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The Potential of Low Altitude Aerial Data for Large Scale Mapping

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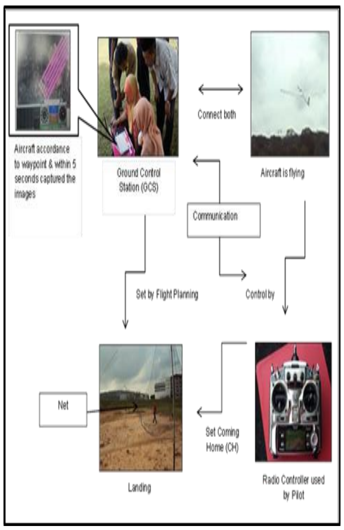
Graphical abstract



Abstract

Unmanned Aerial Vehicle (UAV) system offers many advantages in several applications such as topographic mapping, thematic mapping, slope mapping, geohazard studies, monitoring, etc. This study utilizes UAV system for large scale mapping by using a digital camera attached to a fixed wing UAV. The main objective of this study is to explore the potential of UAV for large scale mapping and to evaluate the accuracy of the photogrammetric output produced from the UAV system. The UAV was used to acquire low altitude aerial photograph based on photogrammetric technique and subsequently accuracy assessment is performed. The Ground Control Points (GCPs) and Check Points (CPs) were established using GPS rapid static technique for photogrammetric data processing. The GCPs were used in to produce 3D stereomodel and other photogrammetric output while the CP is used for accuracy assessment. For digital image processing of the aerial photograph and map production, Erdas Imagine 8.6 software is employed. For accuracy assessment, the coordinates of the selected points in the 3D stereomodel were compared to the conjugate points observed using GPS and the root mean square error (RMSE) is computed. From this study, the results showed that the achievable RMSE are ± 0.510 m, ± 0.564 m and ± 0.622 m for coordinates X, Y and Z respectively. For this study, the digital map was also produced using the photogrammetric technique and it is compared with an engineering plan produced from ground surveying technique (i.e. total station). From this study, it can be concluded that accuracy of sub-meter is achieved using the UAV system. Also, this study demonstrates that the UAV system has the potential for large scale mapping in the field of surveying and other diversified applications, especially for small area, minimum budget and less manpower.

Keywords: UAV; aerial photogrammetry; ground control point; check point; large scale mapping

Abstrak

Sistem Pesawat Udara Tanpa Pemandu (UAV) telah menyediakan banyak kelebihan dalam pelbagai aplikasi seperti pemetaan topografi, pemetaan cerun, kajian geohazard, pengawasan dan sebagainya. Kajian ini menggunakan sepenuhnya sistem UAV untuk pemetaan skala besar dengan menggunakan kamera digital yang dilekatkan pada UAV kepak tetap. Objektif utama kajian ini adalah untuk teroka potensi UAV bagi pemetaan skala besar dan menilai ketepatan output fotogrametri yang dihasilkan oleh sistem UAV. UAV telah digunakan untuk memperoleh fotograf udara pada ketinggian rendah berdasarkan teknik fotogrametri dan seterusnya penilaian ketepatan dilakukan. Titik Kawalan Bumi (GCP) dan Titik Semakan (CP) ditubuhkan dengan menggunakan cerapan GPS melalui teknik rapid statik untuk digunakan bagi pemprosesan data fotogrametri. GCP ini digunakan untuk menghasilkan model stereo 3D dan lain-lain output fotogrametri manakala CP berfungsi untuk menilai ketepatan. Bagi pemprosesan imej digital untuk fotograf udara dan penghasilan peta, perisian ERDAS Imagine v8.6 digunakan. Bagi penilaian ketepatan, koordinat bagi titik-titik terpilih dalam model stereo 3D dibandingkan dengan titik yang sama yang dicerap dengan menggunakan GPS dan *root mean square error* (RMSE) dihitung. Dari kajian ini,hasil menunjukkan RMSE yang dicapai adalah ± 0.510 m, ± 0.564 m dan ± 0.622 m bagi koordinat X, Y dan Z masing-masing. Untuk kajian ini, peta digital juga dihasilkan dengan menggunakan teknik fotogrametri dan dibandingkan dengan pelan kejuruteraan yang dihasilkan daripada teknik ukur tanah (iaitu menggunakan *total station*). Dari kajian ini,dapat disimpulkan bahawa ketepatan sub-meter berjaya diperolehi dengan menggunakan sistem UAV. Kajian ini juga membuktikan bahawa sistem UAV mempunyai potensi untuk pemetaan skala besar dalam bidang ukur tanah dan pelbagai aplikasi lain terutama bagi kawasan kecil, bajet minima dan kurang tenaga manusia.

Kata kunci: UAV; fotogrametri udara;titik kawal bumi; titik semakan; pemetaan skala besar

1.0 INTRODUCTION

The demand for aerial photogrammetry has increased, especially after development of design, research and production of Unmanned Aerial Vehicle (UAV) platform[4,11]. Therefore, numerous UAV have been developed by organizations or individuals worldwide[1]. These include a complete set of UAV which uses high quality fibers as material for plane model. UAV has been practiced in many applications such as farming, surveillance, road maintenance, recording and documentation of cultural heritage[11].

UAV systems have advantages in several mapping applications. This is apparent in comparison to conventional aerial surveying which offers accurate maps, but very expensive and have limited endurance for only a few hours. The UAV systems could be flown either high or low altitude platforms[8]. Low altitude systems have advantages in conducting photogrammetric surveys in cloudy days, providing different views and tilted images of the surveyed objects, low cost supplying and easy-to-maintain for engineering application systems such as topographic mapping, either large or small scale. These systems can be utilized in several applications such as modelling of cultural heritage[2,3,9], documentation of archaeological sites[3], forest-fire monitoring[13], and mapping urban and suburban areas[12]. The UAV systems are also employed have been employed in environmental, agricultural, and natural resources monitoring[7]. Moreover, a light weight UAV system is recommended for acquiring high quality geospatial information and utilized it for resource management agencies, rangeland consultants, and private land managers[10].

The UAVs have several advantages such as low cost operation, simple manipulation, high resolution, flexibility and others. The advantages in developing the technology of UAV for low altitude photogrammetric mapping are to perform aerial photography under the cloud, to get full image of an object from the top, and to supply a cheap and easy system for high frequency needs of aerial photogrammetric survey[6]. UAV system is not limited by human on aircraft when collecting data in dangerous environment and without risk of pilot. Conceptually, these UAVs are equipped with devices such as camera, sensors, communication tools and other payloads to perform certain activity. UAV can be classified depending on their size, endurance, range and flying altitude that are clearly defined by Unmanned Vehicle Systems International Association. It is because UAVs are not burdened with the physiological constraints of human pilot that can be planned for maximized on-station times. Table 1 shows the different types of UAVs based on their endurance.

Table 1 UAV categories defined by UVS international

Category name	Mass [kg]	Range [km]	Flight attitude [m]	Endurance [hours]
Micro	<5	<10	<250	1
Mini	<25/30/150	<10	150/250/300	<2
Close Range	25 - 150	10 - 30	3000	2 – 4
Medium Range	50 - 250	30 - 70	3000	3 – 6
High Alt. Long Endurance	>250	>70	>3000	>6

In this study, two hardwares are used. They were the fixed wing UAV and high resolution digital camera. Low altitude UAV was preferable in this study because it focused on large scale mapping which involved small area only. UAV is the most potential equipment and uses low cost budget for capturing aerial photograph of small area. Apart from that, digital camera with high resolution images is attached to the UAV and provides small format images. Figure 1 shows an example of (a) Cropcam UAV and (b) Pentax Optio W90 digital camera.

Figure 1 (a) Cropcam UAV; (b) Pentax Optio W90

The Pentax Optio W90 digital camera was used in acquiring the digital aerial images. This digital camera has resolution of 12 megapixel, 5x zoom lens and 2.7" LCD screen. In this study, fixed wing Cropcam UAV (Figure 1) has been used in acquiring digital aerial images that covered the study area. The Cropcam UAV is highly efficient and user friendly which is available in the market. It is a radio control (RC) glider plane and controlled by a autopilot from the pre-programmed ground control software. This Cropcam UAV also works with a RC transmitter for manual control. It utilizes an autopilot for navigation and control of the camera and RC parts (wings, servos, propellers, glow fuel or batteries) that can be purchased locally. The specification of the Cropcam UAV used in this study is shown in Table 2.

Table 2 Cropcam specification

Specification	
Weight	6 lbs./2.42 kg
Wing span	8 feet/2.44 meter
Length	4 feet/1.22 meter
Endurance	Up to 55 minutes
Payload	1 pound/0.373kg
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 or autonomous
Camera Stand	Flexible camera holder
Average Speed	60 km/h

2.0 METHODOLOGY

In this study, the methodology is divided into several phases including preliminary study, data acquisition, result and discussion. The dimension of the study area is approximately 500 m by 100 m. Thereby, few aspects involved in preparation such as flight planning and properly install the instruments that need to be considered, which contributes to the quality of data acquisition. Flight planning involves calculation of dimension of study area, number of strips required, pixel size, photo scale flying height and percentage of end lap and side lap. In general, the aerial photographs should be overlapped at least 60% and side at least 30%[5]. This requirement needs to be fulfilled to make sure quality photogrammetry results could be obtained. Figure 2 shows the flowchart of the research methodology.

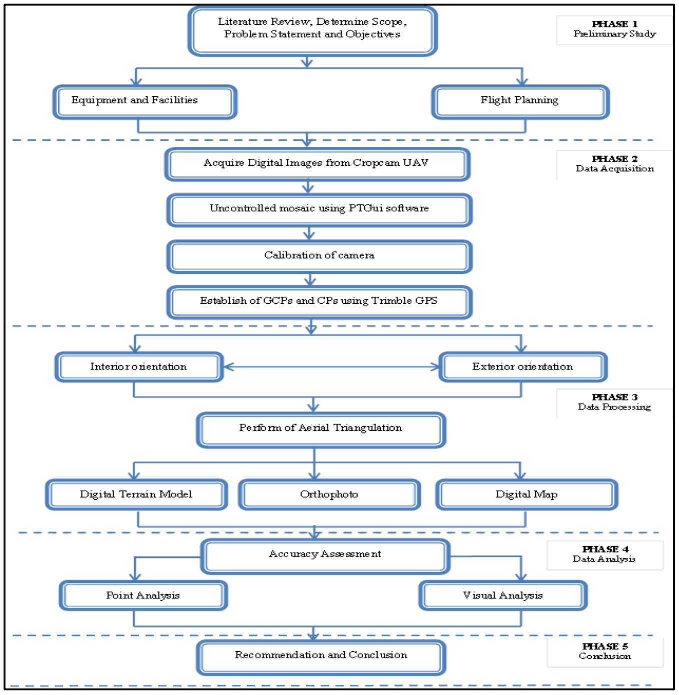


Figure 2 Flowchart of research methodology

2.1 Data *Acquisition*

After installation and sent flight plan to the autopilot UAV's, the UAV fly for take off by hand launch. The crew ground control station informed the pilot (i.e RC pilot on the ground) for the altitude and position from time to time until the UAV fly to the first waypoints. Then the UAV take digital aerial imaging according to waypoint in the flight line. The pilot will change from the position hold (PH) into coming home (CH) for landing. For aircraft landing, it needs a clear area and CropCam UAV will land back to the starting point. Figure 3 shows the procedure of flying the Cropcam UAV and location of the Ground Control Station while Figure 4 shows the study area and two strips of overlapping aerial photograph captured using the Pentax Optio W90 digital camera.

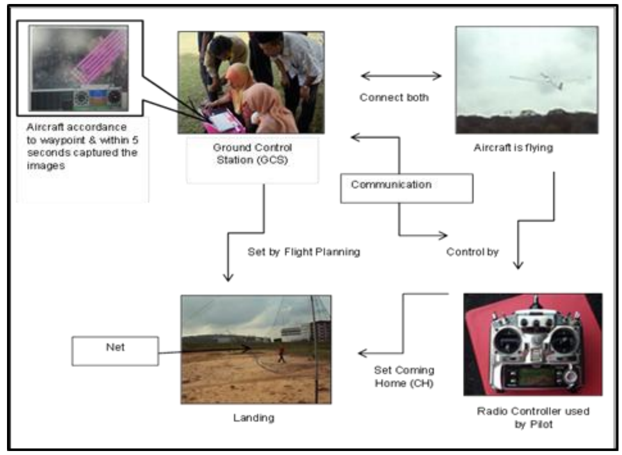


Figure 3 Cropcam UAV and ground control station

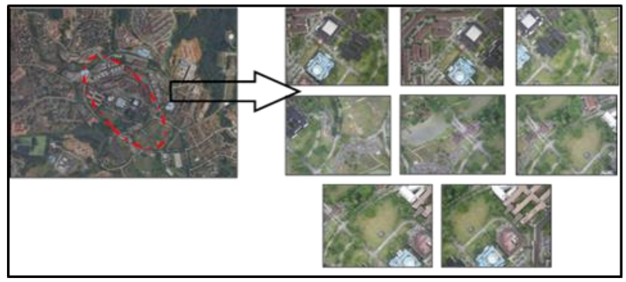


Figure 4 Study area (left) and example for two strips of aerial photograph (right)

2.2 Camera *Calibration*

Camera calibration is carried out after acquiring the digital aerial images or aerial photographs with the purpose of recovering all camera parameters for digital image processing. Table 3 shows the camera calibration parameters after the process of camera calibration and these parameters need to be registered during the interior orientation step in digital image processing

Table 3 Camera calibration parameters of PENTAX Optio W90

Parameter	Value
c (mm)	9.2714
x_p (mm)	-0.1230
y_p (mm)	0.1181
k_1	-1.52053e-004
k_2	2.36738e-005
k_3	-1.68283e-006
p_1	3.00147e-004
p_2	-3.18317e-004
b_1	4.54346e-007
b_2	3.28513e-004

2.3 Establishment *of GCPs and CPs*

The ground control points (GCPs) and check points (CPs) were collected using GPS observation through rapid static technique. This technique can provide the position information includes Northing, Easting, and Elevation (X, Y, and Z) with the post processing by using the Trimble Total Control (TTC) software. This technique only takes 5 to 20 minutes for observation. Strategic point identified on the aerial photographs such as road corner, building, drain and etc. are considered as GCP. Minimum of four GCPs were established for every pair of aerial photograph for the purpose of registration in the exterior orientation process. There are two GPS antennas used in the field of the same brands (Trimble Ground Plane) where one acts as the reference station and the other one acts as the rover. The reference stations consist of ISKANDARnet1, ISKANDARnet2 and ISKANDARnet3 where they are completely installed at their designated location/station and has accurate coordinates. In addition, ISKANDARnet is also operational for data logging and streaming. Figure 5 shows the distribution of GCPs and CPs measured using the rapid static technique. After the GPS observation was carried out, the data need to be downloaded and converted it to the rinex file. Then, the data need to be processed in order to obtain the coordinate using the TTC software. The coordinates obtained after processing are in Geocentric Datum of Malaysia (GDM2000). Then these coordinates were converted to RSO using GDTS software. For this study, the RSO coordinate system was used to process the small format aerial photograph using Erdas Imagine photogrammetric software for digital image processing.

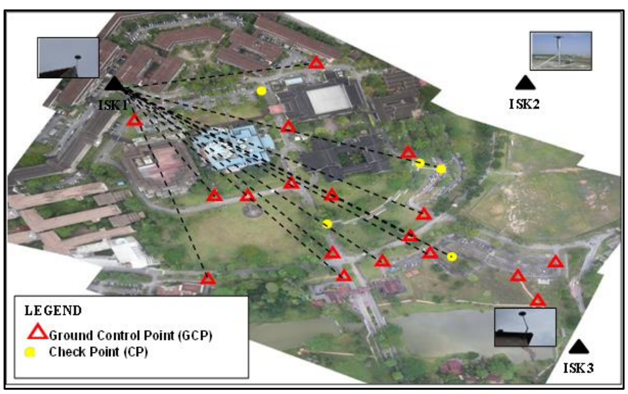


Figure 5 GCPs and check point distribution

■3.0 DIGITAL IMAGE PROCESSING AND RESULTS

After data acquisition has been completed using Cropcam UAV, all acquired images and GCPs were processed using Erdas Imagine software. The results are presented in the form of digital map or hardcopy. Erdas Imagine software requires camera information such as pixel size, focal length, radial lens distortion and tangential distortion to carry out interior orientation. A total of 19 GCPs have been registered during exterior orientation. According to [6], Erdas Imagine software required six tie points or three points for each pair of the overlapped photographs. Figure 6 depicts the flow of aerial triangulation process that involved in the digital image processing stage.

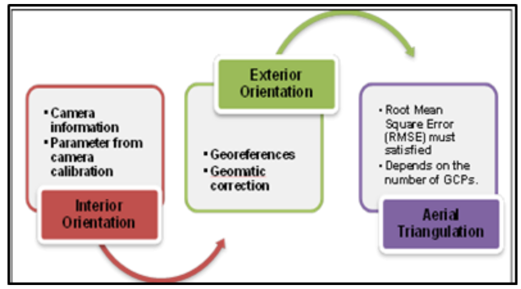


Figure 6 Process of performing the aerial triangulation

After computing and performing the aerial triangulation, a report of aerial triangulation results are prepared. The report include the photogrammetric block layout and a diagram showing the location and names of all points used in the adjustment. Figure 7 shows the RMSE of aerial triangulation based on 19 GCPs and 5 CPs used in the two strips of the small format aerial photograph. The calculated RMSE is + 0.0168 meter.

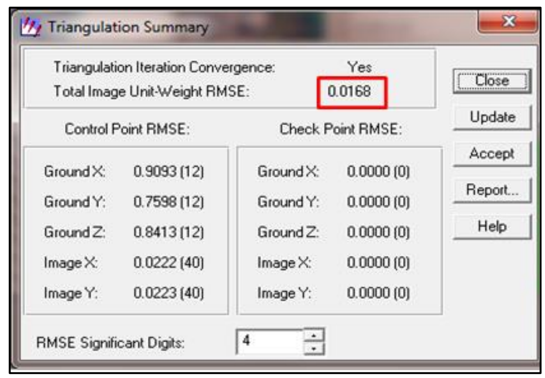


Figure 7 Triangulation summary of a block of photograph for the study area

The footprint of the study area is shown in Figure 8. The distribution of GCP and tie points can be viewed in Figure 8. The value of RMSE must be less than one meter (1 m) in order to obtain good results.

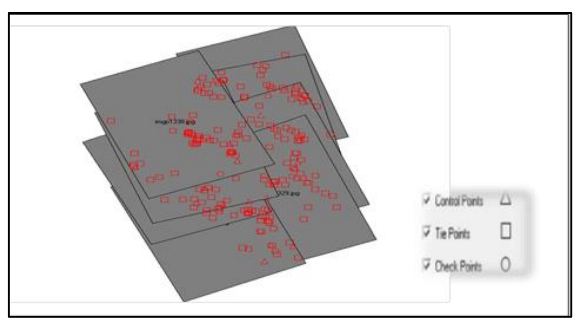


Figure 8 Footprint of the study area

3.1 Results

In this study, three photogrammetric results were generated after performing interior, exterior orientation and aerial triangulation. The photogrammetric results generated are the Digital Terrain

Model (DTM), orthophoto and digital map. The result of the DTM is shown in Figure 9.

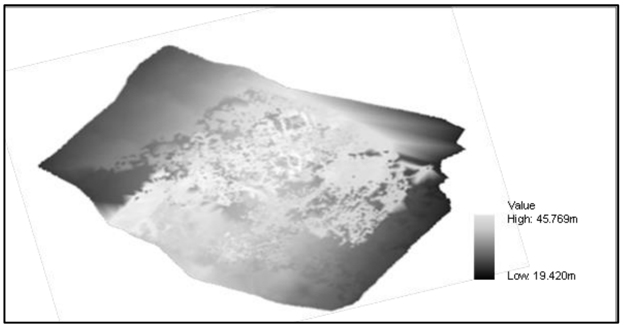


Figure 9 DTM of the study area

The results depend on the accuracy of the GCPs. If the quality of GCPs are not good, then the results of digital DTM and orthophoto are also less accurate. The result of digital orthophoto for small format aerial photograph which comprise of eight (8) images covered the study area. After producing the individual orthophoto, Erdas Imagine was used to generate a mosaic image of the individual orthophoto. The mosaic image comprised of eight orthophotos where all of them were joined together to form an image. Figure 10 shows the digital orthomosaic of the study area which was generated based on the invidual orthophoto for the two strips of small format aerial photograph.

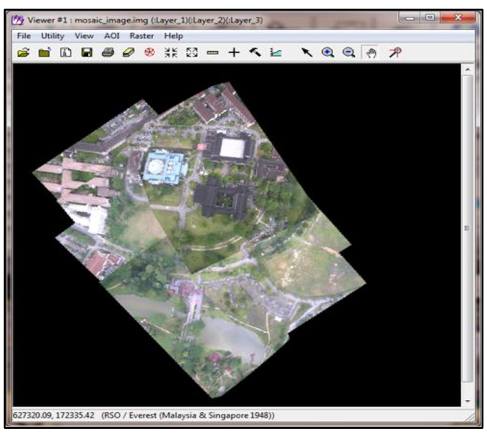


Figure 10 Digital orthomosaic

The other result produced from this study is extraction of 3D features. The 3D Feature Extraction tool available in Stereo Analyst orErdas Imagine software allows user to digitize features in the 3D stereomodel. The vector or digital map was produced using this tool. The digitizing process takes place in stereo-viewing environment and the viewing in 3D is performed by wearing the red/blue anaglyph glasses. By digitizing features in 3D, human eyes could compensate for relief displacement. The left eye is used to view the left image and the right eye views the right image from the stereopair. Then the brain perform correction on the geometric effects of sensor geometry and relief displacement automatically. In addition, 3D feature is easier to be recognized, measure and the coordinates of the features could be recorded accurately, hence, planimetric features are vectorized correctly. Usually, after aerial triangulation process was done successfully, features such as roads and buildings could be digitized and exported to ArcGIS.

4.0 ANALYSIS AND ACCURACY ASSESSMENT

The objective of this study is to investigate the potential use of UAV for large scale mapping and to evaluate the accuracy of the photogrammetry output obtained from the UAV system. Therefore, this section describes the point and visual analysis as shown in Figure 11.

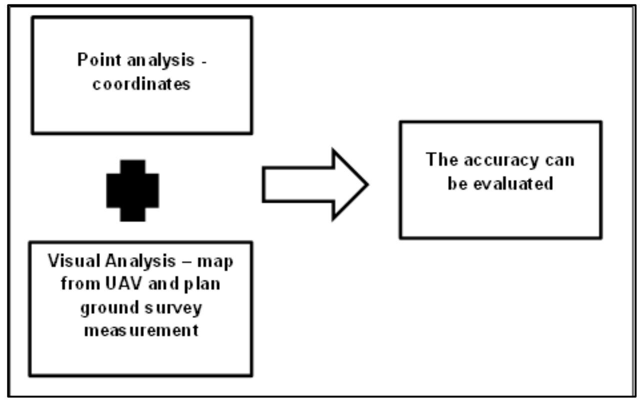


Figure 11 Data analysis diagram

For this study, analysis of point accuracy is carried out based on computing the RMSE between the coordinates differences of 3D stereomodel and the CPs. Figure 12 shows the RMSE formula used for the accuracy assessment and the calculated RMSE is shown in Table 4.

$$RMSE = \pm \sqrt{\frac{\Sigma\,[\,(X - \overline{X})^2 + (Y - \overline{Y})^2 + (Z - \overline{Z})^2]}{N - 1}}$$

X, Y, Z = GPS coordinates
$\overline{X}, \overline{Y}, \overline{Z}$ = Stereomodel coordinates
N = Total of points

Figure 12 RMSE formula

Table 4 shows the comparison of check points between ground survey (GPS) and 3D coordinates of the stereomodel in Erdas Imagine, where the calculated RMSE is ± 0.565 meter (<1 meter). It can be seen that the accuracy could be achieved using UAV system based on the two strips of aerial photograph. The smaller the RMSE calculated, the higher the accuracy. Hence, the accuracy of orthophoto is influenced by the RMSE value.

Table 4 Comparison of check points

Check Points	Trimble 4800			ERDAS Imagine v8.6			Differences		
	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)	ΔX (m)	ΔY (m)	ΔZ (m)
209 (CP 1)	626930.568	172270.152	37.372	626930.362	172270.137	37.889	0.015	0.206	-0.517
210 (CP 2)	626927.058	172248.999	33.485	626926.554	172249.541	34.725	-0.542	0.504	-1.240
3 (CP 3)	626877.725	172485.731	43.343	626876.069	172485.459	42.179	0.272	1.656	1.164
211 (CP 4)	626779.969	172254.677	34.128	626779.776	172256.085	35.060	-1.408	0.193	-0.932
212 (CP 5)	626879.374	172115.487	23.096	626880.344	172115.124	23.505	0.363	-0.970	-0.409
			RMSE				±0.510	±0.564	±0.622
			AVERAGE					±0.565	

In Erdas Imagine Software, digitizing of the features were carried out using the Stereo Analyst and then exported to ArcGIS in order to produce map. The analysis was carried out based on two types of features i.e building and road. The digitized features could be displayed in ArcGIS to visualize the differences between features from the AutoCAD drawing. The AutoCAD drawing obtained from ground survey measurement was carried out by using total station (Figure 13). Figure 14 and 15 showed the topographic plan for certain part of the study area for overlaid building and road features respectively.

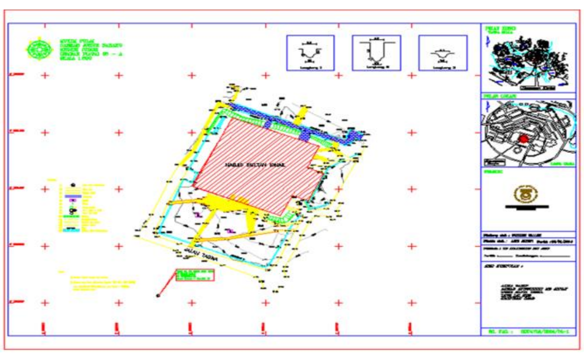


Figure 13 Topographic plan from ground survey measurement

As an example, an overlapping of a building is shown in Figure 14. It is clearly seen the slight difference between two methods of producing map. In Figure 14, the building with the red outline is drawn from using AutoCAD software where it is based on ground survey measurement while the grey outline with the hatch line was digitized from Stereo Analyst in Erdas Imagine software.

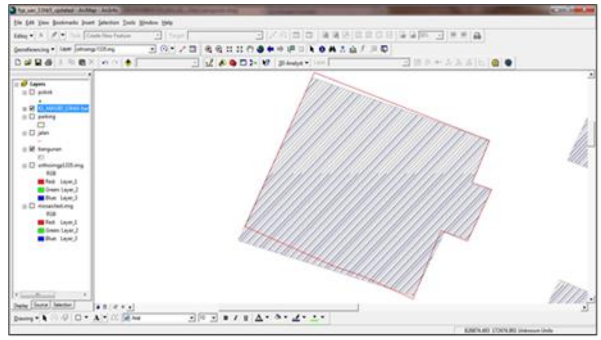


Figure 14 Visual analysis of the building feature

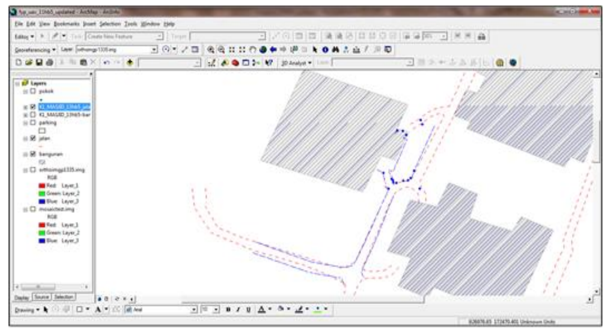


Figure 15 Visual analysis of the road feature

Referring to Figure 15, both methods that is ground survey measurement and Cropcam UAV shows not much different for the overlapping road. The blue line represents the road feature from AutoCAD drawing obtained also from ground survey measurement and the red line was digitized from Stereo Analyst in Erdas Imagine software. It is clearly seen that both methods showed same accuracy in producing the topographic plan.

In general, UAV system and Erdas Imagine software are easy to use and required more experience in order to understand how the UAV work. The equipment especially the UAV provides more advantage compared to conventional method because it uses less manpower, low budget and minimal time constraint in order to produce map at sub-meter accuracy. Table 5 shows the comparison of the time taken for data acquisition, processing and manpower for 500 m x 100 m. The digital image processing are carried out step by step such as interior orientation, exterior orientation, DTM extraction and finally orthophoto production. The results were analyzed in two methods which are point and visual analysis. In point analysis, the RMSE is less than one meter (1m) which shows that the photogrammetric output such as the orthphoto and digital map could be produced for sub-meter accuracy. The smaller the RMSE, better photogrammetric output could be produced. For visual analysis, the comparison between the digital/vector map produced from the UAV technology and the ground survey measurement showed slight difference and it can be considered as acceptable.

Table 5 Comparison of time estimation and man power

Method	Tacheometry method	Manned Air-Craft	UAV Technology
Fieldwork	Traversing – 1 days (24 hours) Tacheometry - 2 days 948 hours)	Traversing, Pre-Marking and Flight Planning – 4 days	UAV setup – 20 minute Flight – 30 minute
Processing	Generate the topographic plan – 1 days	Image scanning and Processing – 1 months	Image processing until Map production – 4 hours
Man power	4 person	2 pilot onboard + 2 person on the ground	1 professional pilot + 1 person

From Table 5, it could be concluded that the UAV technology provides more advantages in term of time and manpower. While the conventional methods which are ground surveying and manned aircraft have disadvantage in fieldwork stage and data processing.

■5.0 CONCLUSION

This study demonstrates that the Cropcam UAV together with the digital camera is capable of acquiring aerial photograph successfully for large scale mapping. The photogrammetric outputs such as DTM and orthophoto were successful and generated too. These results have been analyzed using the Root Mean Square Error (RMSE). With the new technology, UAV could solve problems in many applications especially for small area. It has been proven that UAV platform is very suitable for the project that has limited time, budget and manpower. This technology could be adopted in photogrammetric work, which requires up to date information in short time. This technology could be used by any agency or ministry related with environmental studies too. For the future, it is hope that this study could be expanded for large area and uses different flying height to determine the accuracy and cost involve for data acquisition and processing.

The accuracy of orthophoto can be improved and enhanced, by increasing the number of GCP and CPs during data collection in the field using GPS technique. It also can help to minimize the RMSE in data processing. Secondly, the use of the different software such as PCI, DVP and others should be used so that different results could be achieved and analysed.

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