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Full Length Research Paper

A simulation study on the capabilities of rotor wing unmanned aerial vehicle in aerial terrain mapping

Khairul Nizam Tahar[1]* and Anuar Ahmad[2]

[1]Department of Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
[2]Department of Geoinformatics, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.

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Many applications can be solved by using the unmanned aerial vehicle (UAV) technology such as farming, surveillance, monitoring, fire disaster, flood monitoring and aerial terrain mapping. This study was carried out to investigate the use of light weight rotary-wing UAV for mapping simulation model. The accuracy of photogrammetric product will be assessed as one of the objectives of this study. There are two types of UAV units known as rotor wing and fixed-wing. Based on few studies, rotor wing units are more stable and are able to capture images easily. It allows remote control UAV to be practiced in the environment and urban mapping. In the simulation model, ground control points (GCP) and checked point (CP) were established using total station. The GCP is used in the photogrammetric processes to produce photogrammetric output while the CP is used for accuracy assessment. This study also used a low cost digital camera in image acquisition to capture the aerial image of a simulated model. Two methods were implemented in this study. In the first method, the camera was mounted vertically at a fixed height on the simulated model. In the second method, the camera was mounted vertically; it was then attached at the bottom of rotary-wing UAV and the images were captured at an altitude. The productions of digital orthophoto and digital elevation model of the simulated model were obtained after the acquired images were processed using the photogrammetric software. Based on the finding, the root mean square errors (RMSEs) for fixed platform are ±0.002, ±0.001 and ±0.214 for coordinate x, y and z, respectively while the RMSE for UAV platform are ±0.002, ±0.002 and ±0.223 for coordinate x, y and z, respectively. It can be concluded that the differences between the mobile and fixed platforms are small. In conclusion, UAV system can be used for large scale mapping of aerial terrain mapping.

Key words: Mobile mapping, non-metric, digital elevation models (DEM), photogrammetry, simulation.

INTRODUCTION

Data acquisition for aerial photogrammetry covers kites, gliders, balloon, airship, rotary and fixed wing unmanned aerial vehicle (UAV) with the various flight modes such as manual, semi-automated or fully-automated. The methods of data acquisition depend on the budget of the project, time of project and level of accuracy that is required in the project.

The demands of aerial photogrammetry have increased especially after the development of design, research and production of UAV platform (Breckenridge and Dakins, 2011; Chao et al., 2010). The new UAV with the complete set was developed by using high quality fibers as the material for the model plane (Li et al., 2008). UAV has been used in most applications such as farming, surveillance, road maintenance, recording and documentation of cultural heritage (Bryson and Sukkarieh, 2009).

Recently, the development of science and technology is widely spread in many education fields (Tahar and Ahmad, 2011). The military uses the UAV in surveillance

*Corresponding author. E-mail: nizamtahar@gmail.com.

Table 1. UAV categories.

Categories		Mass	Range	Flight alt.	Endurance
µ	Micro (µ)	< 5 kg	< 10 km	250 m	1 h
Mini	Mini	< 25/30/150*	< 10	150/250/300*	< 2
CR	Close range	25 to 150	10 to 30	3.000	2 to 4
SR	Short range	50 to 250	30 to 70	3.000	3 to 6
MR	Medium range	150 to 500	70 to 200	5.000	6 to 10
MRE	MR Endurance	500 to 1500	> 500	8.000	10 to 18
LADP	Low alt. deep penetration	250 to 2500	> 250	50 to 9.000	0,5 to 1
LALE	Low alt. long Endurance	15 to 25	> 500	3.000	> 24
MALE	Medium alt. long Endur.ance	1000 to 1500	> 500	5/8.000	24 to 48
HALE	High alt. long Endurance.	2500 to 5000	> 2000	20.000	24 to 48
Strato	Stratospheric	>2500	> 2000	>20.000	> 48
EXO	Exo-stratospheric	TBD	TBD	>30.500	TBD
UCAV	Unmanned combat	>1000	>+/ to 1500	12.000	+/ to 2
LET	Lethal	TBD	300	4.000	3 to 4
DEC	Decoys	150 to 500	0 to 500	50 to 5.000	< 4

*TBD, to be determined.

(a) (b)

Figure 1. (a), Hexacopter; (b), digital camera.

system because it is small and noiseless, thus, this will reduce the risk of being attacked at the enemy areas. Most of UAVs were attached with a camera in order to capture images or record videos at a certain location (Lin, 2008). Nowadays, the UAV is used by civilian as a hobby. There are many kinds of UAV that are available in the market. According to the Unmanned Vehicle System International Association, UAV can be categorized into 15 classes based on different mass, range, flight altitude and endurance of the UAV itself. Table 1 shows UAV categories.

Table 1 shows categories of the UAV that is available all over the world. These categories were divided into a few types of UAV according to its mass, range, flight altitude and time of endurance. UAV data collection is possible under the cloudless conditions. In addition, the quality of the image is much better than satellite images, which are located a hundred thousand kilometers away from the surface of the earth. With this advantage, UAV has been focused in the mapping research and various applications such as environmental, agricultural, monitoring hazardous area and exacta. Two main hardwires were used in this study: the UAV and high resolution digital cameras. Low altitude UAV was preferred because this study only focused on large scale mapping, which was involved in small area only. UAV is the most potential equipment used to capture the aerial photographs on a small area because it is very low in cost. In this study, an amateur digital camera with high resolution images was attached at the UAV. The amateur digital camera provides small format images and it has many different kinds of resolution in which each of them has different pixel size. Figure 1 shows an example of the UAV and amateur digital cameras.

In this study, Nikon Coolpix L4 was used to acquire the simulation model images. Nikon Coolpix digital camera has 3x optical zoom lens and 2.0” liquid crystal display (LCD) screen. Micro UAV, also known as Hexacopter, was used to acquire images for the simulation model. Hexacopter has six blades in which three blades rotate in clockwise direction and the other three blades rotate in counterclockwise direction. Nikon Coolpix camera was attached at the bottom of Hexacopter to capture aerial images during flight operation. The specification of rotary wing used in this study is shown in Table 2.

METHODOLOGY

The methodologies of this study consist of method of image acquisition and method of image processing. Figure 2 shows a flowchart of the research methodology which concentrates on the fixed and mobile platforms using rotary wing UAV to obtain aerial images of the simulated model. The dimension of the simulated model was approximately 3 m × 1 m and it was built using sand and cement. Before photogrammetry work is carried out, flight planning

Table 2. Hexacopter specification.

Rotary wing	Specification
Weight	1.2 kg
Rotor	6 rotor
Endurance	Up to 36 min
Payload	1 kg
GPS on board	Yes
Special function	Automatically return to home location (1st point)
Stabilizer	Inbuilt stabilizer to deal with wind correction
Capture data	Using software to reached waypoints
Flight control	Manual and autonomous
Camera stand	Flexible camera holder

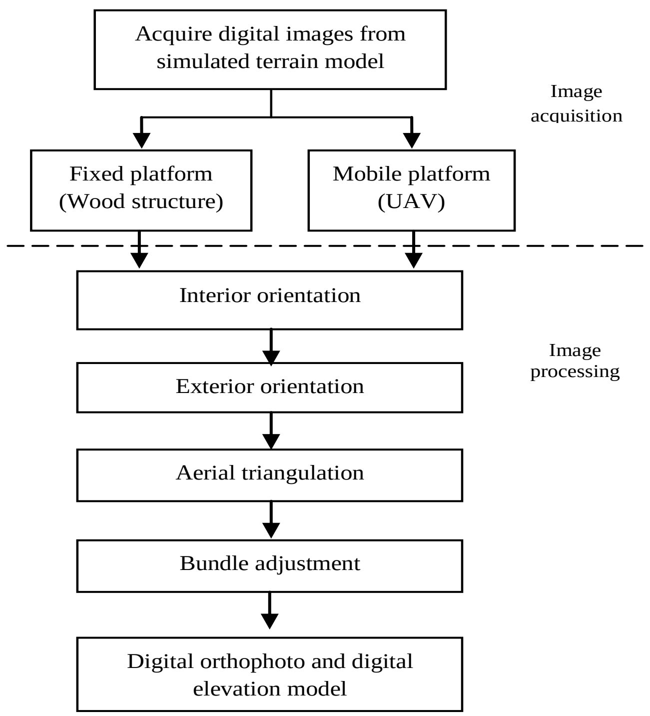

Figure 2. Methodology flowchart.

is the most important task that needs to be considered. This contributes to the quality of data acquisition. Flight planning involves calculation of the study area, number of strips required, pixel size, photo scale, flying height and percentage of end lap and side lap. In this study, the aerial photographs were overlapped at least 60% and side at least 30%. This requirement needs only to be fulfilled in order to obtain high quality phtogrammetry results.

Camera calibration should be carried out to obtain all camera information for image processing input. Three samples of camera calibration were applied in this study. Plate calibration, which has a dimension of about 0.4 m × 0.4 m and consist 36 points were used for camera calibration. The images of plate calibration were taken at four different positions. The distance and angle of the four positions were approximately the same. In digital images, the important thing that should be considered is pixel size. Pixel size will determine the smallest coverage of an area or of the object. The size of pixel involves a few elements such as the number of pixel for object image, length of an object in real measurement, focal length of the camera and flying height during the capturing of the images. Furthermore, each digital camera has different pixel size and it must be calculated during flight planning phase. Pixel size will determine the ground coverage area that was covered by one digital image. The ground coverage area of the images from the digital camera could also be determined by multiplying the scale of the photography with the dimension of the digital image. Results of this study were based on generated digital elevation model and orthophoto. In the analysis, differences between results from the fixed and the mobile platform were compared based on 33 ground control points (GCP). It was distributed evenly for the whole model which was established using total station. The accuracy of photogrammetric results was analyzed using the root mean square error RMSE) equation based on measured value and ground truth.

Quantitative assessment involves statistical mathematical model such as mean, variance, standard deviation and RMSE.

Quantitative assessment was used to determine the accuracy and precision of measured data. In this study, the photogrammetric products such as digital elevation model and digital orthophoto were assessed using statistic model and RMSE formula. The formula to calculate the RMSE (x,y,z) is shown in Equation 1.

$$RMSE(x,y) = \pm\sqrt{\sum_{i=1}^{i=n}\frac{(Xi - Xo)^2 + (Yi - Yo)^2}{n}} \; ; \quad RMSEz = \pm\sqrt{\sum_{i=1}^{i=n}\frac{(Zi - Zo)^2}{n}} \quad (1)$$

DATA PROCESSING

After data acquisition had been completed by using fixed and mobile platforms, all acquired images were processed by using photogrammetric software, that is, Erdas imagine software. Erdas imagine software requires camera information such as pixel size, focal length, radial lens distortion and tangential distortion to carry out interior orientation. Each pair of photographs has 60% overlapped and 11 photographs were processed for the whole simulation model. The footprint of the fixed and mobile platforms is shown in Figures 3 and 4, respectively. All GCP were registered during exterior orientation. Erdas imagine software requires six tie points or three control points for each pair of the overlapped photographs. Thirty-three (33) GCP were registered as a full control (XYZ) and 11 check points (CPs) were established evenly in the simulated model. However, 33 GCP and 404 tie points were established during image processing for fixed platform while 33 GCP and 353 tie points were established during image processing for mobile platform. The distribution of GCP and tie points for both platforms can be viewed in Figures 3 and 4. During image processing, the accuracy was maintained by checking the value of RMSE. The value of RMSE must be less than 1.0 in order to obtain good results.

RESULTS

In this study, two photogrammetric results were generated after performing interior orientation, exterior orientation and aerial triangulation such as digital elevation model and digital orthophoto. The result of digital orthophoto for fixed and mobile platforms is shown in Figures 5 and 6, respectively.

Digital orthophoto described the images of the simulated model from a nadir angle and it was free from any distortion. Individual orthophoto for each individual model was produced and maintained; they were mosaiced using mosaic operation. Figures 5 and 6 show a digital orthophoto which was covered for the whole simulated model. Digital orthophoto only gives a two-dimensional view which generally involves x and y axis. The digital elevation models (DEMs) were produced using Erdas imagine software and it was in raster form. The DEMs were produced after performing aerial triangulation using GCP and tie points. In this study, digital elevation model for fixed and mobile platforms are shown in Figures 7 and 8, respectively.

The quality of digital orthophoto and DEM depends on the accuracy of GCP. If the quality of GCP is poor, therefore the result of digital orthophoto and DEM will be less accurate.

ANALYSIS AND ACCURACY ASESSMENT

The aims of this study are to investigate the use of light weight rotary-wing UAV for mapping simulation model and to determine the accuracy of the photogrammetric output produced from acquired UAV images. The analysis focused on RMSE, visualization analysis on DEM and digital orthophoto from different platforms. Several CP were established during this study which was used to check the accuracy of DEM. Tables 3 shows that the results of accurate assessment of a digital elevation model and digital orthophoto were based on RMSE, mean and standard deviation of sample dataset after image processing.

Based on Table 3, the accuracy of horizontal coordinates were very high for both platforms. The accuracy can be measured up until millimeter level and it can be accepted in photogrammetric work. However, the accuracy of vertical coordinates was very low but it was constant for both platforms. Based on the table, it can be seen that the values of RMSE for fixed and mobile platforms were not significant. It might be affected by image matching algorithm that was used in the same software during image processing. The error was usually caused by different flying height during image acquisition, image matching during image processing and motion movement such as omega, phi, and kappa. Figure 9 shows the graph of RMSE versus ground control X, Y and Z for fixed and mobile platforms. It was found that the residual error was not significant for both platforms.

RMSE for ground control x and y were not much different but it was slightly different for ground control z, which represented the result for mobile and fixed platforms, respectively. The difference on ground control z might occur due to the effect of the automated tie point which implemented the image matching technique. The constant error of ground control z will be discussed further in the upcoming paper and the method to improve the accuracy will be discovered. The quality of terrain mapping can be analyzed by using slope angle and slope aspect analysis. Slope angle analysis involved the classification slope from the degree of the minimum value until the maximum value for the whole simulated model. Slope aspect analysis involved the classification of the direction of slope such as flat area, north, northeast, east,

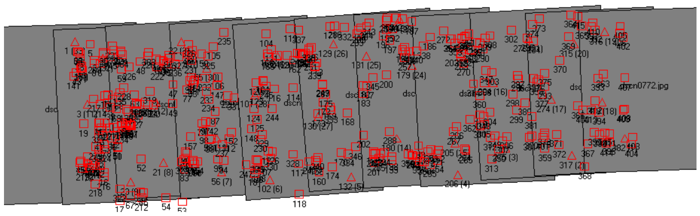

Figure 3. Footprint (Fixed platform).

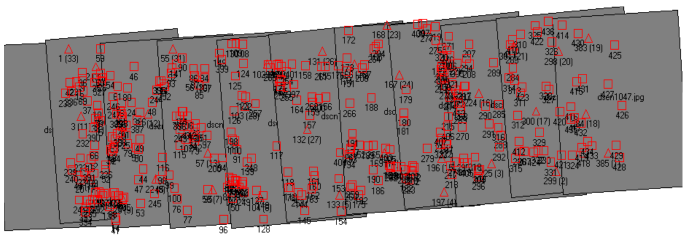

Figure 4. Footprint (Mobile platform).

Figure 5. Digital orthophoto (Fixed platform).

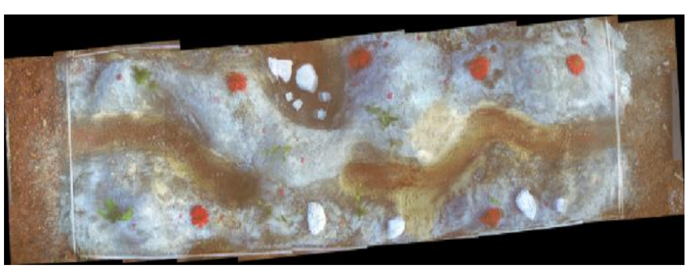

Figure 6. Digital Orthophoto (Mobile platform). Where Xi; Yi; Zi = measured value, X_o; Y_o; Z_o = true value and n = number of dataset.

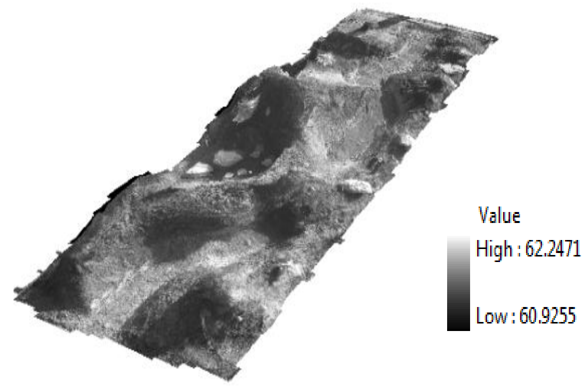

Figure 7. Digital elevation model (Fixed platform).

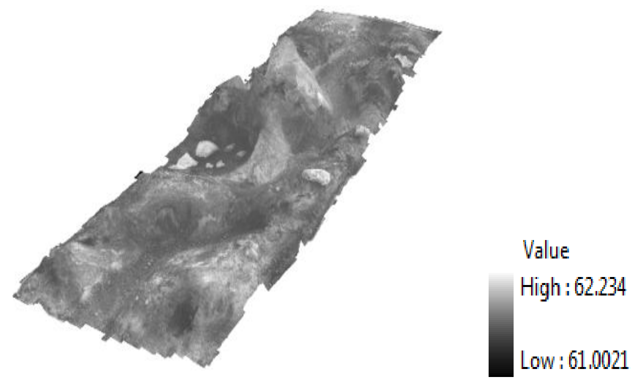

Figure 8. Digital elevation model (Mobile platform).

southeast, south, southwest, west and northwest. This study compared the differences between fixed platform dataset and UAV platform dataset. The sample dataset for fixed and UAV platform is shown in Figure 10.

From Figure 10a, it can concluded that, the result of the slope angle between fixed and UAV platform are mostly similar while Figure 10b shows a slight difference between fixed and UAV platforms. Based on these graphs, the slope angle did not change when images were either taken by using fixed or UAV platform. In contrast, the slope aspect recorded a slight difference between fixed and UAV platforms.

In general, UAV is lower in cost and it offers a faster response platform in data acquisition if compared to manned aircraft and surveying technique. Therefore, a time analysis was carried out in this study to compare the time taken when three different techniques such as tacheometry method (conventional surveying method), fixed platform (wood structure) and mobile platform (UAV) were used. The analysis of time estimation was divided into a few categories including project planning, field work, processing and labor needed. The analysis of estimation time is shown in Table 4. This estimation only covers simulation work with the study area of 1 × 3 m.

From Table 4, it can be concluded that tacheometry method has the disadvantage in fieldwork stage but it is efficient in data processing since lesser time are required. Mobile platform or UAV has the advantage in fieldwork but it requires more time in image processing. This estimation is only valid for the simulation model used in this study. However, if the project involves large area, it

Table 3. Result of fixed and mobile platforms.

Platform	Aerial triangulation	GCP	RMSE (m)	Mean (m)	Std Dev (m)
	33 GCP	X	±0.002	±0.002	±0.002
Fixed platform	404 tie points	Y	±0.001	±0.001	±0.001
		Z	±0.214	±0.148	±0.163
	33 GCP	X	±0.002	±0.002	±0.002
Mobile platform	353 tie point	Y	±0.002	±0.001	±0.001
		Z	±0.223	±0.156	±0.167

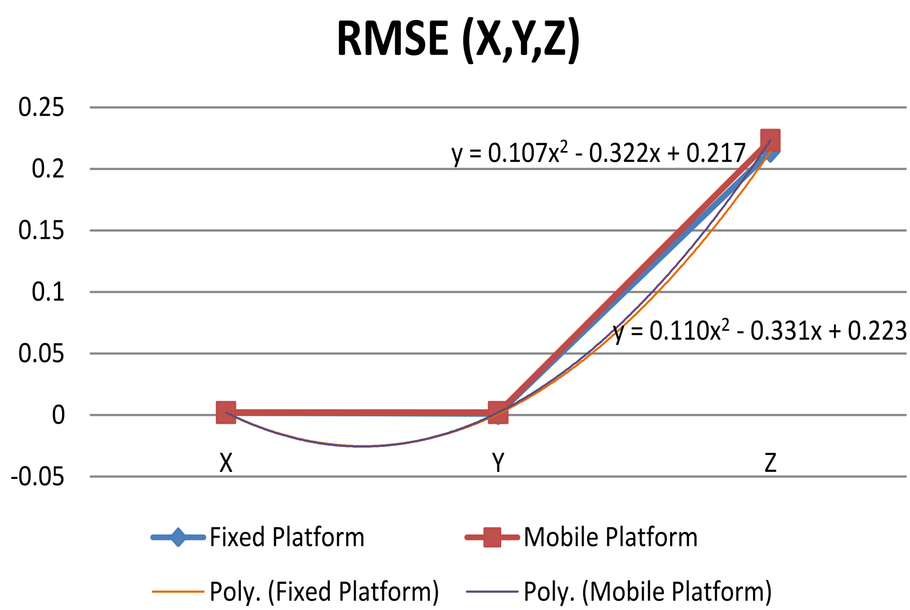

Figure 9. Root mean square error (x,y,z).

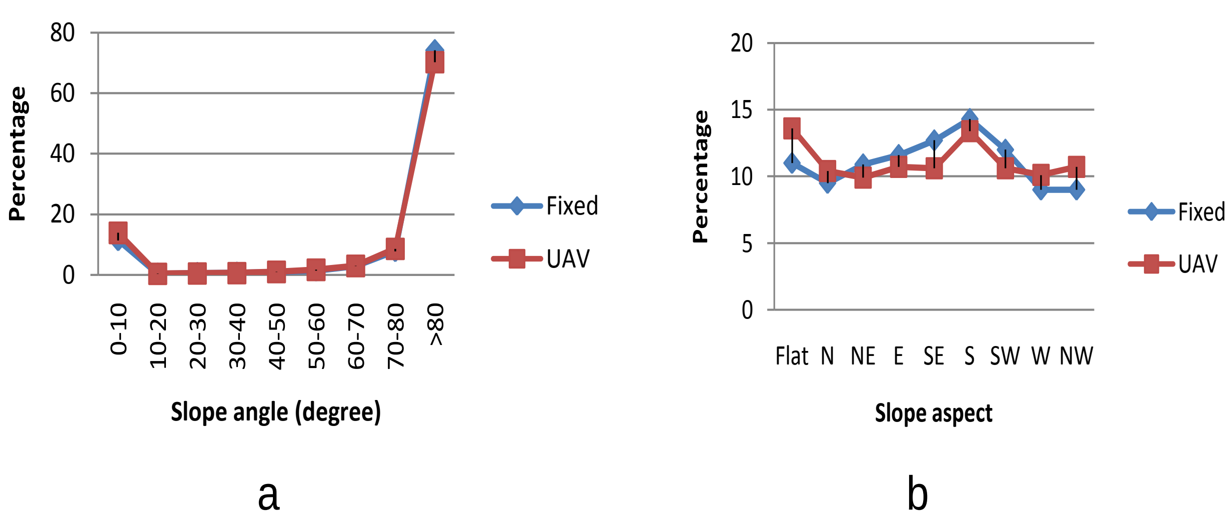

Figure 10. Slope angle and slope aspect analysis.

Table 4. Time estimation for simulation work.

Method	Tacheometry method	Fixed platform	UAV platform
Project planning (reconnaissance, calculation flight planning, establish station traverse, establish ground control point)	1.5 h	2 h	2 h
Fieldwork	Traversing – 2 h	Traversing – 2 h	Traversing – 2 h
	Spot height – 2 h	Static platform setup - 30 min	UAV setup – 20 min
		Acquire images – 15 min	Flight - 10 min
Processing	Export ASCII file to point data – 20 min	Image Processing until DEM – 2 h	Image processing until DEM – 2 h
	Generate DEM – 1 h		
Labor	3 persons	2 persons	1 professional operator
Total (h)	6 h 55 min	6 h 45 min	6 h 30 min

will take a long time to complete the traversing work when tacheometry method is used. In contrast, UAV will only take 1 or 2 h to complete image acquisition. In conclusion, UAV platform is very helpful in large scale mapping especially in aerial terrain mapping.

CONCLUSION AND FUTURE WORK

This study has proved that rotor wing UAV can be used for large scale terrain mapping. This study is more extensive if compared to the previous work done by Tahar and Ahmad (2011). The previous work only used the low cost digital camera in image acquisition. The technique of image acquisition using rotor wing UAV is based on a study done by Lin (2008). This study implemented two approaches for data acquisition namely the fixed platform and the mobile platform. Two photogrammetric results were produced; digital orthophoto and digital elevation model. These results were analyzed using the RMSE, slope angle analysis and slope aspect analysis. Based on slope angle analysis, rotor wing UAV platform produced the same result as fixed platform. Therefore, rotor wing UAV images can be used in slope angle analysis or production of slope map. With the new technology, UAV can solve many problems in various applications especially in places with small area. It has been proved that UAV platform is very suitable for the project with limited budget and duration. This technology can be adopted in photogrammetry work, which requires an up-to-date information in a short period of time. This technology can be used by any agency or ministry within the environmental field. For the future work, it is hope that this research will expand to determine the accuracy and cost for data acquisition in places of large area. Furthermore, it is also hope that a variety of UAVs can be explored in aerial terrain mapping.

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