obtain high ground resolution data and generate good quality of Digital Terrain Model (DTM) as much as can decrease the cost of data acquisition and processing time. This study aims to evaluate the influences of flying altitude and terrain on DTM accuracies obtained with UAV-based LiDAR. In this study, point clouds from UAV AL3 S1000 and AL3 – 32 LiDAR were used for generating DTM on two different terrains (i.e. flat, slope and overall) with three different flying altitudes (i.e. 20m, 40m and 60m) and validate with ground control points by using 129 reference points which taken from ground survey technique (GPS, total station and optical levelling). The Root Mean Square Error (RMSE) of point clouds elevation obtained at different altitudes for the flat area are 0.015m, 0.027m and 0.105m at the altitudes of 20m, 40m and 60m, respectively. Meanwhile, RMSE values for slope area are 0.267m, 0.298m and 0.343m at the altitudes of 20m, 40m and 60m, respectively. Overall study area gives the RMSE values of 0.323m, 0.450m and 0.616m at 20m, 40m and 60m altitude, respectively. The result shows that the change of RMSE values influenced by the different of altitude and terrain, which provides accurate and faster results.

1. Introduction
Light aircraft without human pilot onboard has been used in monitoring activities especially for map production. The aircraft known as drone or UAV which can fly with different flying heights that remotely controlled at the ground station. Presently, UAV technology has grown rapidly and was used in various geospatial mapping applications such as archaeological sites [8-13], road maintenance [16, 17], urban and rural [14], disaster management [18, 19], river and coastal erosion [2, 3], landslide, surveillance [15] and agricultural [7].

A UAV can carry various optical cameras such as compact digital camera, multispectral camera, LiDAR, thermal and many more. There were different uses of optical camera which depends on the purposes of the research. For an example, the multispectral cameras was used in capturing multi band image where the images can be used for scientific studies such as land use, plant health, leaking pipes and others. In addition, compact digital camera required for capturing the natural Red Green Blue (RGB) imagery in producing orthophoto for the area coverage. Meanwhile, LiDAR technology is one
of an important tool in the remote sensing based technique where it allows the direct measurement been done without make any contact with the object being measured.

Thermal camera can also carry by UAV, which allow users to view thermal images, showing differences that identify problems in buildings, electrical components, mechanics, and pipes and waterproofing systems. Moreover, the infrared camera used to acquire images specifically in differentiating between water and land. Table 1 shows previous research on the applications of UAV-based technology and the main findings.

| No. | Authors | Method | Application | Findings |
|-----|---------|--------|-------------|----------|
| 01. | [1]     | UAV-Based LiDAR | Forest Change Detection | The limitation of ability in resolving the effects of footprint size and scanning angle is due to the poor quality of data collected from the high altitudes which higher than 50m. |
| 02. | [2, 3]  | UAV Photogrammetry | Coastal Mapping | The imagery taken from 50m produced a georeferenced point cloud with accuracy of 25-40 mm. Coastal erosion cases is monitored to sub-decimeter terrain changes. |
| 03. | [4, 5]  | Multi-rotor UAV Photogrammetry | Slope Mapping | The accuracy of slope is influenced by the condition of slope at undulated and semi-undulated area. |
| 04. | [6]     | UAV Photogrammetry | River Mapping | Values of RMSE is decreased as the flying height is increased as achieved to sub-meter accuracy. |
| 05. | [7]     | UAV | Agricultural | The difference between the herbicide damaged area obtained from ground survey and estimation from imagery were only 1.5 %. Besides, UAV has good spatiotemporal capabilities. |
| 06. | [8-13]  | UAV Photogrammetry | Cultural heritage, documentation of archaeological sites | Man-made structures and 3D surveying and mapping of site can be carried out using low-altitude image-based approaches. |
| 07. | [14]    | UAV | Recording large scale of urban and suburban | The acquisition of images id easy but the image block configuration and the flight performance were not ideal as compare to other standard aerial photogrammetry cases. |
| 08. | [15]    | UAV | Surveillance | Two quadrotors multi-UAV surveillance system has been used to demonstrate the field experiment. |
| 09. | [16, 17]| UAV – based remote sensing | Road Mapping | Video orthoimage achieved approximately 0.5–1.5 pixels accuracy. Between May 2007 and October 2008, the daily average displacements rates is about 0.1 to 0.01m ± 1mm per day which achieved between 7 and 55m ± 0.5m of horizontal displacements. |
| 10. | [18, 19]| UAV – based remote sensing | Disaster Management | |

Table 1. Previous Research of UAV Applications.
Based on the previous research, a study conducted by [5] where found the accuracy of DEM generated using UAV with photogrammetric technique was evaluated with 30 check points and obtained overall vertical accuracy of 6.62 cm from an altitude of 60m. Apart from numbers of check point effect the vertical accuracy, different level of altitudes also affected the RMSE values which also used the UAV with photogrammetric technique [20]. However, most of the previous research used the autonomous UAV-based photogrammetric method for aerial mapping to study the accuracy of slope mapping at different altitudes, landslide evaluation, DTM generation and others. The previous research also used UAV-based LiDAR system for terrain operation without specific investigation on the accuracy.

Currently, the research on the effect of different terrain to the accuracy of DEM generated using UAV-based LiDAR is still on going. The combination of UAV and laser sensor has become popular since it consists of real time capability of 3D data capture [21]. It has high capabilities in providing the information related to the registration and segmentation of heterogeneous LiDAR data to generate DTM [22]. All these methods (as shown in Table 1) provide different levels of accuracy depend on the applications.

Theoretically, the smaller the RMSE value, the more accurate the land surface data and it is suitable for monitoring and mapping purposes. This is specifically for slope area which prone to be landslide incident. Therefore, this study aims to evaluate the influences of flying altitude, conditional of terrain, and the Ground Control Points (GCPs) number towards the DTM accuracies using UAV-based LiDAR dataset. The selected study area is at UTM Campus of Johor Bahru, which located near to the parking area of Faculty of Biosciences and Medical Engineering building. This size of the study area is about 180m x 120m, which consists of flat and slope area (as shown in Figure 1).

![Figure 1. The study area](image-url)

### 2. Materials and Method

In this study, the Octocopter AL3 S1000 UAV system was used as a platform to carry the LiDAR sensor to acquire point cloud data of the study area. This system is a complete ready-to-fly aerial system and suitable to carry the AL3 LiDAR sensor. The Octocopter AL3 S1000 was equipped with eight rotor engines where four rotors rotated in clockwise direction and the other rotors rotated in counter-clockwise direction. The system was fully autonomous. Meanwhile, the AL3 LiDAR system consists of satellite constellation support such as GPS dual-frequency and optional heading receiver for fast alignment. This AL3 LiDAR system is capable for scanning an area up to a square kilometer. AL3 includes the Velodyne HDL-32 high definition LiDAR sensor where it can provide 700,000 scan points per second with 2mm range resolution. Figure 2 and 3 shows the UAV AL3 S1000 and AL3 – 32 LiDAR system, respectively.
2.1. Field Survey
Field survey involved with GPS static survey and total station survey. GPS static survey was carried out to setup the control points of the study area. The Topcon ES-105 total station equipment was used to measure 129 reference points. The reference points were then used for accuracy assessment of the LiDAR derived DTM. Figure 4 and 5 shows the GPS stations and 129 reference points that were observed using GPS and total station, respectively.

2.2. Filtering of LiDAR Data
The purpose of filtering process is to extract ground data from the raw LiDAR dataset. The filtered ground data were then used to generate the DTM. Five parameters are required to define the best and suitable ground points, which are: 1) maximum building size, 2) terrain angle, 3) iteration angle, 4) iteration distance and 5) reduce iteration angle. This process collects the lowest ground points that hits on the ground and then generating the triangulated surface models iteratively. Table 2 shows the parameters used for ground classifications. The maximum building size parameter is set to the value of 20 m because the study area consists only a small temporary building with the approximate height of 20 m. It is assuming that there is at least one point with the 20 m by 20 m area located on the ground level.

According to [23], the triangles in the model mostly below ground level and only the vertices that touched the ground then the model pushed by the routine upwards by adding new laser points iteratively. After adding new laser points, the model will make the true ground surface more closely. Next, the iteration parameters of the ground will find out how closed a point to a triangle plane in order to be accepted as ground point so that it can be added into the model. Iteration angle is the
maximum angle between a point where its projection on the triangle plane and closest to the triangle vertex. Iteration angle plays an important parameter where it controls how many points to be classified into the ground class. While iteration distance is used to constraint the iteration from making big jumps upwards when the triangles are huge. The iteration angle can be reduced to decrease the eagerness for adding new points into ground inside a triangle if every edge of the triangle is shorter than the edge length. It shows that the total number of raw LiDAR data is decreased after the filtering process which represent as ground points.

| Parameters                    | Values                |
|-------------------------------|-----------------------|
| maximum building size         | 20m                   |
| terrain angle                 | 20°                   |
| iteration angle               | 3.5° to plane         |
| iteration distance            | 1.0m to plane and lastly |
| reduce iteration angle        | 1.2m                  |

3. Results and Analysis
In this study, two types of DTM are produced. The first DTM is generated from the 129 reference points (as shown in Figure 6). The second DTM is derived from filtered LiDAR data that has been classified into flat areas (as in Figures 8, 9 and 10) and the slope area (as in Figures 11, 12 and 13). The RMSE values indicated that the accuracy of the elevation of LiDAR point decreased as the altitudes increased for three different areas which are flat, slope and whole area (as shown in Figure 7). Table 3 shows the RMSE results, the Mean Absolute Error (MAE), and the mean bias error (MBE) of LiDAR data of every altitude and terrain. RMSE and MAE show the magnitude of average error and no information provided at the relative size of the average difference between the ground points obtained from UAV-LiDAR and field survey. Meanwhile, MBE illustrates the bias of the error where the negative MBE occurs when the UAV-LiDAR ground point is smaller than the field survey.

Table 3 shows that the accuracies of flat area for flying altitude of 20m have smaller RMSE and MBE values as compared to slope and overall area. Meanwhile, the flat and slope area shows the negative MBE values due to the ground points obtained from UAV-LiDAR data, for flying altitude of 20m and 40m, are smaller than the field survey ground points. The overall area shows that positive value of MBE for flying altitude of 60m. This is due to the values of ground points obtained from UAV-LiDAR is greater than the field survey. It was found that the accuracy for flat area for flying altitudes of 20m and 40m reach up to millimeter level since it shows the RMSE and MAE value below 0.030m.
Table 3. RMSE, MAE and MBE for Different Flying Altitudes and Terrain.

| Accuracies | Terrain | 20m   | 40m   | 60m   |
|------------|---------|-------|-------|-------|
| RMSE (m)   | Flat    | 0.015 | 0.027 | 0.105 |
|            | Slope   | 0.267 | 0.298 | 0.343 |
|            | Overall | 0.323 | 0.450 | 0.616 |
|            | Flat    | 0.010 | 0.020 | 0.075 |
| MAE (m)    | Slope   | 0.155 | 0.177 | 0.231 |
|            | Overall | 0.191 | 0.242 | 0.345 |
|            | Flat    | -0.003| -0.005| 0.056 |
| MBE (m)    | Slope   | -0.018| -0.030| 0.098 |
|            | Overall | -0.061| -0.011| 0.150 |

According to [24], good quality of DTM depends on MBE value when MBE value is close to zero. MBE values for flat areas and slopes show zero values for altitude of 20m and 40m. Therefore, the flying altitude and condition of terrain give a significance influence to the accuracy of the generated DTM. When flying altitude increases, its accuracy improves.

![Figure 8. DTM generated form LiDAR ground points at 20 m for flat area](image)

![Figure 9. DTM generated form LiDAR ground points at 40 m for flat area](image)

![Figure 10. DTM generated form LiDAR ground points at 60 m for flat area](image)

![Figure 11. DTM generated form LiDAR ground points at 20 m for Slope area](image)
4. Conclusion
This study successfully evaluates the DTM accuracy based on different flying altitudes and conditional of terrain using UAV-LiDAR technology. The contribution of this study is to determine the level of details for each flying altitude for different terrain (i.e. flat, slope and overall). This study demonstrates that the UAV-based LiDAR is capable to scan at three different altitudes over the study area. Three different flying altitudes were tested at three different types of terrains. Throughout the investigation, this study has proved that the overall RMSE values of point clouds elevation at different altitudes for the study area is 0.323m, 0.450m and 0.616m at 20m, 40m and 60 m altitudes, respectively. Different altitudes have influence on the point cloud elevation, which means that the higher the altitudes, the higher the error of the point clouds obtained from the system. However, the result from this study is as an initial planning to support other applications. In conclusion, the result obtained from this study can be used as a guideline for future applications and should be carry out in order to see the sensitivity of the LiDAR system and the related filtering process.

Acknowledgments
The author wish to acknowledged and thanked UTM for awarding the research fund (Vot 01M09) and also appreciated the Geospatial Imaging & Information Research Group and the Faculty of Geoinformation and Real Estate, UTM.

References
[1] Wallace, L., A. Lucieer, and C. Watson. Assessing the feasibility of UAV-based LiDAR for high resolution forest change detection. in The 12th Congress of the International Society for Photogrammetry and Remote Sensing. 2012.
[2] Darwin, N., A. Ahmad, and O. Zainon. The potential of unmanned aerial vehicle for large scale mapping of coastal area. in IOP Conference Series: Earth and Environmental Science. 2014. IOP Publishing.
[3] Harwin, S. and A. Lucieer, Assessing the accuracy of georeferenced point clouds produced via multi-view stereopsis from unmanned aerial vehicle (UAV) imagery. Remote Sensing, 2012. 4(6): p. 1573-1599.
[4] Tahar, K.N., Multi rotor uav at different altitudes for slope mapping studies. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 2015. 40(1): p. 9.
[5] Uysal, M., A. Toprak, and N. Polat, DEM generation with UAV Photogrammetry and accuracy analysis in Sahitler hill. Measurement, 2015. 73: p. 539-543.
[6] Udin, W. and A. Ahmad, *Assessment of Photogrammetric Mapping Accuracy Based on Variation Flying Altitude Using Unmanned Aerial Vehicle*. in *IOP Conference Series: Earth and Environmental Science*. 2014. IOP Publishing.

[7] Xiang, H. and L. Tian, *Development of a low-cost agricultural remote sensing system based on an autonomous unmanned aerial vehicle (UAV)*. Biosystems engineering, 2011. 108(2): p. 174-190.

[8] Eisenbeiss, H. and E.T.H. Zürich, *UAV photogrammetry*. 2009, ETH.

[9] Eisenbeiss, H. and L. Zhang, *Comparison of DSMs generated from mini UAV imagery and terrestrial laser scanner in a cultural heritage application*. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVI-5, 90e96, 2006.

[10] Püschel, H., M. Sauerbier, and H. Eisenbeiss, *A 3D model of Castle Landenberg (CH) from combined photogrammetric processing of terrestrial and UAV-based images*. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci, 2008. 37: p. 93-98.

[11] Bendea, H., et al. *Mapping of archaeological areas using a low-cost UAV*. The Augusta Bagiennorum test site. in XXI International CIPA Symposium. 2007. Citeseer.

[12] Nex, F. and F. Remondino, *UAV for 3D mapping applications: a review*. Applied Geomatics, 2014. 6(1): p. 1-15.

[13] Remondino, F., et al., *UAV photogrammetry for mapping and 3d modeling–current status and future perspectives*. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2011. 38(1): p. C22.

[14] Spatalas, S., V. Tsioukas, and M. Daniil, *The use of remote controlled helicopter for the recording of large scale urban and suburban sites*. Culture of Representation, Xanthi, Greece, 2006.

[15] Perez, D., et al., *A ground control station for a multi-uav surveillance system*. Journal of Intelligent & Robotic Systems, 2013. 69(1-4): p. 119-130.

[16] Zhou, G., C. Li, and P. Cheng. *Unmanned aerial vehicle (UAV) real-time video registration for forest fire monitoring*. in *Geoscience and Remote Sensing Symposium, 2005. IGARSS’05. Proceedings. 2005 IEEE International*. 2005. IEEE.

[17] Kiss, K., J. Malinen, and T. Tokola, *Comparison of high and low density airborne LiDAR data for forest road quality assessment*. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2016. 3: p. 167.

[18] Niethammer, U., et al., *UAV-based remote sensing of the Super-Sauze landslide: Evaluation and results*. Engineering Geology, 2012. 128: p. 2-11.

[19] Ambrosia, V.G., et al., *Demonstrating UAV-acquired real-time thermal data over fires*. Photogrammetric Engineering and Remote Sensing, 2003. 69(4): p. 391-402.

[20] Tahar, K., *Photogrammetric Micro Unmanned Aerial Vehicle for Large Scale Slope Mapping*. 2013, University Technology of Malaysia

[21] Pfeifle, S., *What is 3D Data Capture?* Editor, SPAR Point Group, 2012.

[22] Polat, N. and M. Uysal, *Dtm Generation With Uav Based Photogrammetric Point Cloud*. ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2017: p. 77-79.

[23] Soininen, A., *Terrascan user’s guide*. Terrasolid: Helsinki, Finland, 2004.

[24] Ismail, Z., et al., *An improved progressive morphological filtering algorithm based on spatially-distributed slope value over tropical vegetated regions*. Jurnal Teknologi, 2015. 77(26): p. 87-93.