International Journal of Physical Sciences Vol. 7(42), pp. 5678-5686, 9 November, 2012
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS12.142
ISSN 1992 - 1950 ©2012 Academic Journals

Full Length Research Paper

A new approach on production of slope map using autonomous Unmanned aerial vehicle

Khairul Nizam Tahar[1]*, Anuar Ahmad[2], Wan Abdul Aziz Wan Mohd Akib[2] and Wan Mohd Naim Wan Mohd[1]

[1]Department of Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying, Universiti Teknologi Mara, 40450 Shah Alam, Selangor Darul Ehsan, Malaysia.
[2]Faculty of Real Estate and Geoinformation, Univerisiti Teknologi Malaysia, Skudai, Johor, Malaysia.

Accepted 1 June, 2012

Many studies have been done previously to generate a slope map at the area of interest. However, most of these methods can be time consuming and they require huge cost. Currently, aerial mapping using Unmanned aerial vehicle (UAV) is very popular in the mapping field. UAV can promise a high accuracy data with low cost and less time needed to produce a slope map at certain area. Therefore, a scientific approach needs to be carried out to determine the accuracy level of the result. This paper investigates the capabilities of autonomous UAV in production of slope map. The aim of this study is to identify a slope pattern at the selected development area using UAV. All acquired images from the UAV were processed by using photogrammetric software. Two primary results were produced after going through all photogrammetric processing; digital elevation model (DEM) and digital orthophoto. On the other hand, these results were used to identify the slope pattern at the selected development area. Several ground control points and checkpoints were established evenly at the study area by using Real Time Kinematic-Global Positioning System (RTK-GPS). It was found that the total root mean square equation (RMSE) vector for this study is about ±5.131 m and each coordinates of easting, northing and height recorded the RMSE value of ±1.342, ±1.660 and ±4.666 m, respectively.

Key words: Unmanned aerial vehicle, slope map, digital orthophoto, digital elevation model (DEM), analysis

INTRODUCTION

Slope instability caused many losses and huge economic expenses especially in tropical countries. Therefore many previous techniques have been used to generate slope map at the risk area frequently. These techniques include light detection and ranging (LiDAR), manned aerial photograph, terrestrial laser scanner (TLS), satellite imagery and fieldwork survey. Each of these techniques has its own advantage and disadvantage such as LiDAR and TLS which can provide high density point cloud, but this technology is very expensive for monitoring work. Manned aircraft also requires an expensive cost to fly at certain area from certain altitude because it requires an expensive camera and professional pilot to navigate the aircraft according to the specific run line. Manned aircraft involves huge cost and time for each flight mission. Field survey requires a professional surveyor to do survey at the study area and it is not practical for the large area because it will involve many labors, huge cost and more time to complete the survey work. A new solution needs to be explored in order to obtain the slope map at specific area with low cost, less time and less labour.

This study introduces the potential of unmanned aerial vehicle (UAV) in fast production of slope map at the specific area. UAV has become the most popular method in the mapping field. The development of design, research and production of UAV has increased the demand of aerial photogrammetry. Previously, many studies have been done in order to determine the capabilities of UAV in various applications. UAV promises a low cost, less time and less manpower during the data collection. Lin (2008) mentioned that most of UAV are

*Corresponding author. E-mail: nizamtahar@gmail.com. Tel: +60123709462.

(a) (b) (c)

Figure 1. Equipment: (a), UAV; (b), Net; (c), Digital camera.

attached with camera or video recorder to acquire image and video of the ground from a certain altitude. In 1858, Gaspar Felix Tournachon was the first person to photograph a French village at approximately 80 m above the earth surface from a balloon. Many fields such as archeology, town planning, monitoring, natural hazard warning, environmental studies, farming, road maintenance, recording and documentation of cultural heritage and surveillance can make use of the aerial mapping (Mitch and Salah, 2009). There are two famous units in UAV system; rotary wing unit and fixed wing unit. Rotary wing unit is based on rotor and blade, while fixed wing unit is similar to the model of an aircraft. UAV can operate in two condition; manually or autonomously (Grenzdorffer et al., 2008).

A professional operator is needed for the launching and the landing phase to avoid any damages on the UAV. A model of rotary wing was introduced in 1980 that was able to carry payload until 3 kg and it flew about 10 to 100 m. A camera mount was installed to carry the rolleiflex camera in order to acquire images from the space. The technologies of UAV’s increase year by year. An autonomous chip is installed in the UAV and it can be flown autonomously (David et al., 2008). The user or operator only needs to enter the initial position and download it into the autonomous chip. This autonomous technology is used by Cropcam UAV and Hexacopter UAV in data acquisition. Autonomous flight needs to communicate with the computer on the ground to monitor the condition of the UAV during flight duration. Radio modem is used to communicate between the computer and UAV during flight mission (Herwitz et al., 2004; Albaker and Rahim, 2011). During fixed wing UAV flight mission, a net is set up at an open area for landing purpose. The net is used to absorb the UAV speed and avoid the UAV from any damages. It is very difficult to operate a high speed fixed-wing UAV for it to land safely on the ground.

Based on numerous studies, rotary UAV can achieve a flying height of 100 m and fixed wing UAV can fly about thousand foot. However, this condition must be approved by the government civil aviation because it involves the space security (Tahar et al., 2011; Eisenbeiss, 2009). Recently, UAV images are used to investigate the three-dimensional slope models. This study carried out an accuracy assessment to find the level of UAV data for slope mapping. Cropcam UAV was used to acquire the images of the study area. The digital camera was attached at the bottom of UAV and it captured the images automatically (Rodriguez et al., 2008). The preparation before flight mission was explained in the UAV preparation section. A net size of approximately 7 by 5 m was set up during the flight mission for landing purpose. Figure 1 shows the UAV, digital camera and net used in this study. Basically, this study applied the aerial photogrammetry technique and all acquired images were orthogonally captured from the bottom of the UAV. All acquired images were processed by using photogrammetric software and went through a few photogrammetric processes such as interior orientation, exterior orientation, aerial triangulation and bundle adjustment.

METHODOLOGY

The methodology involves four main phases including flight planning, UAV preparation, camera calibration and image processing. Generally, camera calibration determines the camera parameters, flight planning discussed about calculation of coverage area of single digital image on the ground and design waypoints, UAV preparation discusses the flow of UAV preparation before flight mission, and image processing discusses photogrammetric processing from UAV raw images to photogrammetric products and slope map product. Figure 2 shows a flowchart of the general methodology in this study.

Camera calibration

Camera calibration can provide several parameter of the camera. This information is very useful in flight planning and photogrammetric processing. In this study, self calibration bundle adjustment methods were used to define all parameters involved for the photogrammetric processing. One plate calibration was used,

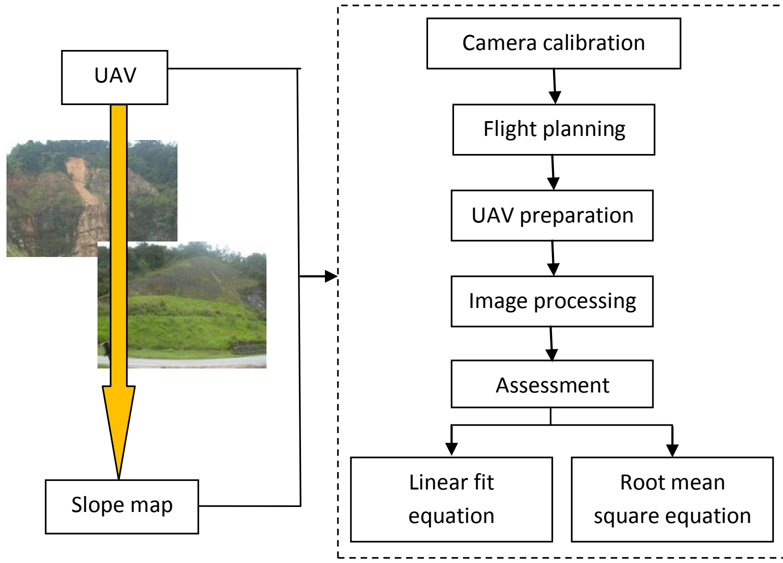
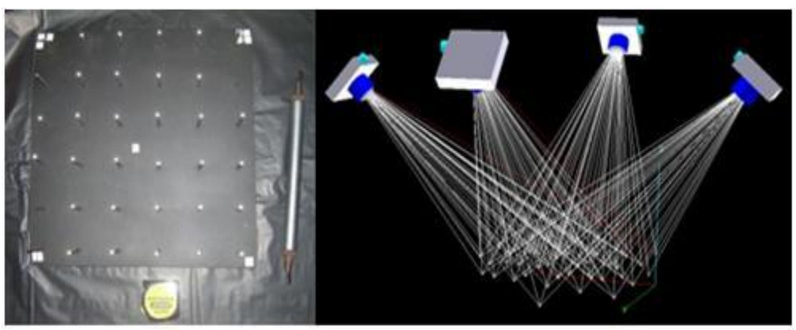


Figure 2. General methodology.



(a) (b)

Figure 3. Camera calibration: (a), Calibration plate; (b), Camera position during calibration.

Table 1. Camera calibration results.

Camera parameter	c (mm)	Xp (mm)	Yp (mm)	Radial (k_1)	Radial (k_2)	Radial (k_3)	Tangential (p_1)	Tangential (p_2)	Affinity (b_1)	Scale factor (b_2)
Pentex Optio W90	6.627	-0.096	0.084	-2.298e-004	6.181e-005	-8.364e-006	4.442e-004	-4.087e-004	2.604e-005	1.303e-004

with the dimension of 0.6 × 0.6 m and consisted of 36 reflective points. This plate was used as camera calibration platform. Figure 3a shows the equipment that was used in camera calibration process which includes camera calibration plate, scale bar, and measurement tape. Figure 3b shows the position of camera during the calibration process. The image of calibration plate was captured from four different positions; two positions of portrait view and two positions of landscape view. The angle and the distance between camera and calibration plate should be approximately the same to avoid any error during image processing. The acquired images were processed by using Australis software to produce calibration parameter of digital camera.

In the Australis software, user needs to enter camera information such as an approximate focal length, pixel size, horizontal resolution and vertical resolution of digital camera. Subsequently, user needs to digitize each reflective point according to the initial coordinate of calibration plate. The camera calibration result is shown in Table 1.

Table 1 shows the parameters of a camera after camera calibration process namely focal length, principal distance, radial

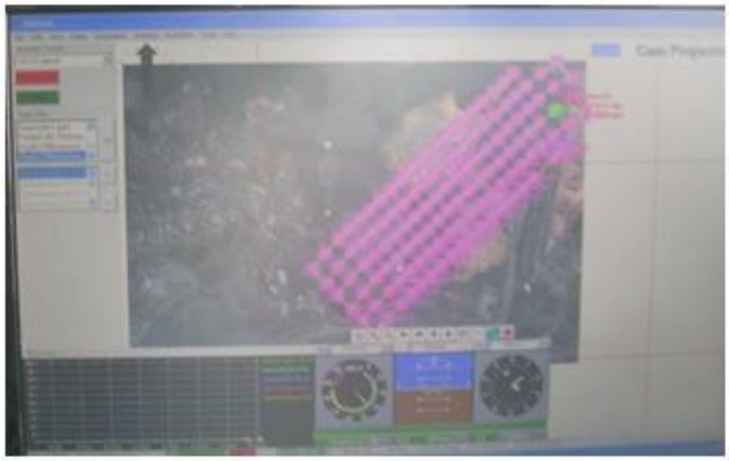


Figure 4. Horizon software.

lens distortion, tangential distortion and affinity. All parameters were used as an input for interior orientation during image processing.

Flight planning

UAV flight mission has the same concept with manned aircraft which requires flight planning stage in order to identify the coverage area of single digital images with respect to the ground measurement. In flight planning stages, we design an appropriate number of waypoints required to cover the whole study area. Several parameters need to be clarified during the flight planning stages. There are flying height, coverage of the study area, camera focal length to be used during flight mission, required scale, percentage of the end lap and the side lap. These parameters can affect the result of image acquisition during the flight mission. The parameters of digital camera can be obtained during the camera as calibration process. The results of camera calibration are shown as previously described. On the other hand, pixel size of the camera is used to estimate each size of the image. The ground coverage area of one image can be calculated by using resolution dimension, pixel size and scale (Equation 1):

$$C_{area} = r * PS * S \tag{1}$$

Where; C_{area} = Coverage area; r = resolution dimension (horizontal or vertical); *PS* = pixel size; S = scale.

In this study, Lentsika software was used to design the flight path for the flight mission. It required at least one initial position to be entered in Lentsika software for the creation of flight path. The boundary of the study area can be approximately determined by using Google earth software. Google earth was used as a background display in the Lentsika software. Lentsika software designed a flight path based on the user's requirement such as output resolution and scale. After the design of flight path was completed, the flight path file was exported to the horizon format file. Flight path file showed the exposure station of digital camera and flight line during flight. Horizon software finalized the flight pattern and altitude control. The flight path file was downloaded in autonomous chipset in the UAV via data transfer cable. The operator had to make sure that the file was downloaded successfully into the autonomous chipset. Figure 4 shows an example of flight path in horizon software. It can be seen that there are various number of waypoints available and also the position of UAV during flight mission.

Horizon software monitored the UAV altitude, attitude, battery status and speed. The communication between UAV and horizon software were connected by using radio modem.

UAV preparation

In this study, UAV was operated in autonomous mode except during launching and landing, which was controlled manually by a professional operator. Several things need to be checked before flight mission such as functionality of autonomous chipset, radio modem, camera mount to hold digital camera, power of battery, electronic speed controller and global positioning system. Then, the operator needs to check the motion sensor of the UAV such as elevator, rudder and throttle before launching it. Figure 5 shows the preparation steps of the UAV before its launching.

Image processing

All acquired images from digital camera were downloaded into the computer after flight mission. Each image was saved in jpeg file. The quality of images was checked before they were used in the processing stage. Some of the images might have some quality problem such as blurring image and colour balancing error which was caused during flight mission. These problems usually arise from the attitude of the UAV during flight. If the quality of all images were very bad, another flight mission might need to be done. However, in this study, all acquired images were in good quality and they were being preceded for the photogrammetric processing. Mosaic mill product, which is known as Enso Mosaic software, is one of photogrammetric software that is available in the market. This software is able to process aerial images and to produce digital orthophoto and digital elevation model (DEM) for the study area. One of the unique qualities of this software is that, it requires Global Positioning System (GPS) log file during the flight mission. GPS log file can be downloaded from the GPS onboard that are installed in the UAV itself. This GPS log file contains information such as longitude, latitude, altitude, heading, date, time, year, yaw, pitch, roll and tilt. This GPS log file describes the exposure station of each image. In practical, this GPS log files needs to identify the location of each images during flight mission. By using these coordinates in the GPS log file, each image can be roughly positioned. As usual, photogrammeric technique involves many

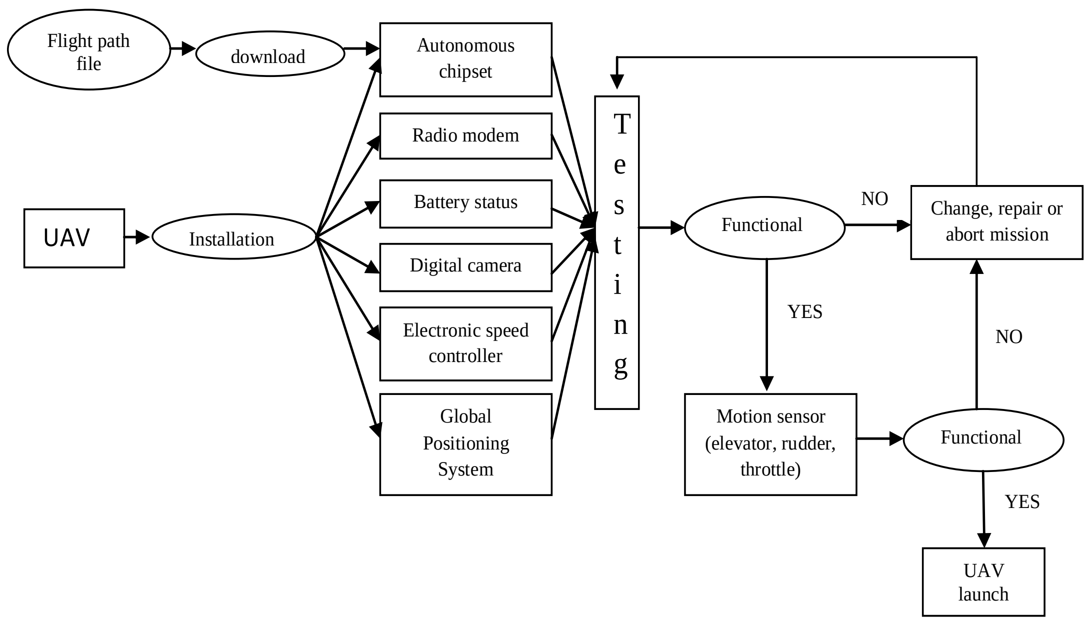


Figure 5. UAV preparation.

processes such as interior orientation, relative orientation, aerial triangulation and bundle adjustment. Interior orientation requires the information of camera parameters including pixel size, focal length and principal points coordinates. All of these parameters were being defined before the processing stage. Relative orientation involved image correlation algorithm in order to transfer the tie points between images. Tie points were responsible to align all acquired images in the same condition in which the images were taken during flight mission. Ground control points were established during image processing in order to project the result into local coordinate system. Ground control points were collected by using Real Time Kinematic-GPS (RTK-GPS), which required about 2 min observations if the satellite connection is in good condition. Checkpoints were also established evenly at the whole study area. Checkpoints were used to check on the accuracy assessment of photogrammetric result at the study area. After both orientations have been done, then aerial triangulation process will be proceeded to correspond to all established points of the whole model. Aerial triangulation is responsible to establish a precise and accurate relationship between the individual models. Aerial triangulation also coordinated points on the ground by using a series of overlapping aerial photographs. Accuracy assessment on aerial triangulation process can be defined by using root mean square equation (RMSE). There are two main photogrammetric results produced in this study, such as digital terrain model and digital orthophoto.

RESULTS

After all acquired image have went through the photogrammetric image process, two main results were produced, for example, DEM and digital orthophoto. Both results were generated based on the accuracy of the tie point and the ground control points that were established earlier in the image processing stage. Therefore, the accurate assessments of both results need to be assessed to verify the quality of the results. Both results covered the whole study area based on flight planning. Figure 6 shows the photogrammetric results of this study.

As previously mentioned, digital orthophoto and DEM are the primary results of this study. Both results were used in the analysis to determine the slope mapping at the development area. Two secondary results were produced, namely, contour and slope map. Both results were used to fulfill the objective of this study, which is to determine the slope pattern at the development area. Figure 7 shows the results of the contour and the slope map that were generated from the digital elevation model. Contour was generated with the interval of 1 m and it was covered for the whole study area. Contour is used to carry out the qualitative assessment at the study area. For example, contour lines were different at the slope area and the flat area. Slope maps were generated from DEM and it was classified into nine classes, for example,5, 10, 15, 20, 25, 30, 35, 40 and >40°. Slope map was used to identify the slope area of the study area.

DISCUSSION

The analysis discussed the assessment of photogrammetric results based on UAV images after going through photogrammetric processed. The analysis concentrate on residual mean square error to assess the accuracy of the photogrammetric results and linear fit equation were used to assess the precision of the results in easting, northing and height coordinates. As previously

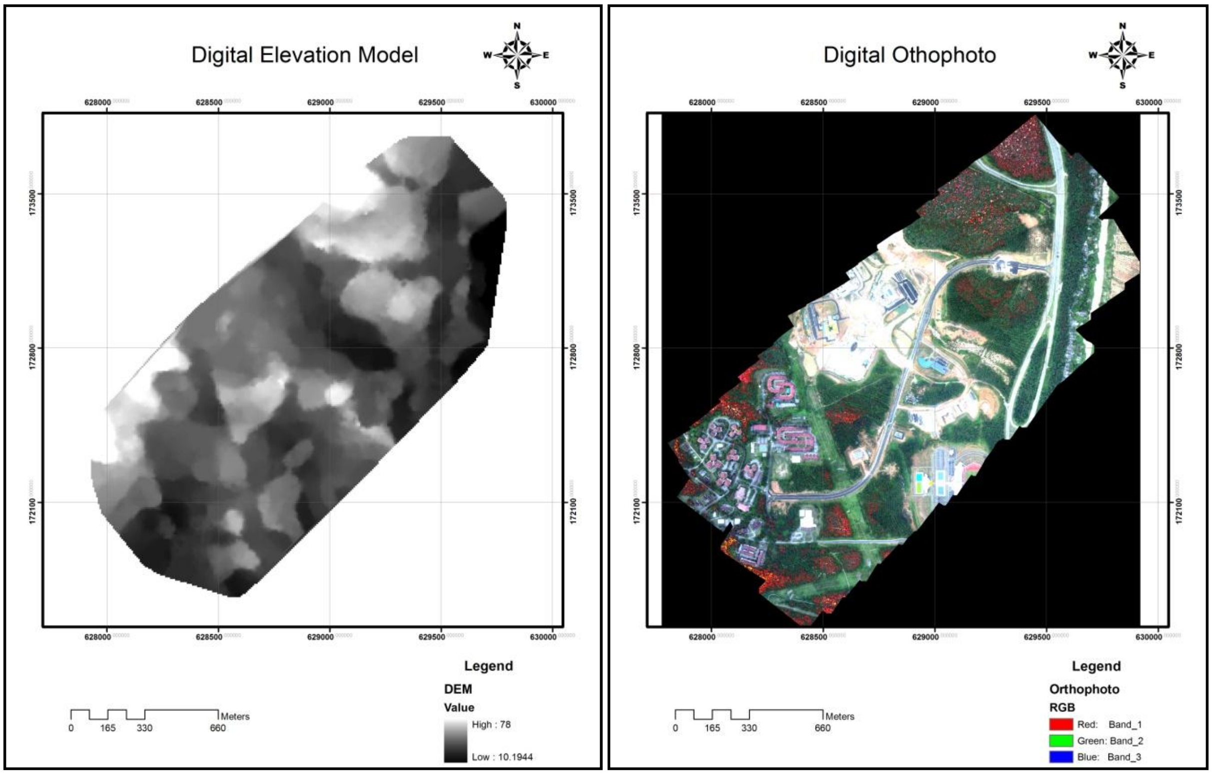


Figure 6. Photogrammetric primary result: (a) Digital elevation model; (b), Digital orthophoto.

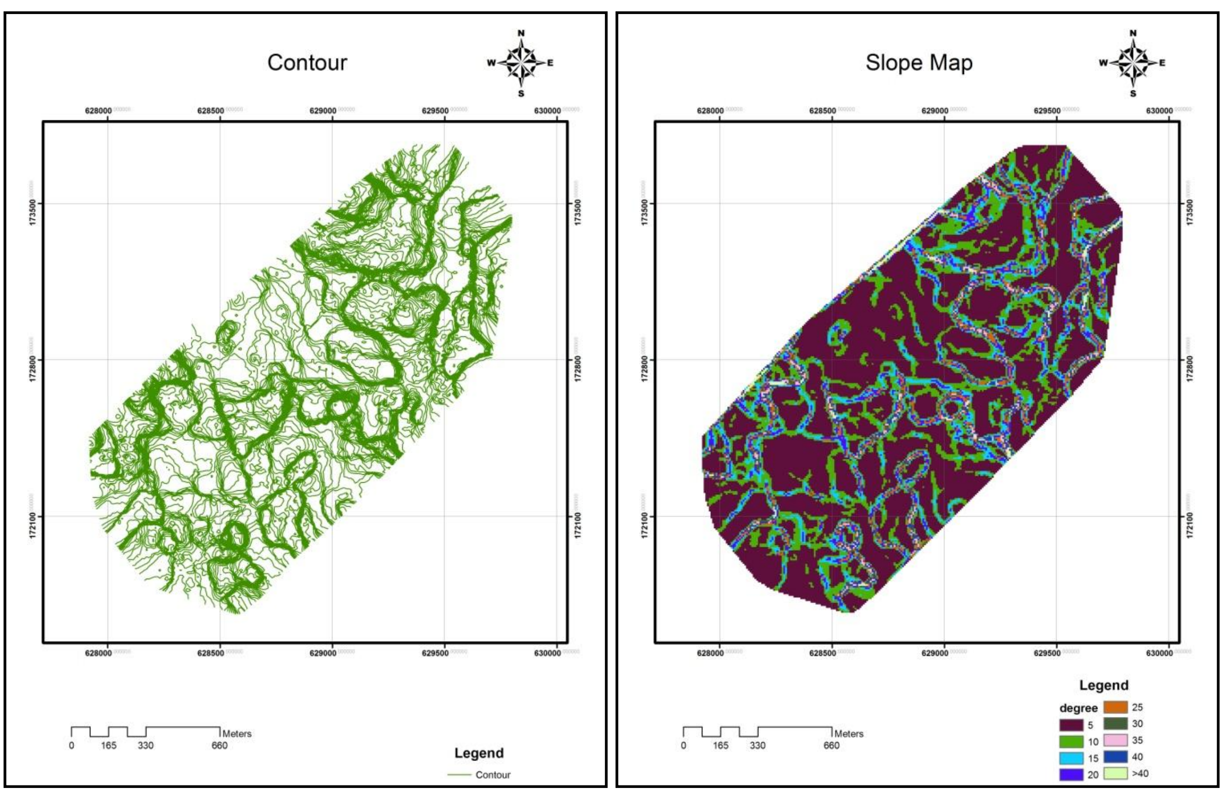


Figure 7. Photogrammetric secondary result: (a), Contour; (b), Slope map.

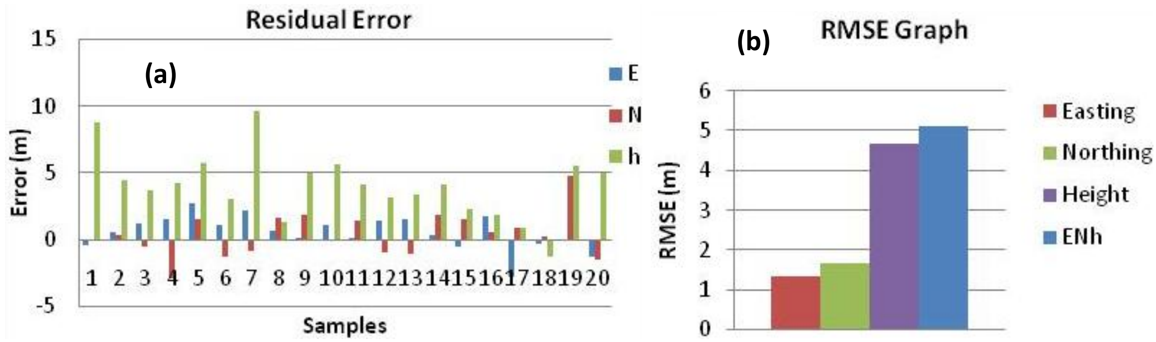
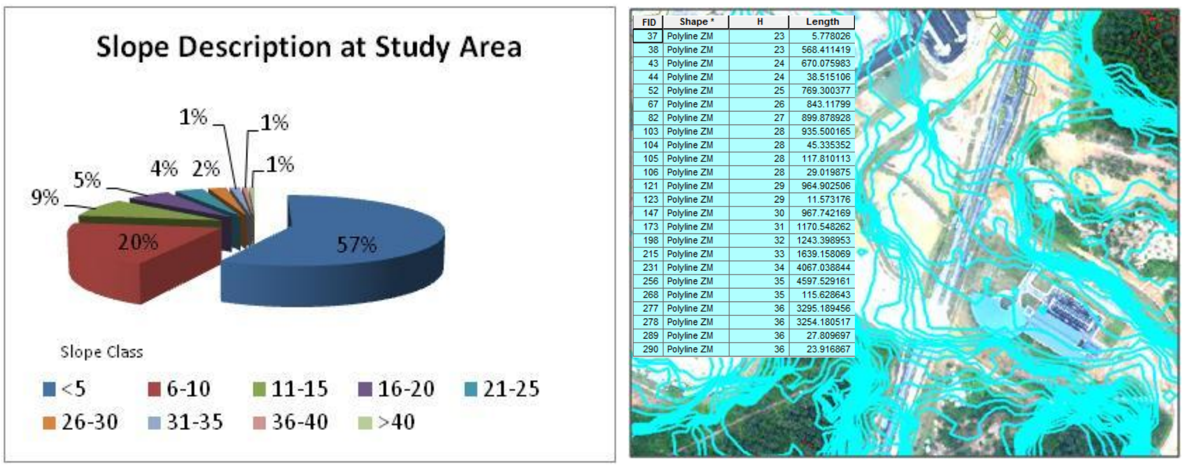


Figure 8. (a), Residual graph; (b), RMSE graph.



(a) (b)

Figure 9. (a), Slope description; (b), An example of selected contour lines.

mentioned, all photogrammetric products were assessed to determine the level of accuracy of the result. These results were compared with the ground truth and were based on the point measurement. 20 checkpoints were established evenly at the study area and each of point was marked on the ground. The coordinates of each point were taken by using RTK-GPS. In this study, RTK observation took approximately 2 to 3 min to determine the coordinate of each point. Figure 8 shows the residual graph and the RMSE graph based on 20 samples.

Based on the residual graph, it can be concluded that height contributes a big error if compared to easting and northing. The maximum residual error for height achieved ±8.731 m, which might be caused by systematic error during the data acquisition of the establishment of checkpoint. RMSE graph shows easting, northing and height which were recorded at ±1.342, ±1.660 and ±4.666 m, respectively. The total RMSE for all samples is about ±5.131 m. Figure 9 shows the percentage of slope at the study area and attribute of the selected contour line at the study area.

Figure 9 shows that UAV can provide slope description at the study area in detail and accurately. Based on the UAV images, we can manage to provide contour lines at the study area immediately and all the data are reliable and accurate.

All samples were included in a linear fit equation to determine the level of precision of the easting, northing and height coordinates. Figure 10 shows the comparison between the actual value and the measured value of easting, northing and height based on 1:1 line (red line).

Figure 10 shows that the value of R-squared recorded as one, which statistically is the perfect result, while height is recorded as 0.778. Graphically, all samples of easting and northing lie within 1:1 line, while the samples for height are located on the upper and lower 1:1 line. A portion of study area has been crop in order to analyze the slope map and contour results in graphical view. The analysis of slope can be viewed based on the slope map that was generated as a secondary data in this study.

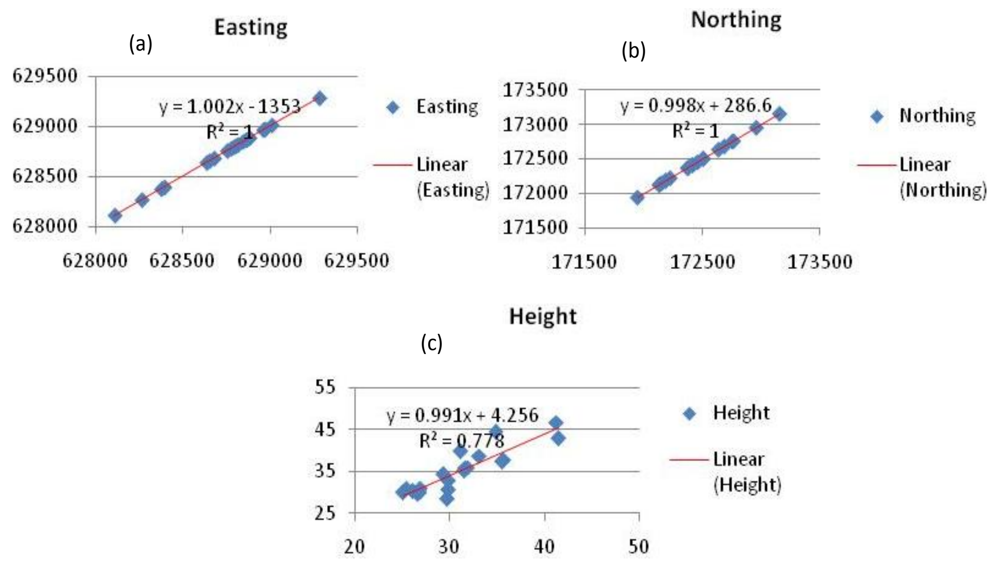


Figure 10. Linear regression graph: (a), Easting; (b), Northing; (c), Height.

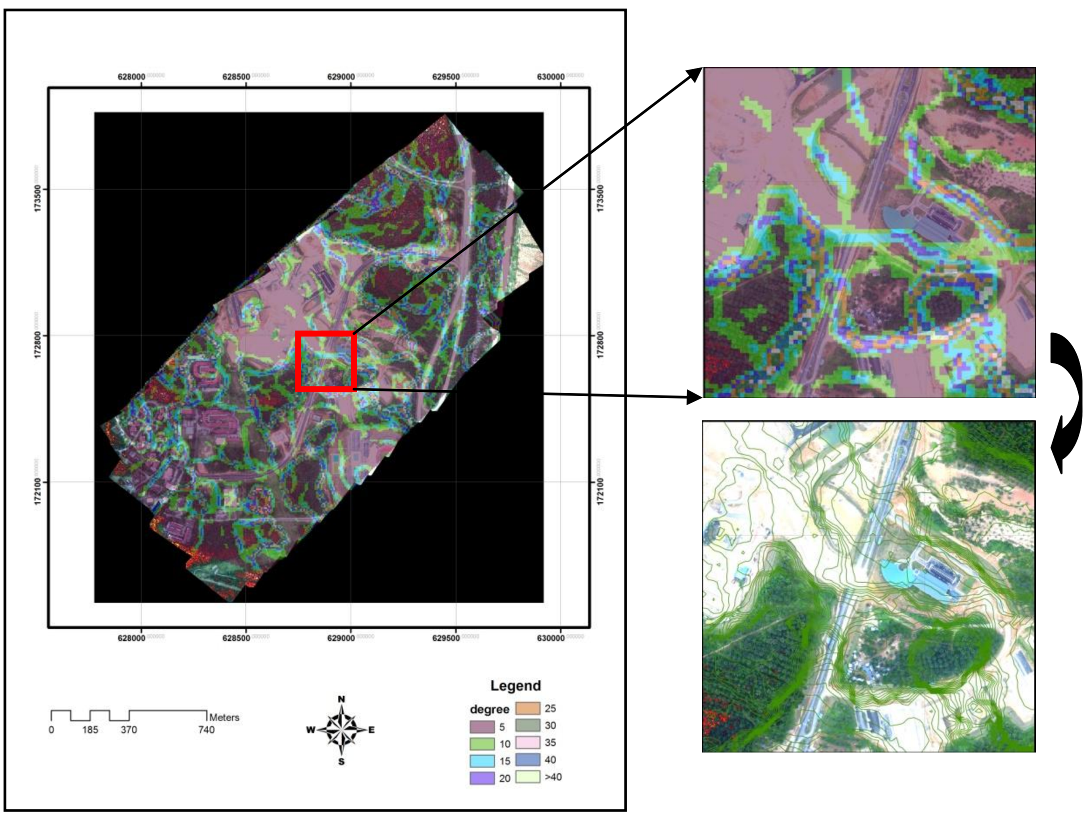


Figure 11. Superimposition between slope map and digital orthophoto.

Figure 11 shows the results after the superimposition between slope map and digital orthophoto at the study area.

Figure 11 shows the classification of the slope in degree at the study area. Figure 11 illustrates the relationship between contour lines pattern and slope map pattern in the same area. It can be concluded that the slope area has high contour lines density and has different slope map. By using these results, it also be can concluded that the UAV images is capable of providing high density results and accurate data. A big error on height value might be caused by the auto tie points that were not well established, which were being affected due to the image resolution, colour balancing and image quality itself such as blurring effects.

Conclusion

All photogrammetric results were produced successfully in this study. DEM was used in developing a slope map at the selected development area. Two main analyses were carried out in this study, for example, root mean square error was used to analyze the accuracy of photogrammetric result based on the ground truth measurement and linear regression analysis was used to determine the precision of the UAV results for all coordinates, such as easting, northing and height. Based on these results, it can be concluded that the UAV can be used to generate slope map at the study area with the condition that the raw images must be processed by a person who is familiar with the photogrammetric concepts. UAV is one of the solutions to obtain fast production of slope map at the specific area with low cost, less time and less labour needed. In the future, rotary platform could be employed to capture the images in the same area. In that case, a comparison study between fixed-wing and rotary platform result could be done by using scientific analysis.

ACKNOWLEDGEMENTS

Faculty of Architecture, Planning and Surveying Universiti Teknologi MARA (UiTM) and Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia (UTM) are greatly acknowledged. The authors would also like to thank the Sustainability Research Alliance, Universiti Teknologi Malaysia for providing the fund that enables this study to be carried out.

REFERENCES

Albaker BM, Rahim NA (2011). Flight path PID controller for propeller-driven fixed-wing unmanned aerial vehicles. Int. J. Phys. Sci. 6(8):1947-1964.

David GS III, Benjamin RD, Charles R (2008). Development and Application of an Autonomous Unmanned Aerial Vehicle for Precise Aerobiological Sampling above Agricultural Fields. J. Field Robot. 25(3):133-147.

Eisenbeiss H (2009). UAV Photogrammetry. DISS. ETH NO. 18515.

Grenzdorffer GJ, Engel A, Teichert B (2008). The Photogrammetric Potential of Low Cost UAVs Forestry and Agricultural. The International Archive of the Photogrammetry, Remote Sens. Spat. Inf. Sci. 38(Part B1) Beijing.

Herwitz SR, Johnson LF, Dunagan SE, Higgins RG, Sullivan DV, Zheng J, Lobitz BM, Leung JG, Gallmeyer B, Aoyagi M, Slye RE, Brass J (2004). Demonstration of UAV-based imaging for agricultural surveillance and decision support. Comput. Electron. Agric. 44:49-61.

Lin Z (2008). UAV for Mapping – Low Altitude Photogrammetric Survey. The International Archive of the Photogrammetry, Remote Sens. Spat. Inf. Sci. 38(B1) Beijing.

Mitch B, Salah S (2009). Architecture for Cooperative Airborne Simultaneous Localization and Mapping. J. Intell. Robot. Syst. 55:267-297.

Rodriguez BDD, Garcia SHG, Pinero YB (2008). Experience using non-metric cameras in photogrammetry. The International Archive Photogrammetry, Remote Sens. Spatial Inf. Sci. 37(B5) Beijing.

Tahar KN, Ahmad A, Wan Mohd Akib WAA (2011). UAV-Based Stereo Vision for Photogrammetric Survey in Aerial Terrain Mapping. IEEE Conference on Computer Applications and Industrial Electronics, Malaysia.