Comprehensive Analysis of UAV Flight Parameters for High Resolution Topographic Mapping

Muizzuddin Muhammad and Khairul Nizam Tahar

August 31, 2020

Comprehensive Analysis of UAV Flight Parameters for High Resolution Topographic Mapping

Abstract. Unmanned Aerial Vehicles (UAVs) are aircraft without pilot onboard which being controlled by ground station or transmitter. The ability of UAV to provide high resolution imageries and accurate positioning make it is the best platform compared to satellite image. Therefore, UAV can speed up the topographic works especially during data collection. Topographic mapping has been used by many agencies such as government, private and military. Furthermore, the geotagged high resolution UAV images can provide accurate results using Ground Control Points (GCPs). UAV flight parameters such as flight altitude, percentage of overlap and sidelap can effect the topographic map result derived from UAV images. The optimal flight altitude, overlap and sidelap percentage based on specific topographic surface need to be investigated in order to produce accurate topographic map. The aim of this study is to assess the accuracy topographic map from different flight parameters. There are two objectives to achieve the aim i.e. to produce photogrammetric products from different altitude, overlap, sidelap and analyze the photogrammetric products with ground survey data. In this study, the selected flight altitude in this study are 60m, 80m and 100m. However, the percentage of overlap are 70%, 80%, 90% and percentage of sidelap are 50%, 60% and 70%. GCPs and Check Point (CPs) will be established using Global Navigation Satellite System (GNSS) techniques where the Global Positioning System (GPS) receiver capable of Real-Time Kinematic (RTK) in order to receive the real time data correction from Continuously Operating Reference Station (CORS) in different locations. This study will analyze the topographic results at different flight altitude, percentage of overlap and sidelap using Root Mean Square Error (RMSE). The expected outcome of this study includes comparison coordinates between CPs coordinates and ground survey data coordinates, different Digital Terrain Model (DTM) and different topographic map.

1. Introduction

Unmanned Aerial Vehicles or known as UAV are one of the aircraft without pilot which is control by ground based controller [7]. With the latest technology, UAV are the common aircraft that use in commercial industry such engineering work, surveying and others. With the ability of UAV that provide high resolution imageries and accurate positioning which is better than satellite image, the advantage help topography survey work become faster in collecting data [10]. An another advantage of UAV are easy to operate, image with no cloud obstacle, detail is clear to identify, high resolution, low cost production and one of the most prefer for topographic mapping in engineering survey [5]. Topographic mapping are one of the important map which is used by all agencies either government, private, personal and military. In the topographic mapping, it is represent an information about the reality of ground truth on certain location. Before topographic map are produce with latest from aerial photogrammetry, the

data acquisition are collected by using total station. The data also are represented in 2-dimension (2D) map. With a new technology of photogrammetry, topographic mapping can be produce by using UAV with high resolution image. The process in data acquisition also help to reduce time taken in collecting data. A new technology in photogrammetry can generate and represent data for topographic mapping in 3-dimension (3D) map [3].
Plus, the positioning of high resolution image that produce from UAV can be more accurate by applied the ground control point (GCP). Refer to the previous journal about GCP, to established the GCP in one orthophoto or topography mapping must at least 5 control point or more. The more control point in image, the increase of accuracy in image. For locating the GCP in study area, the features need to use a permanent object and the position for established GCP also need to covered all the study area. The locating GCP not only put near to the boundary of area study but need covered together at the middle or centre of study area. This is important in locating or choose the position for GCP because this factor will use for overlapping to produce mosaic image for topographic mapping and orthophoto [5].

In producing topography mapping, flight altitude and overlap need to be consider as a process to produce a better result. For flight altitude, the preferred altitude for testing the optimal altitude are from 20 meter to 120 meter [17]. This is because the increase of altitude more than 120 meter above, the features from image may be cannot identified and interpret but with flight altitude more than 120 meter can covered large area for image captured. However, the decrease flight altitude which is fly less than 120 meter altitude, the feature can be seen clear and easy to interpret. Another factor in produce topographic mapping is overlap and side lap. This is important because it will during the process for mosaic image. An optimal overlap and sidelap for produce topographic mapping 80%-50% and 70%-40% [27]. With the optimal flight altitude and overlap, it can produce the best result for digital elevation model (DEM), orthophoto and topographic map. Plus, a good production of topographic map can be validate through the Root Mean Square Error (RMSE) [5]. From the verified point, it can be analyse the coordinate that shown on the final product of topography map either the coordinate are same as actual coordinate or different.

2. Material and Methods

In this study, it consist of four phase which for the phase 1 is about the preparation, phase 2 is data acquisition, phase 3 is data processing and phase 4 is result and analysis. Preparation is to reconnaissance some of area that have been use for some purpose to get the information about specification and features that found in the study area. According to this part, selection for study area have been selected for preparation for this study research. Based on this study, the information of study area have be list on what the features are found at the location of study area for considering the optimum altitude for flight can fly around the area that located on study area. Furthermore, the selection for software use on this study also have been selected with compatible hardware that already prepared for this study. For software, the selected software that already used are Agisoft, Global Mapper and PCI Geomatics. All this software have been use to process until come out with final product of photogrammetric such as DSM and DTM. Plus, another software that important to this study are Altizure software which help to prepare the flight mission before collecting raw data. However, to perform the process and acquisition of data, the used of hardware of this study also have been chosen such the use of DJI Phantom 3 Pro as instrument to collect raw data of aerial photo and ROG Asus Gaming as hardware that help to perform the process of data by using the software.

Image acquisition are the planning stage in collecting data. It is to describe the method in producing of flight planning and type of UAV were be used in collecting the data. Next, the sensor of image acquisition that attached to the body of UAV also need to be inspection the sensor by calibrate the sensor using the method of camera calibration. In the part of image acquisition also it include with the distribution of GCP which the position of GCP in study area need to be design the position of GCP to make sure the design of distribution GCP are covered all surrounding of study area. Figure 1 illustrates the research methodology in this study.

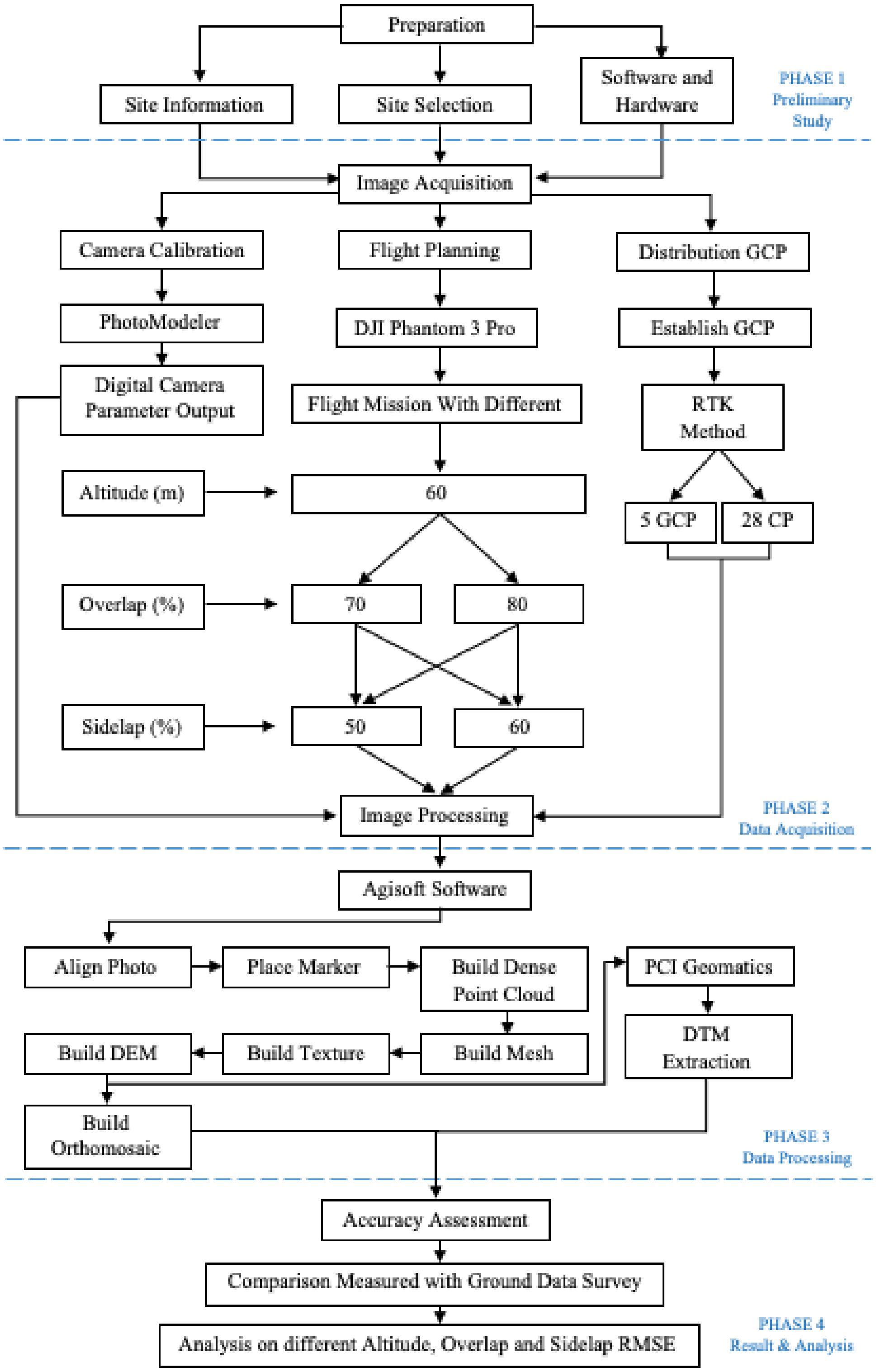


Figure 1. Research Methodology

3. Result and Analysis

According to this study, this study area have been located at Canseleri UITM Shah Alam, Selangor. The size of this area have been estimate about 2 hectares. To obtain the data for this study, the flight parameter of this study also have been chosen by using three different altitude, overlap and sidelap. For flight altitude, three different altitude that used while obtained the data are 60m, 80m and 100m. However, every each of flight altitude have been setup with three different overlap percentage 70%, 80%, 90% and also three different sidelap percentage which is 50%, 60% and 70%. All data that have been collected are contain 27 of data set orthophoto with different altitude, overlap and sidelap. To process the data, Agisoft software were selected to produce orthomosaic and DSM. The DSM were go through the next process of DTM extraction by using PCI Geomatics software. All this process are using 5 GCP. For the verification point process, total of 28 check points have been extracted from DTM. This extraction of check point coordinate were be compared with ground survey data (RTK). All this comparison were be conclude into final result of accuracy assessment. The accuracy assessment were be compute by using method of Root Mean Square Error (RMSE) to finalize the comprehensive analysis of flight parameter for high resolution topographic mapping using UAV.

3.1 Result of Orthophoto, Digital Surface Model (DSM) and Digital Terrain Model (DTM)

In this study, 27 set of result Orthophoto, DSM and DTM from different altitude, overlap percentage and sidelap percentage have been process through Agisoft software and PCI Geomatics software. All of this dataset have been registered with 5 number of Ground Control Point (GCP). In producing orthophoto by using Agisoft software, all dataset of altitude with different overlap percentage and sidelap percentage were marked with 5 GCP and verified separately. The verification of all dataset are process through accuracy assessment by using 28 CP. Figure 2 describes the digital orthophoto after image processing.

Figure 2. The product of orthophoto generate by Agisoft software

Apart from orthophoto, DSM are also generate through Agisoft Software. This process of DSM are been perform to all dataset. Figure 3 shows the result of DSM. This result of DSM are important to be produce because this product were used for next phase in producing DTM product.

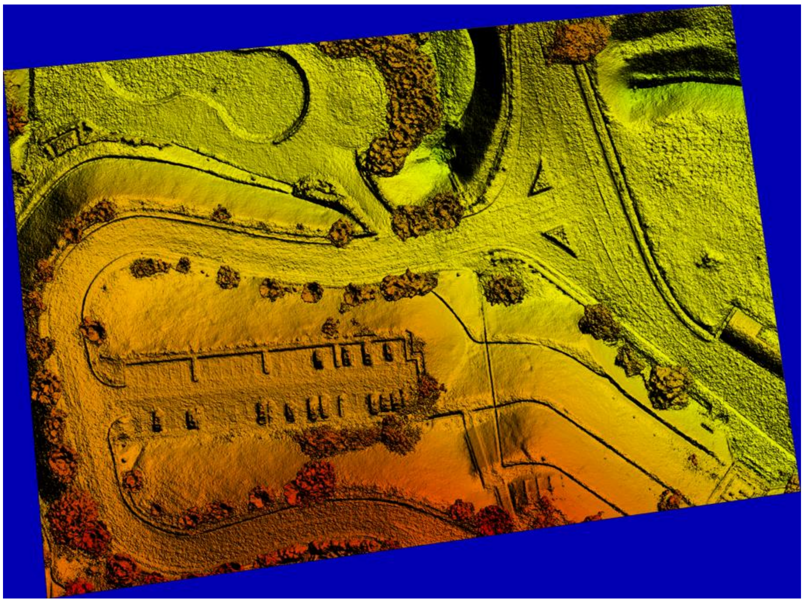


Figure 3. Result of Digital Surface Model generated by Agisoft Software

Digital Terrain Model are been generate from Digital Surface Model of all dataset by using PCI Geomatic Software. The result of DTM are shown in Figure 4 which it obtain from PCI Geomatic Software. The elevation from final product of DTM are important because this elevation is the reference for verify the Z coordinate through accuracy assessment.

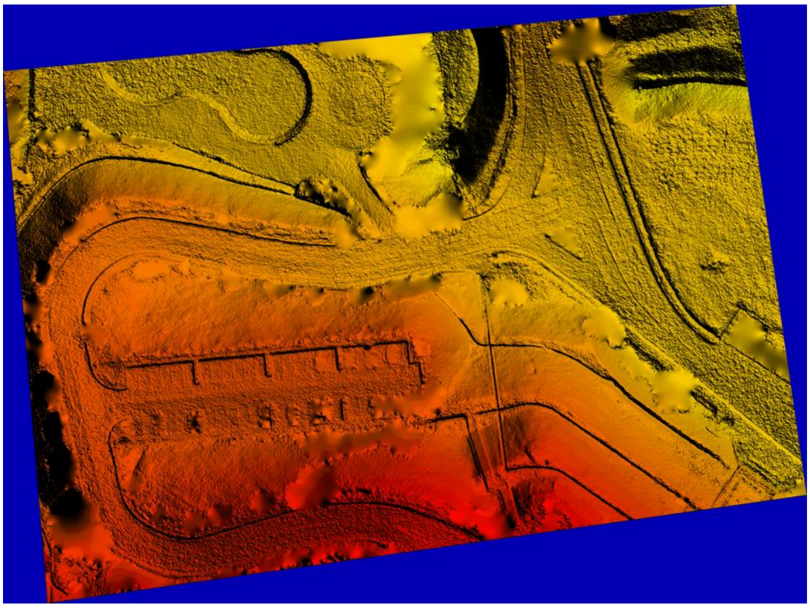
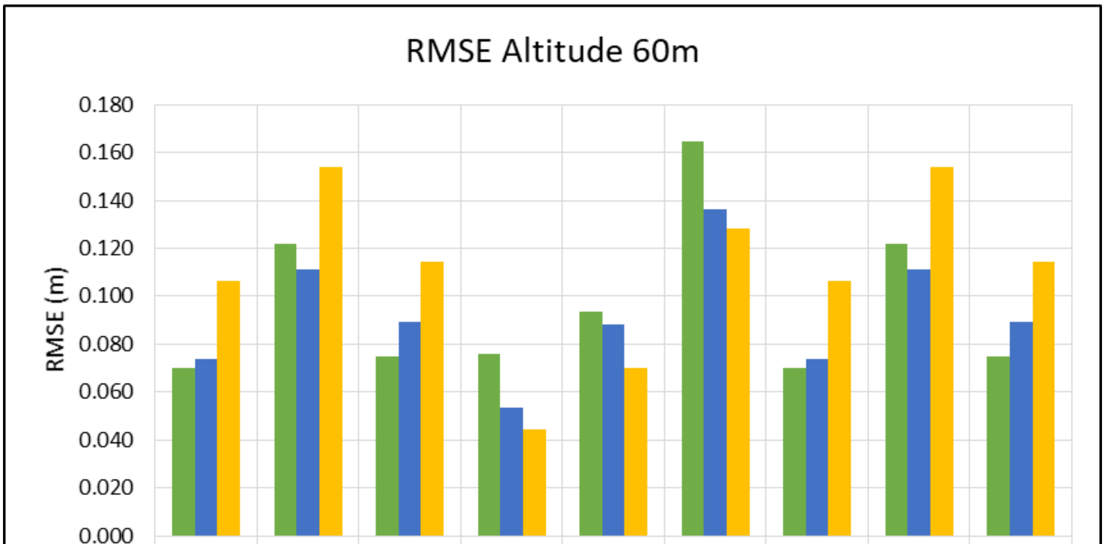


Figure 4. Result of Digital Terrain Model generated by PCI Geomatics Software

3.2 Accuracy Assessment

The accuracy assessment of the result will be validate through analysis number of check point X, Y, Z error and Root Mean Square Error (RMSE). All the result were be represent based on different altitude, overlap and sidelap. Figure 5 shows the trending bar graph for result RMSE altitude 60m with difference overlap and sidelap percentage. The result RMSE have been determine into 3 type of coordinate which is X, Y and Z. The result RMSE for X coordinate are represent as green color, Y coordinate represent as blue color and Z coordinate represent as yellow color.



	Overlap 70% Sidelap 50%	Overlap 70% Sidelap 60%	Overlap 70% Sidelap 70%	Overlap 80% Sidelap 50%	Overlap 80% Sidelap 60%	Overlap 80% Sidelap 70%	Overlap 90% Sidelap 50%	Overlap 90% Sidelap 60%	Overlap 90% Sidelap 70%
X (m)	0.070	0.122	0.075	0.076	0.094	0.165	0.070	0.122	0.075
Y (m)	0.074	0.111	0.089	0.053	0.088	0.136	0.074	0.111	0.089
Z (m)	0.106	0.154	0.114	0.044	0.070	0.128	0.106	0.154	0.114

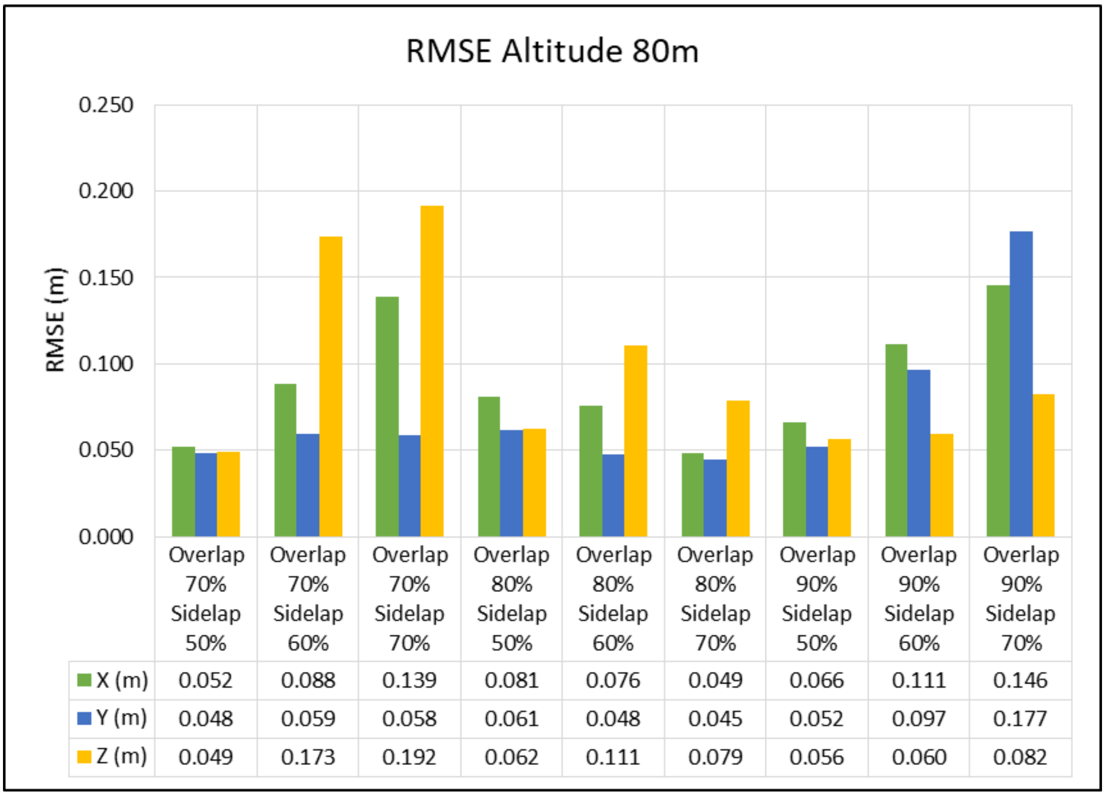
Figure 5. RMSE Altitude 60m with different overlap and sidelap percentage

According to Figure 5, this result of RMSE for altitude 60m with different overlap and sidelap percentage have been calculate by using 28 check point (CP) for every of dataset which all this CP were be conclude through RMSE result. The result also are not consistent. The trending bar graph shown the most highest result of RMSE are dataset altitude 60m with overlap 80% and sidelap 70%. The result of this data shown RMSE for X are 0.165m and RMSE for Y are 0.136m. For height, the result show the RMSE for Z are get 0.128m. However, the lowest result RMSE based on this graph are come from dataset altitude 60m with overlap 80% and sidelap 50%. It shown the result RMSE for X are 0.076m and RMSE for Y are 0.053m. For height, the result shown the RMSE for Z are 0.044m.

In topographic mapping also, the height of ground surface are important because with the high accuracy of height ground surface will produce high accuracy of topographic map. By refer to the bar graph in Figure 5, coordinate Z or known as ground level have been produce by using Digital Terrain Model (DTM). The result of the coordinate Z also have be conclude through calculation of RMSE for all dataset of altitude 60m with different overlap and sidelap percentage.

The result RMSE for coordinate Z shown the most dataset are get low accuracy are come from dataset altitude 60m with overlap 70% and sidelap 60% and also overlap 90% and sidelap 60%. Both of this dataset get result 0.154m. This factor may cause by effect of interpolation process of DTM. However, the higher accuracy of height are from dataset altitude 60m with overlap 80% and sidelap 50%. The result RMSE shown this dataset get 0.044m.

Figure 6 shows the trending bar graph for result RMSE altitude 80m with difference overlap and sidelap percentage. The result RMSE have been determine into 3 type of coordinate which is X, Y and Z. The result RMSE for X coordinate are represent as green color, Y coordinate represent as blue color and Z coordinate represent as yellow color.



	Overlap 70% Sidelap 50%	Overlap 70% Sidelap 60%	Overlap 70% Sidelap 70%	Overlap 80% Sidelap 50%	Overlap 80% Sidelap 60%	Overlap 80% Sidelap 70%	Overlap 90% Sidelap 50%	Overlap 90% Sidelap 60%	Overlap 90% Sidelap 70%
X (m)	0.052	0.088	0.139	0.081	0.076	0.049	0.066	0.111	0.146
Y (m)	0.048	0.059	0.058	0.061	0.048	0.045	0.052	0.097	0.177
Z (m)	0.049	0.173	0.192	0.062	0.111	0.079	0.056	0.060	0.082

Figure 6. RMSE Altitude 80m with different overlap and sidelap percentage

By refer to Figure 6, this result of RMSE for altitude 80m with different overlap and sidelap percentage have been calculate by using 28 check point (CP) for every of dataset which all this CP were be conclude through RMSE result. The result also are not consistent. The trending bar graph shown the most highest result of RMSE are dataset altitude 80m with overlap 90% and sidelap 70%. The result of this data shown RMSE for X are 0.146m and RMSE for Y are 0.177m. For height, the result show the RMSE for Z are get 0.082m. However, the lowest result RMSE based on this graph are come from dataset altitude 80m with overlap 70% and sidelap 50%. It shown the result RMSE for X are 0.052m and RMSE for Y are 0.048m. For height, the result shown the RMSE for Z are 0.049m.

The height of ground surface in topographic map are important because with the high accuracy of height ground surface will produce high accuracy of topographic map. By refer to the bar graph in Figure 6, coordinate Z or known as ground level have been produce by using Digital Terrain Model (DTM). The result of the coordinate Z also have be conclude through calculation of RMSE for all dataset of altitude 80m with different overlap and sidelap percentage.

The result RMSE for coordinate Z shown the most dataset are get low accuracy are come from dataset altitude 80m with overlap 70% and sidelap 60% and also overlap 70% and sidelap 70%. Both of this dataset get result 0.173m and 0.192m. This factor may cause by effect of interpolation process of DTM. However, the higher accuracy of height are from dataset altitude 80m with overlap 70% and sidelap 50%. The result RMSE shown this dataset get 0.049m.

Figure 7 shows the trending bar graph for result RMSE altitude 100m with difference overlap and sidelap percentage. The result RMSE have been determine into 3 type of coordinate which is X, Y and Z. The result RMSE for X coordinate are represent as green color, Y coordinate represent as blue color and Z coordinate represent as yellow color.

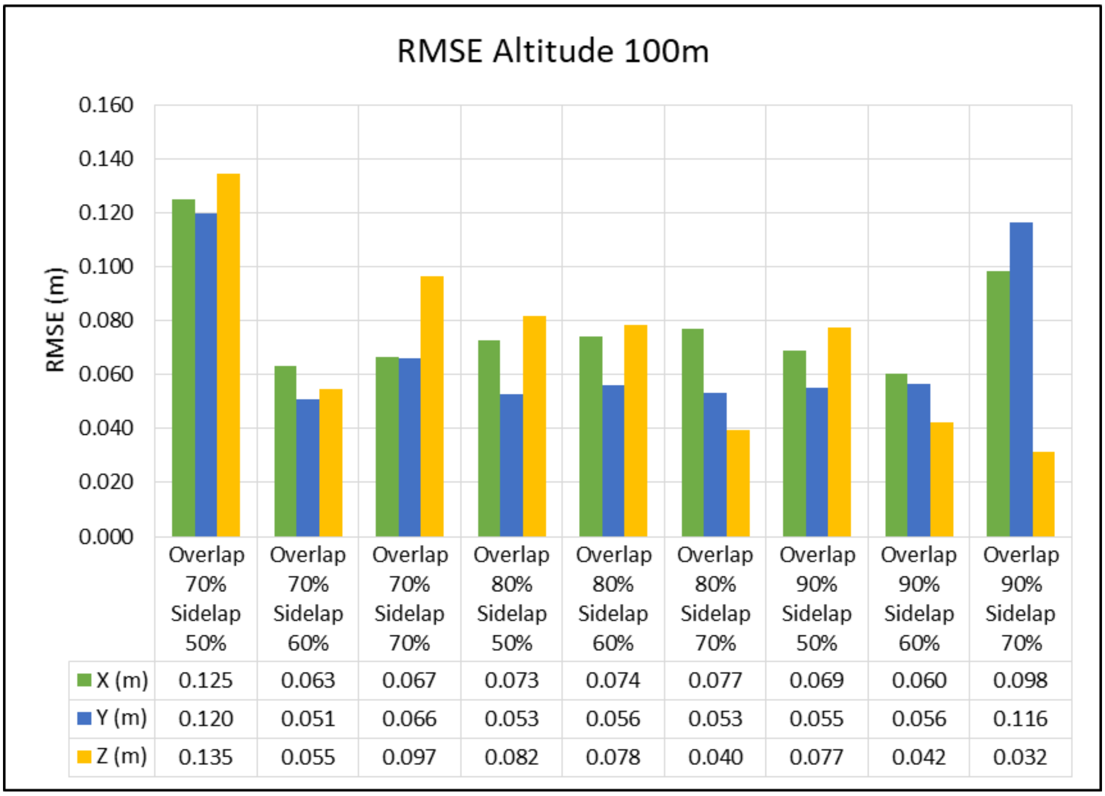


Figure 7. RMSE Altitude 100m with different overlap and sidelap percentage

Based on Figure 7, this result of RMSE for altitude 100m with different overlap and sidelap percentage have been calculate by using 28 check point (CP) for every of dataset which all this CP were be conclude through RMSE result. The result also are not consistent. Refer to the Figure 7, the trending bar graph shown the most highest result of RMSE are dataset altitude 100m with overlap 70% and sidelap 50%. The result of this data shown RMSE for X are 0.125m and RMSE for Y are 0.120m. For height, the result show the RMSE for Z are get 0.135m. However, the lowest result RMSE based on this graph are come from dataset altitude 100m with overlap 90% and sidelap 60%. It shown the result RMSE for X are 0.060m and RMSE for Y are 0.056m. For height, the result shown the RMSE for Z are 0.042m.

Height level of ground surface for topographic map are important because with the high accuracy of height ground surface will produce high accuracy of topographic map. By refer to the bar graph in Figure 6, coordinate Z or known as ground level have been produce by using Digital Terrain Model (DTM). The result of the coordinate Z also have be conclude through calculation of RMSE for all dataset of altitude 100m with different overlap and sidelap percentage.

The result RMSE for coordinate Z shown the most dataset are get low accuracy are come from dataset altitude 100m with overlap 70% and sidelap 50% and also overlap 70% and sidelap 70%. Both of this dataset get result 0.135m and 0.097m. This factor may cause by effect of interpolation process of DTM. However, the higher accuracy of height are from dataset altitude 100m with overlap 90% and sidelap 70%. The result RMSE shown this dataset get 0.032m.

Figure 8 shows the trending bar result for RMSE among 3 different altitude which is altitude 60m, altitude 80m and altitude 100m. The result RMSE have been determine into 3 type of coordinate which is X, Y and Z. The result RMSE for X coordinate are represent as orange color, Y coordinate represent as yellow color and Z coordinate represent as green color.

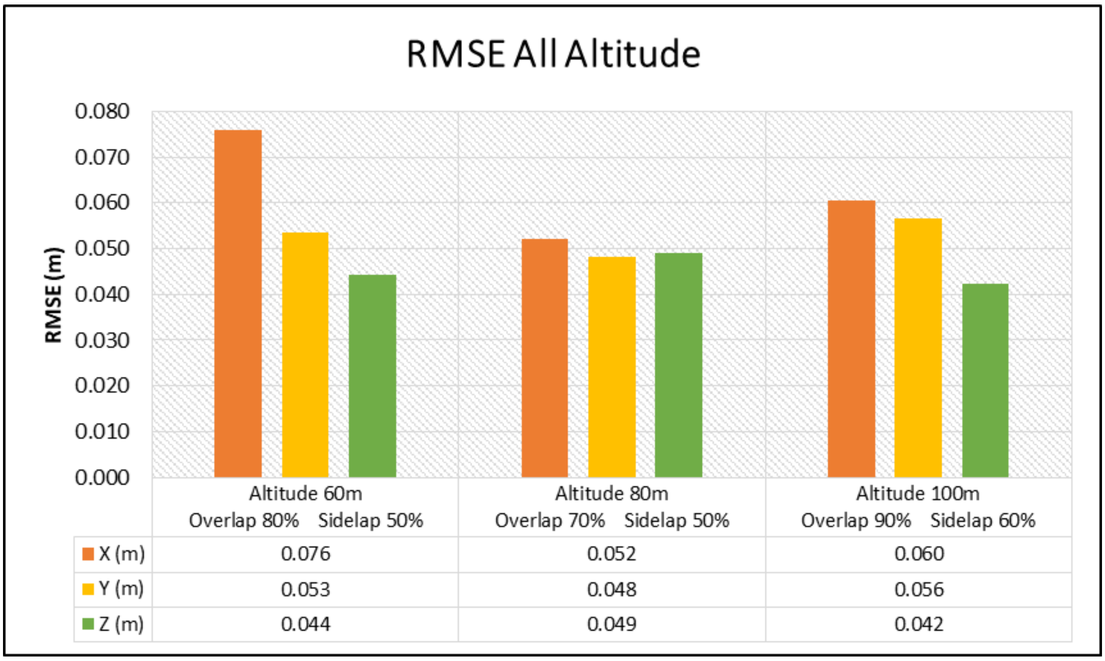


Figure 8.RMSE result among 3 different altitude

By refer to Figure 8, it shown the result consist 3 type of result RMSE with different altitude. The altitude consist of altitude from altitude 60m with overlap 80% and sidelap 50%, altitude 80m with overlap 70% and sidelap 50% and altitude 100m with overlap 90% and sidelap 60%. For result RMSE altitude 60m with overlap 80% and sidelap 50%, RMSE for X coordinate get 0.076m, Y coordinate get 0.053m and Z coordinate get 0.044m. Result RMSE for altitude 80m with overlap 70% and sidelap 50%, X coordinate get 0.052m, Y coordinate get 0.048m and Z coordinate get 0.049m. Another result RMSE is altitude 100m with overlap 90% and sidelap 60%. The result RMSE for X coordinate get 0.060m, Y coordinate get 0.056m and Z coordinate get 0.042m.

Based on three result shown in the Figure 8, it shown the highest result for RMSE are come from dataset altitude 60m with overlap 80% and sidelap 50%. The result shown the result RMSE for X coordinate get 0.076m, Y coordinate get 0.053m and Z coordinate get 0.044m. However the lowest result RMSE are come from dataset altitude 80m with overlap 70% and sidelap 50%. The result RMSE shown this dataset result for X coordinate get 0.052m, Y coordinate get 0.048m and Z coordinate get 0.049m.

In produce a good product of topographic mapping, the accuracy of coordinate not only based on X and Y coordinate but height of elevation ground surface also are important to make sure the product of topographic map are get the best result accuracy for topographic map. Based on 3 dataset that shown in Figure 8, the result RMSE for height of elevation which Z coordinate shown the height coordinate are come from dataset altitude 80m with overlap 70% and sidelap 50%. The result get 0.049m. However, the middle result RMSE for height of elevation are come from dataset 60m with overlap 80% and sidelap 50% which the result get 0.044m. For the lowest result RMSE for height of elevation are come from dataset altitude 100m with overlap 90% and sidelap 60% and the result get 0.042m. Based on this 3 result, the average for this 3 result RMSE get 0.045m or 4.5cm which it below than 5cm.

Through all dataset that shown in Figure 8, the best result for RMSE of all dataset shown the dataset altitude 80m with overlap 70% and sidelap 50% are the optimal of flight parameter that can use in topographic map. This is because based on the trending graph of all dataset shown the dataset altitude 80m with overlap 70% and sidelap 50% get the consistent graph trending compare to other dataset. With the lowest result RMSE between all dataset make this dataset are the best dataset can be used for topographic mapping by using altitude 80m with overlap 70% and sidelap 50%.

4. Conclusions

The aim of this study is to assess the accuracy topographic mapping from different flight parameter. To assess the accuracy of this study, flight parameter have been selected which it consist of three different altitude, overlap and sidelap percentage. Altitude that use in this study are 60m, 80m and 100m. For overlap and sidelap percentage use in this study are 70%, 80%, 90% and 50%, 60%, 70%. The main objective to use this flight parameter is to produce a product of photogrammetric with different altitude, overlap and sidelap percentage which this photogrammetric product were be analyze the accuracy through accuracy assessment for all twenty seven dataset. According to the result accuracy assessment to all altitude, every altitude have been carried out the best result with the lowest value of RMSE. For altitude 60m, the dataset get lowest RMSE are dataset altitude 60m with overlap 80% and sidelap 50%. However, for altitude 80m which get lowest RMSE are dataset altitude 80m with overlap 70% and sidelap 50%. The highest altitude use in this study which altitude 100m, the result shown the lowest RMSE get from this dataset are dataset altitude 100m with overlap 90% and sidelap 60%. By comparing this three best result such as altitude 60m with overlap 80% and sidelap 50%, altitude 80m with overlap 70% and sidelap 50% and altitude 100m with overlap 90% and sidelap 60% through accuracy assessment which get the lowest RMSE, the result of accuracy assessment can be conclude of this study that result from dataset altitude 80m with overlap 70% and sidelap 50% are the optimal of flight parameter that can use in topographic map. This is because based on the trending graph of all dataset shown the dataset altitude 80m with overlap 70% and sidelap 50% get the consistent graph trending compare to other dataset. With the lowest result RMSE between all dataset make this dataset are the best dataset can be used for comprehensive of flight parameter using UAV for topographic map by using altitude 80m with overlap 70% and sidelap 50%.

References

[1] Abbas Zedan Khalaf & Doaa Taha Yassin. (2016). Evaluation the Calibration of Non-Metric (Digital Camera) With Photo Modeler Software. Ijir,2016, (10), 1765–1772.

[2] Abdullah, S., Tahar, K. N., Rashid, M. F. A., & Osoman, M. A. (2019). Camera calibration performance on different non-metric cameras. Pertanika Journal of Science and Technology, 27(3), 1397–1406.

[3] Ahmad, M. J., Ahmad, A., & Kanniah, K. D. (2018). Large scale topographic mapping based on unmanned aerial vehicle and aerial photogrammetric technique. IOP Conference Series: Earth and Environmental Science, 169(1). https://doi.org/10.1088/1755-1315/169/1/012077

[4] Amran, M. S., & Tahar, K. N. (2017). Assessment on different digital camera calibration software for photogrammetric applications. Journal of Advanced Research in Applied Mechanics, 30(1), 17–28.

[5] Azmi, S. M., Ahmad, B., & Ahmad, A. (2014). Accuracy assessment of topographic mapping using UAV image integrated with satellite images. IOP Conference Series: Earth and Environmental Science, 18(1). https://doi.org/10.1088/1755-1315/18/1/012015

[6] Bagnardi, M., González, P. J., & Hooper, A. (2016). High-resolution digital elevation model from tri-stereo Pleiades-1 satellite imagery for lava flow volume estimates at Fogo Volcano. Geophysical Research Letters, 43(12), 6267–6275. https://doi.org/10.1002/2016GL069457

[7] Barba, S., Barbarella, M., Di Benedetto, A., Fiani, M., Gujski, L., & Limongiello, M. (2019). Accuracy Assessment of 3D Photogrammetric Models from an Unmanned Aerial Vehicle. Drones, 3(4), 79. https://doi.org/10.3390/drones3040079

[8] Brown, O. (2016). Spatial Accuracy of UAV Derived Orthoimagery and Topography: Comparing Photogrammetric Model Process With Direct Geo-Referencing, 70(1), 21–30.

[9] Busari, Q. A. (2018). Determination of the Position and Orientation of Aerial Photogrammetry Sensors : A Practical Implementation, 94(February), 131–148.

[10] Colomina, I., & Molina, P. (2014). Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS Journal of Photogrammetry and Remote Sensing, 92, 79–97. https://doi.org/10.1016/j.isprsjprs.2014.02.013

[11] Forlani, G., Dall'Asta, E., Diotri, F., di Cella, U. M., Roncella, R., & Santise, M. (2018). Quality assessment of DSMs produced from UAV flights georeferenced with on-board RTK positioning. Remote Sensing, 10(2). https://doi.org/10.3390/rs10020311

[12] H.H,Ali and F.M, A. (2019). The impact of UAV flight planning parameters on topographic mapping quality control The impact of UAV flight planning parameters on topographic mapping quality control. https://doi.org/10.1088/1757-899X/518/2/022018

[13] Hirt, C. (2016). Sources of DTM Data. Digital Terrain Model, (June), 2–7. https://doi.org/10.1007/978-3-319-02370-0

[14] James, M. R., Robson, S., Oleire-oltmanns, S., & Niethammer, U. (2017). Geomorphology Optimising UAV topographic surveys processed with structure-from-motion : Ground control quality , quantity and bundle adjustment. Geomorphology, 280, 51–66. https://doi.org/10.1016/j.geomorph.2016.11.021

[15] Koeva, M., Muneza, M., Gevaert, C., Gerke, M., & Nex, F. (2018). Using UAVs for map creation and updating. A case study in Rwanda. Survey Review, 50(361), 312–325. https://doi.org/10.1080/00396265.2016.1268756

[16] Lee, J. H., & Sull, S. (2019). Regression tree CNN for estimation of ground sampling distance based on floating-point representation. Remote Sensing, 11(19), 1–17. https://doi.org/10.3390/rs11192276

[17] Mesas-Carrascosa, F. J., García, M. D. N., De Larriva, J. E. M., & García-Ferrer, A. (2016). An analysis of the influence of flight parameters in the generation of unmanned aerial vehicle (UAV) orthomosaicks to survey archaeological areas. Sensors (Switzerland), 16(11), 1–19. https://doi.org/10.3390/s16111838

[18] Nagendran, S. K., Tung, W. Y., & Mohamad Ismail, M. A. (2018). Accuracy assessment on low altitude UAV-borne photogrammetry outputs influenced by ground control point at different altitude. IOP Conference Series: Earth and Environmental Science, 169(1). https://doi.org/10.1088/1755-1315/169/1/012031

[19] Oniga, E., Breaban, A., & Statescu, F. (2018).   Determining the optimum number of ground control points for obtaining high precision results based on UAS images, 5165. https://doi.org/10.3390/ecrs-2-05165

[20] Seifert, E., Seifert, S., Vogt, H., Drew, D., Aardt, J. Van, Kunneke, A., & Seifert, T. (2019). Influence of Drone Altitude , Image Overlap , and Optical Sensor Resolution on Multi-View Reconstruction of Forest Images. https://doi.org/10.3390/rs11101252

[21] Sels, S., Ribbens, B., Vanlanduit, S., & Penne, R. (2019). Camera calibration using gray code. Sensors (Switzerland), 19(2). https://doi.org/10.3390/s19020246

[22] Semeniuta, O. (2016). Analysis of Camera Calibration with Respect to Measurement Accuracy. Procedia CIRP, 41, 765–770. https://doi.org/10.1016/j.procir.2015.12.108

[23] Tonkin, T. N., & Midgley, N. G. (2016). Ground-Control Networks for Image Based Surface Reconstruction : An Investigation of Optimum Survey Designs Using UAV Derived Imagery and, 16–19. https://doi.org/10.3390/rs8090786

[24] Udin, W. S., & Ahmad, A. (2014). Assessment of photogrammetric mapping accuracy based on variation flying altitude using unmanned aerial vehicle. IOP Conference Series: Earth and Environmental Science, 18(1). https://doi.org/10.1088/1755-1315/18/1/012027

[25] Uysal, M., Toprak, A. S., & Polat, N. (2015). DEM generation with UAV Photogrammetry and accuracy analysis in Sahitler hill. MEASUREMENT, 73, 539–543. https://doi.org/10.1016/j.measurement.2015.06.010

[26] Wallace, L., Lucieer, A., Malenovskỳ, Z., Turner, D., & Vopěnka, P. (2016). Assessment of forest structure using two UAV techniques: A comparison of airborne laser scanning and structure from motion (SfM) point clouds. Forests, 7(3), 1–16. https://doi.org/10.3390/f7030062

[27] Yusoff, A. R., Darwin, N., Majid, Z., Ariff, M. F. M., & Idris, K. M. (2018). Comprehensive analysis of flying altitude for high resolution slope mapping using UAV technology. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42(3W4), 583–589. https://doi.org/10.5194/isprs-archives-XLII-3-W4-583-2018

[28] Zeybek, M. (2019). Point cloud filtering on UAV based point cloud, c, 99–111. https://doi.org/10.1016/j.measurement.2018.10.013

Acknowledgements

Faculty of Architecture, Planning, and Surveying Universiti Teknologi MARA (UiTM), Research Management Institute (RMi) and Ministry of Higher Education (MOHE) are greatly acknowledged for providing the fund BESTARI 600- RMC/DANA 5/3/BESTARI (TD) (006/2019) to enable this research to be carried out. The authors would also like to thank the people who were directly or indirectly involved in this research.