Digital aerial imagery of unmanned aerial vehicle for various applications

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Digital Aerial Imagery of Unmanned Aerial Vehicle for Various Applications

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***Abstract*—Digital aerial imagery (DAI) can be acquired using digital mapping camera attached to light aircraft. The DAI is used for the production of topographic and thematic map. The cost of acquiring DAI is very expensive and suitable for large area coverage. The acquisition of DAI is not economical and suitable for small area coverage. Therefore an alternative method should be used to fulfill this need. There are two alternative methods that can be used for acquisition of DAI which include using a small format digital camera attached to light aircraft and using a small format attached to an unmanned aerial vehicle (UAV). UAV system has been reported used in various and diversified applications such as mapping applications (eg. map revision, landslide, coastal erosion, archaeology, forestry), industrial application (eg. engineering, crash accident), Geographic Information System (GIS) applications and others. In this study, micro unmanned aerial vehicle (UAV) systems which comprise of fixed wing UAV flying and rotary UAV are attached with small format high resolution digital camera to acquire DAI for the purpose of mapping at the flying height of 300m at 100m respectively. The micro UAVs were flown autonomously (i.e automatically) and a series of DAIs of a slope using fixed wing UAV and a stream using rotary UAV were acquired rapidly within short period. Ground control point (GCP) and check point (CP) were established using the Global Positioning System and conventional Total Station techniques around the study area for the slope and stream respectively for the purpose of digital image processing and accuracy assessment. The DAIs were processed to produce photogrammetric output such as digital elevation model (DEM) and orthophoto. All these photogrammetric products were successfully produced and assessed. The achievable accuracy is less than ±1m for slope mapping and ±0.280m for stream mapping. In this study, it is proven that the micro UAV system can be used for mapping which cover small area. As conclusion, micro UAV is suitable for mapping small area, rapid data acquisition, accurate, low cost and can be employed for various applications.**

***Keywords* –** *Unmanned aerial vehicle, digital camera, digital aerial imagery, photogrammetry, mapping*

I. Introduction

Currently, many mapping organisations around the world still used large format aerial camera for acquisition of large format aerial photograph for the production of topographic map. However, some mapping organisations have started using digital mapping camera of different make for mapping. However, due the high cost of the digital mapping camera only not many mapping organisation afford to use it even though it can deliver accurate and rapid photogrammetric output. Usually, the procedure in conventional aerial photogrammetry is lengthy and very costly to produce topographic map because the whole process of mapping involves many stages which include producing flight map, acquisition of aerial photograph, establishment of ground control point and lengthy image processing procedure. Also this procedure is suitable for mapping large area only. However, there are instances where aerial photograph which covers small area is required for mapping purposes. The large format aerial camera is not economical for mapping small area. To overcome this problem, photogrammetrist has started using small format camera for acquiring aerial photograph. Research on the use of small format camera for mapping has been conducted and promising results have been achieved [1],[2],[3],[4],[5]. Photogrammetric output such as digital map and orthophoto can be successfully obtained from small format camera. Further research has been conducted on the use of light platform for acquiring aerial photograph for the purpose of mapping and other purposes. Today, it is common for people from all around the world using small format camera such as high resolution digital camera, video camera and other sensor combined with light platform such as helicopters, gliders, balloon and etc for acquiring digital aerial images/photographs. For the light platform, it can be remotely control manually or it can fly autonomously (i.e automatically) based on pre-programmed flight plans or more complex dynamic automation systems. The combination of the sensor, light platform and procedure of flying the system without pilot is known as unmanned aerial vehicle (UAV). In Malaysia, the use of UAV for mapping and other applications is still new. UAV has been used successfully for large scale mapping for the production of photogrammetric output such as digital map, digital orthophoto, digital elevation model (DEM) and contour line [6],[7],[8],[9],[10],[11],[12],[13],[14].

There are a wide variety UAV shapes, sizes, configurations, and characteristics. The earliest UAV, the Hewitt-Sperry Automatic Airplane was developed during and after World War I. During the World War II, a number of remote-controlled airplane advances were made in the technology rush. These were used to train anti-aircraft gunners and to fly attack missions. With the maturing and miniaturization of applicable technologies as seen in the 1980s and 1990s, interest in UAVs grew within the military. UAVs were seen to offer the possibility of cheaper, more capable fighting machines that can be used without risk to aircrews. Initial generations were primarily surveillance aircraft, but some were fitted with weaponry (such as the MQ-1 Predator, which utilized AGM-114 Hellfire air-to-ground missiles).

II. MAPPING BASED ON AERIAL PHOTOGRAMMETRY TECHNIQUE

In aerial photogrammetry, the flight planning must be carefully planned and executed to secure good result. The most important task of aerial photogrammetry is to constitute an aid in production of topographic maps. A primary requisite for rational utilization of photogrammetry is that the type and the tolerances of the map desired are clearly determined at an early stage of the working procedure.

In aerial photogrammetry it is a common practice to used metric camera for acquiring aerial photograph and later processed to produce topographic map. Aerial photogrammetry using manned aircraft has been used for many years and it is very efficient for large area. Manned aerial photogrammetry is also used to update new areas which need to be included in the existing topographic map. Previously, manned aerial photogrammetry uses film as the raw images of the earth surface but now it has been converted into digital images. Today, digital mapping camera such DMC, ADS 40, Vexcel etc which produce direct digital aerial images (DAI) has been widely used by mapping organization who afford to purchase it since digital aerial images could be acquired rapidly and photogrammetric output could be produced rapidly too. In photogrammetry, close range photogrammetry (CRP) is a branch of photogrammetry which can be utilized for mapping including aerial mapping. CRP is suitable for small area or focused at the specific object to fulfill the project needs. CRP is used in many applications such as cultural heritage recording and in architectural surveying. The conventional way in both photogrammetry methods (i.e aerial photogrammetry and CRP) permit the 3D model of the terrain to be produced and, by means of digital elevation model (DEM), to realize multi-temporal studies. The massive introduction of modern digital photogrammetric workstations, with automatic matching procedures, allows for a rapid DEM production.

Small format camera (i.e metric camera) and non-metric camera such as digital camera, video camera etc could also be employed to acquire DAI. The DAIs produced from non-metric camera can be used for various applications such as for map revision in GIS, research work/project and any applications which do not require high accuracy. The non-metric camera especially the digital camera offers several advantages compared to metric camera. Some examples of the advantages are ease of use, handy, cheap and the images are in digital form which is ready to be used.

A. Digital photogrammetry and UAV

At present there are many digital photogrammetric systems available in the market. In general, these digital photogrammetric systems can process satellite imageries and aerial photographs of metric or non-metric imageries. Today, non-metric camera with high resolution could be used to acquire aerial imagery. A digital camera of high resolution has been used for the acquisition of aerial photograph [3],[4],[5]. In other study, an unmanned aerial vehicle (UAV) has been used for the acquisition of high resolution DAI [15]. Also UAV was used to acquire DAI and successfully produced orthophoto [6],[7],[8],[9],[10],[11],[12],[13],[14],[16], [19].

In the last few years, UAV has received an increasing interest as one of the reliable methods for slope studies. Since the reality is three-dimensional (3D), it is a great advantage to conduct modeling in 3D environment. Today, UAV has made it possible to efficiently process and visualize data in 3D. It is especially important to acquire fast and accurate 3D geometric and visual information with minimum costs [6]. UAV is one of the surveying methods conceived years ago that in a short time it can supply digital elevation model (DEM) and good quality digital terrain model (DTM) as a result of elaborations with specific procedures. The main advantage of UAV over traditional surveying techniques is its property of direct, rapid and detailed image capture of study area. According to [17], the advantages of UAVs are; low in cost, flexible, high resolution images, able to fly under cloud, easy to launch and land, and very safe. Other advantages are the dramatic reduction in costs and much faster project completion, possibility to survey remotely very complex, inaccessible and hazardous objects and areas, where the conventional techniques failed. The disadvantages of UAV include payload limitation, small coverage for one image, increasing numbers of images that need to be processed, and large geometric distortion.

UAV is capable to fly in an autonomous way and operates in a wide range of missions and emergencies that can be controlled from a ground base station. UAV consists of the airframe, flight computer, payload, the mission/payload controller, the base station and the communication infrastructure. For UAV that has mass less than 5kg, it is known as micro UAV. Figure 1 shows example of micro fixed wing UAV and rotary UAV system.

Fig. 1. (a) Fixed wing UAV (left) & (b) Rotary UAV (right)

The micro UAV airframe is a simple, lightweight, aerodynamically efficient and stable platform with limited space for avionics. The flight computer is a computer system designed to collect aerodynamic information through a set of sensors (accelerometers, gyros, magnetometers, pressure sensors, GPS, etc.), in order to automatically direct the flight of an airplane along its flight-plan via several control surfaces present in the airframe. The payload consists of sensors composed of cameras, infrared sensors and thermal sensors to gather information that can be partially processed on-board or transmitted to a base for further analysis.

B. Cropcam UAV

Cropcam UAV is a product from Canada [18]. It is a new, self-guided plane that creates GPS-based digital images. It was originally designed to monitor agriculture crops (Figure 1(a)). Using the Cropcam UAV, the user can scout disease, view crop development and stop problems before they get out of control. Cropcam UAV is inexpensive and easy to use with preset flight plans. The DAI are accessible within hours and provide latitude, longitude and altitude coordinates. The Cropcam UAV is a radio controlled model glider plane equipped with a Trimble GPS, a miniature autopilot and a high resolution digital camera. It can be hand launched and automatic from take off to landing. It is easily operated by simply stand at one corner of an agriculture field and hand launch the 2.7 kg UAV. The powerful miniature autopilot and Trimble GPS, does the rest navigating in a pattern over the field. Both the CropCam UAV and the Pentax Optio digital camera with 12.0 megapixels perform automatically to take GPS based DAI. After flight mission, the Cropcam UAV landed at the spot it started automatically or the autonomous flight can be override before landing to avoid damage to the UAV.

The digital aerial photograph acquired by the Cropcam UAV at 600m above the ground has a spatial resolution of approximately 15cm. However, increased spatial resolution can be achieved by simply programming the Cropcam UAV to fly closer to the ground. In this study, the Cropcam UAV was flown autonomously at 300m above the ground for the slope mapping study area and the spatial resolution is approximately 8 cm.

C. Hexakopter UAV

Hexakopter UAV has 6 blades where 3 blades rotate clockwise direction and 3 blades rotate counter-clockwise. A high resolution digital camera is attached at the bottom of Hexakopter UAV. The Hexakopter UAV is assembled with complete set gadget such as GPS on board, pressure board, speed board, gyro and mainboard (Figure 1(b)). The total weight of the Hexakopter (i.e including the digital camera is less than 5kg. The Hexakopter UAV can be flown autonomously or manually. In this study, the Hexakopter UAV was flown autonomously at 40-100m over a stream in the study area and after reaching the required flying altitude, it moved to the exposure station or way point for acquiring DAI. After completing the flight mission for the first flying altitude, the next flying altitude is performed according to the planned flying altitude.

The Sony Alpha NEX-5N digital camera with interactive 16.1 megapixel and 3.0" touch liquid crystal display (LCD) screen is attached to the Hexakopter UAV. At the flying altitude of 300m, the ground spatial resolution is 5cm. The digital camera needs to be calibrated for obtaining good accuracy and results. It is calibrated with the purpose to obtain the correct focal length and other camera calibration parameters [11],[12]. Similarly, the digital camera attached to the Cropcam UAV was calibrated too. These parameters were substituted in the digital photogrammetric software together with the GCPs for the process of aerial triangulation (AT). The AT was successfully performed for digital aerial photographs for both types of UAVs. The results of the digital image processing and photogrammetric output are shown in the following section.

III. METHODOLOGY

3D spatial information can be extracted from the digital aerial photograph after the formation of the stereomodel that can be viewed in 3D using special glasses. The Cropcam UAV has been successfully employed in acquiring digital aerial photograph and produced orthophoto [3],[4],[5]. The aim of this study is to produce mapping product based on high resolution DAI acquired from the micro UAV mentioned in Section II. The flow chart of the research methodology is shown in Figure 2 for the Crompcam UAV and Hexakopter UAV for data acquisition and data processing.

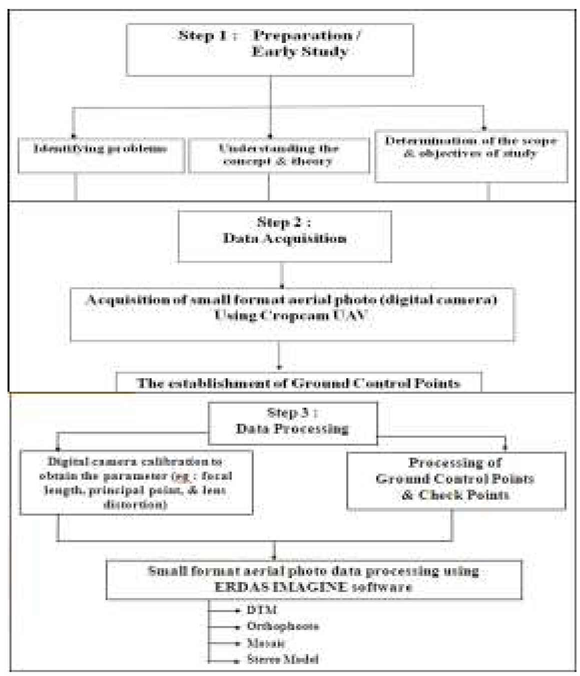


Fig. 2. The flow chart of the research methodology

A. Slope Mapping

For slope mapping, the Cropcam UAV was used for acquiring DAI of slope in the study area within Universiti Teknologi Malaysia precinct. The UAV was flown at 300m. The acquired raw DAI were processed by using digital photogrammetric software. All the acquired images were processed which involved interior orientation, exterior orientation, aerial triangulation and bundle adjustment. Pixel size is one of the important inputs in the interior orientation.

This is because pixel size can determine the ground coverage area of an image on the ground. Exterior orientation involves the establishment of tie points and ground control points (GCPs) between images. Tie points can be generated manually or automatically. Manual editing requires a user's concentration in order to locate the point between two images or in one model. User can also use automatic tie points generation to establish tie point in the models. Automatic tie points generation uses image matching correlation algorithm to identify the same features in two images. However, user needs to select good tie points and remove bad points after running the automatic tie points operation. This step is required to control the accuracy of the final results. GCPs were established by using real time kinematic global positioning system (RTK-GPS). Aerial triangulation is performed after interior orientation and the accuracy of aerial triangulation is analyzed using root mean square error equation. There are two main products produced after the photogrammetric process i.e digital elevation model (DEM) and digital orthophoto.

B. Stream Mapping

The study area is an area within Universiti Teknologi Malaysia, Johor, Malaysia. The first stage in the research activities involves flight planning, photographic scale, flying height of UAV, coverage and others are determined before acquisition of DAI. It involved the determination of 60% side lap and 30% end lap. A well-organized image requires an essential arrangement because it is vital for data processing and analysis. For stream mapping, the Hexakopter UAV was used for data acquisition and these data are processed using digital photogrammetric software. The GCP and CP were established before the aerial photography mission. About 33 white crosses were painted as GCP which enclosed the study area. The GCPs were fixed along both side of the stream flood plain and coordinated by Total Station. Twenty-three (23) points were used as GCP with full 3D (XYZ) coordinates points and ten (10) points were used as CPs.

The DAIs were collected using the digital camera with wide angle lens mounted on the Hexakopter UAV. The aerial photographs were acquired in a straight line and form a series of DAI. Flying height and speed were fixed, with variation in flying altitude of 40m, 60m, 80m and 100m. A timing interval was determined in order to obtain consistent flying height with 60% overlapping. One strip of the images in JPEG (Joint Photographic Experts Group) for four different flying altitudes was captured. Digital photogrammetric software was used to perform data processing, generating digital elevation model (DEM) and producing orthophoto of the stream. The GCPs were used to perform the aerial triangulation in order to produce 3D stereoscopic model. GCPs were also used to geo-reference images to the local coordinate system. The step is continued by generating DTM and orthophoto of the DAI.

IV. RESULTS

The results can be divided into two parts. The first part shows the results of flying the fixed wing Cropcam UAV for slope mapping and the second part shows the result of flying the rotary wing Hexakopter UAV for stream mapping.

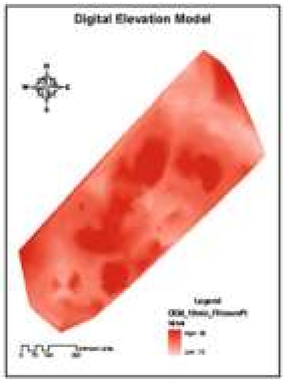
A. Slope Mapping

For this test, the two types of UAVs were used for data acquisition and processed. In this paper, the results from the fixed-wing Cropcam UAV are presented. Two primary results were produced in this study namely DEM and digital orthophoto. The slope map of the study area was also produced. DEM and digital orthophoto were generated after they went through all photogrammetric process. DEM is generally based on the elevation value while digital orthophoto consists of planimetric position x and y coordinates. The final digital orthophoto can be obtained after mosaic operation by using individual othoimages for each model in the photogrammetric block. An accurate assessment of DEM and digital orthophoto were carried out to determine the level of photogrammetric results compared with ground truth measurements.

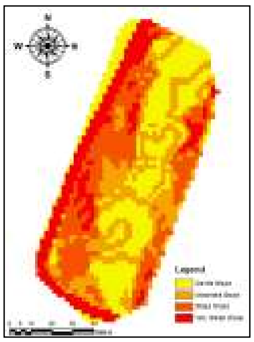
The study area has the dimension of about 400 meter by 200 meter. However, the focus area of interest for accuracy assessment is along the road which has various types of cut slope and it is very suitable for slope error distribution analysis in order to fulfill the objective of this study. The accurate assessment of both results was completed by using root mean square error equation. About 20 checkpoints were being established evenly for the whole study area Figure 3 shows the orthophoto, DEM and slope map of the study area. All ground control points (GCP) and checkpoints (CP) were established evenly to cover the area of interest including flat area, semi-slope area and slope area. All checkpoints were also established by using RTK-GPS.

In this study, accuracy assessment was performed based on RMSE value. As mentioned in Section III, the GCPs and CPs were established by using real time kinematic global positioning system (RTK-GPS). The GCPs are used for the production of DEM and digital orthophoto while the CPs are used for accuracy assessment. Three types of RTK GPS techniques have been conducted to fulfill the objective of this study. For the first technique, RTK GPS received adjustment from Iskandar Network for real time adjustment during the control point observation. For the second technique, RTK GPS received adjustment from master station which was set up at the known GPS point and each point was observed for 2 min. Finally, for the third technique, RTK GPS received adjustment from master station has same result with the second technique except the observation time is 10 min. Figure 4 shows the comparison on photogrammetric results of slope mapping based on different RTK GPS data.

(a) Digital orthophoto



(b) DEM



(c) Slope map

Fig. 3. (a)Digital orthophoto; (b) DEM; (c)Slope map

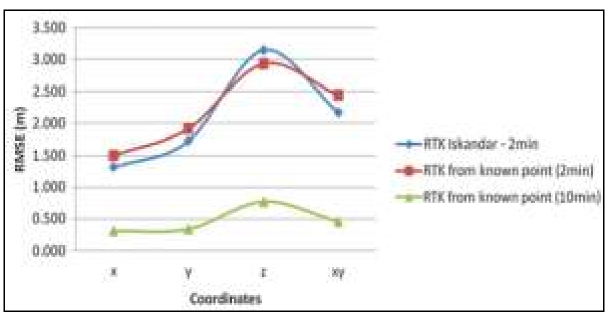


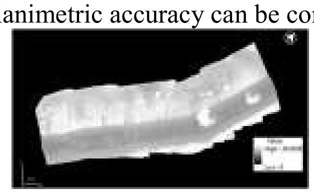
Fig. 4. Comparison of slope mapping results with RTK GPS data

Based on Fig. 4, it was found that the accuracy between the first technique and the second techniques are almost similar. Specifically, the different of x coordinate for the first and second technique is about ±18 cm, the different of y coordinate for the first and second technique is about ±19 cm and the different of z coordinate for the first and second technique is about ±22 cm. The range error for x, y and z coordinates are ±1.300 to ±3.1 m. However, the third technique gives different results from the first and second technique. All errors of the third technique were recorded below ±1m. Residual mean square error (RMSE) for x coordinate recorded ±31 cm, y coordinate recorded ±34 cm and z coordinate recorded ±77 cm. The difference between the first and the second technique is huge compared to the third technique. Based on the RMSE graph, it can be concluded that the third technique is the best RTK GPS data for Cropcam UAV image processing.

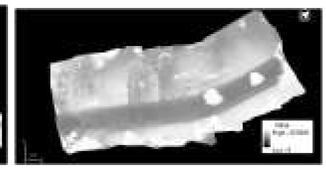
B. Stream Mapping

For this application, the rotary wing Hexakopter UAV was used for data acquisition. After acquisition of the DAI of the stream, digital image processing was performed. In this study, a series of DAI from each flying altitude/height were used to produce DEM and orthophoto. An orthophoto is a product that has pictorial quality of a photograph and correct planimetric characteristics. Orthophoto is produced through the process of differential rectification whereby photo tilt, lens distortion, and relief displacement have been eliminated and adjusted. The orthophoto was created after the process of aerial triangulation. Individual orthophoto was generated for each individual DAI. The individual orthophoto was then mosaic together to create a composite orthophoto. Digital orthophoto only provides a two-dimensional view which generally involves X and Y coordinates. Figure 5 depicts the DEM of the stream and the orthophotos are shown in Figure 6 based on different flying altitude.

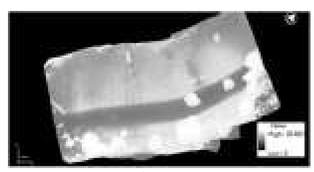
In this study, accuracy assessment was performed based on RMSE value. Table 1 shows that the results of accuracy assessment of digital orthophoto based on RMSE. Based on the Table 1, it is clearly seen that the values of mean RMSE of planimetric accuracy for all the flying altitudes are almost the same with very slight difference. This indicates that the planimetric accuracy can be considered uniform.



DEM of stream (40m)



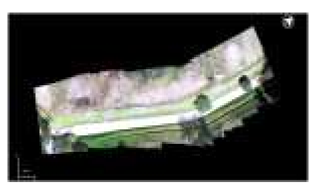
DEM of stream (60m)



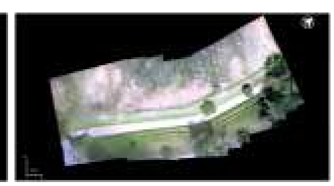
DEM of stream (80m)

DEM of stream (100m)

Fig. 5. DEM of stream at different flying height



Orthophoto of stream (40m)



Orthophoto of stream (60m)

Orthophoto of stream (80m)

Orthophoto of stream (100m)

Fig. 6. Orthophoto of the stream

TABLE I. RMSE OF ORTHOPHOTO BASED ON VARIATION FLYING ALTITUDE

		RMSE (m)		
Flying altitude(m)	**Aerial Triangulation**	**X(m)**	**Y(m)**	**Mean(m)**
40	10 CPs	±0.411	±0.156	±0.284
60	10 CPs	±0.415	±0.159	±0.287
80	10 CPs	±0.410	±0.163	±0.287
100	10 CPs	±0.415	±0.149	±0.282

For height accuracy, it is anticipated that there will be significant since in photogrammetry the height accuracy is normally double the planimetric accuracy.The slight differences in planimetric accuracy might be affected by image matching algorithm used in the image processing software. The differences are usually caused by error in image acquisition process such as motion movement such as omega, phi and kappa and crabbing and image matching during image processing.

VI. CONCLUSION

In this studym, it was found that the for slope mapping RTK GPS from known point with 10 min observation gave the best result in term of accuracy and precision. Based on this observation, an accuracy of less than ±1m was achieved using the Cropcam UAV flying at 300m. UAV is one of the efficient equipment to obtain three dimensional model of the area of interest especially at the slope area. For stream mapping based on Hexakopter UAV flying at 100m, it was found that the DEM and orthophoto were successfully produced and the planimetric accuracy of the orthophoto is ±0.280 m.

This study proved that the UAV systems are capable of acquiring DAI successfully and the mapping product can be produced accurately within short period. The methodology adopted in this study is useful and practical for large scale mapping of small area and when budget is limited.

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