Aerial Mapping using High Resolution Digital Camera and Unmanned Aerial Vehicle for Geographical Information System

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***Abstract*— In aerial photogrammetry, aerial photographs are acquired using aerial camera and light aircraft as a platform. The aerial photographs are usually processed for mapping such as for production of topographic map and other special purpose map known as thematic map. However, this method is expensive and suitable for large area but it is not practical for mapping small area. This study concentrates on the use of high resolution digital camera and a very light platform known as unmanned aerial vehicle (UAV) as data acquisition system in capturing digital aerial photographs. The acquired digital aerial photographs were processed using image processing software to produce digital map and digital orthophoto. The results showed that an accuracy of sub-meter can be obtained using the employed method. In Geographical Information System (GIS), it is quite common that topographic map and orthophoto are used as a base map. Hence, the findings from this study could also be used as an input for GIS. Not to forget, the photogrammetric technique could be used not only for mapping but it could also be used for any environmental protection and conservation.**

***Keywords*— Digital camera, digital map, GIS, photogrammetry, UAV**

I. Introduction

Photogrammetry is a branch of geoinformation science and it can be defined as the art, science and technology of obtaining reliable information about the physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena [1]. It is clearly stated in the definition that photogrammetry can be used for environmental science. Photogrammetry can be divided into aerial photogrammetry and terrestrial photogrammetry. The aerial photogrammetry is more related to mapping, environmental studies etc. The topographic map can be prepared at a given standard of accuracy from aerial photograph. Under most conditions, particularly for large area, aerial photogrammetric techniques are less expensive than purely ground surveying techniques. Until today, many mapping organizations around the world still used aerial photographs to produce map. However, the process of acquiring aerial photograph is very expensive. Today there is a need for mapping small area and it is not economical to use normal large format aerial or metric camera to acquire aerial photographs. Therefore, large format aerial photograph is unsuitable for small area; limited budget, large scale mapping and for special purposes [2]. Currently most processes of photogrammetry turn toward a larger use of digital images [3].

Nowadays, people around the world have started using small format camera including digital camera that is attached to small or light platform such as remote planes, helicopters, gliders, balloon and others. The digital camera is now giving a new perspective to aerial photogrammetry world, mostly to the private company, where it gives a lot more advantage over metric camera. Digital camera is becoming common place in aerial photogrammetry. The transition to fully digital workflows is ongoing. Aerial photography obviously refers to photographs taken from aircraft. The measurement of photographs falls within the discipline of photogrammetry, and through the measurement of aerial photograph it is possible to construct maps and retrieve a great deal of information concerning the topography, landforms, vegetation, and cultural features of the surface of the earth.

Today, small format camera (e.g digital camera or video camera) can be attached to a very light platform such as the unmanned aerial vehicle (UAV) and used in research and development, high impact events, agriculture, commercial and civil applications. The result of using these cameras together with the UAV will be a large amount of image or video data and it could be used for various applications such as for map revision in GIS, research work and any application which does not require high accuracy. This technology is still new especially in Malaysia but it has the potential towards various applications [4]. For example, small format aerial photograph together with the UAV can be used for border patrol, maritime security, crowd control, search and rescue. In this study, small format Pentax Optio A40 high resolution digital camera (i.e

12 megapixels) is attached to UAV as data acquisition system in acquiring the aerial photograph.

II. DIGITAL CAMERA

Digital camera can be categorized as non-metric camera since it is not designed for photogrammetric purposes and has the characteristics such as no fiducial mark, camera calibration parameters are not stable, small format and others. In general, digital camera can be categorized into two types namely "Single Lens Reflex" (SLR) (i.e the lens of the camera is focusable and changeable) and compact. For SLR digital camera, the user has the full control on the camera such as controlling the focus, aperture and shutter speed. For the compact digital camera, it uses the concept of point and shoot and it has the zoom facility.

Digital camera can be categorized as digital still camera or in short as digital camera and analogue video camera [5]. Digital camera could be used to acquire single image at a particular instance and the image could be stored in the camera on-board. For analogue video camera, it can be used to acquire continuous image as electronic signal at the rate of 30 frames per second. However, a frame grabber is required to transform the frame from analogue signal form into digital form. Both types of digital camera and analogue video camera could be used for close range photogrammetric applications. However, the use of digital camera is preferable since digital images could be obtained directly, digital images could stored on-board, easy to operate and not necessary to use direct current. Today, there are many types of digital cameras available in the market. Any person could possess the camera either for personal use, producing report or for research and other purposes.

Digital cameras are manufactured with different sensor size and resolution. Sensor size is defined by width and height of sensor array in millimeter or inches. On the other hand, sensor resolution is defined by the number of horizontal pixel multiplied by number of vertical pixel [5]. A digital camera could be categorized as (i) low resolution (2) medium resolution and (3) high resolution. In this study, a high resolution digital camera with 12 megapixels known as Pentax Optio A40 is used to acquire the aerial photograph of the study area using unmanned aerial vehicle. Figure 1 depicts the Pentax Optio A40 digital camera.

Fig. 1 Pentax Optio A40 digital camera

III. UNMANNED AERIAL VEHICLE

Unmanned aerial vehicle (UAV) is automatically piloted by an embedded system named "Flight Control System". Nowadays, many of those systems are commercially available. An unmanned aerial vehicle identifies an aircraft that can fly without pilot; that is, an airframe and a computer system which combine sensors, Global Positioning System (GPS), serves and CPUs. 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. Fig. 2 and 3 depict an example of a fixed wing UAV system and rotary wing UAV respectively.

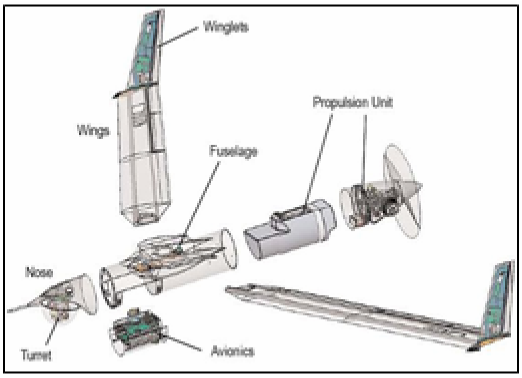

Fig. 2 Fixed wing UAV

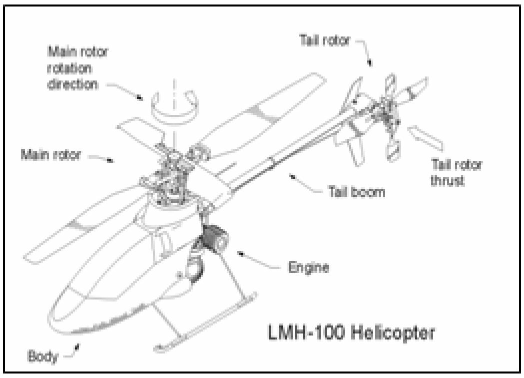

Fig. 3 Rotary wing UAV

The 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 TV cameras, infrared sensors and thermal sensors to gather information that can be partially processed on-board or transmitted to a base for further analysis.

The mission/payload controller is a computer system onboard of the UAV that has to control the operation of the sensors included in the payload. A computer system on the ground is designed at the base station to monitor the mission development and eventually operate the UAV and its payload. The communication infrastructure is a mixture of communication mechanisms (radio modems, microwave links) that make sure continuous link between the UAV and the base station.

Modern digital airborne sensors are also usually mounted with a GPS (Global Positioning System)/ IMU (Inertial Measurement Unit) system. GPS technology assists mapping projects by using a series of base stations in the project area and a constellation of satellites providing positional information accessed by the GPS receiver on-board in an aircraft. GPS and IMU information can be extremely beneficial for mapping areas where limited ground control information is available (e.g. rugged terrain). They also assist in the triangulation process by providing highly accurate initial orientation data, which is then further refined by the bundle adjustment procedure.

A. *Cropcam UAV*

Cropcam is a product from Canada. It is a self-guided plane that creates GPS-based (Global Positioning System) digital images so that user can keep an eye on their crops. UAV can scout disease, view crop development and stop problems before they get out of control. Cropcam is inexpensive and easy to use with preset flight plans that can cover up to 160 acres per launch. Images are accessible within hours and provide latitude, longitude and altitude coordinates. The Cropcam is a radio controlled model glider plane equipped with a Trimble GPS, a miniature autopilot and Pentax digital camera. The UAV can be hand launched and automatic from take off to landing. The Cropcam also provides high resolution GPS based images on demand. The UAV is simple to operate, simply stand at one corner of the field or an area and hand launch the 6 pound Cropcam plane. The powerful miniature autopilot and Trimble GPS, does the rest navigating in a pattern over the field. Both the Cropcam and the camera perform automatically in acquiring GPS based digital imagery. After the flight session, the Cropcam will land at the spot it started. Figure 4 depicts the Cropcam UAV used in this study.

Fig. 4 Cropcam UAV

The UAV can fly at approximately 600 meter above the ground and acquire the digital images that could provides a spatial resolution of approximately 15 cm. However, increased spatial resolution can be achieved by simply programming the Cropcam to fly at much lower altitude or closer to the ground. With this 1.22m length and 2.44 wing span (weight about 2.7kg) Cropcam can fly 160 acres in one flight of approximately 20 minutes depending on wind. It also offers real time video with ability to capture images from ground station and also the user can stitch all the digital images to form a single large image.

IV. RESEARCH METHODOLOGY

A. *Acquisition of Aerial Photograph using Cropcam UAV*

The study area is Universiti Teknologi Malaysia (UTM) main campus in Johor Bahru, Malaysia and it is shown by the red box in Fig. 5. The aerial photographs (in digital form) were acquired by placing the Pentax Optio A40 digital camera underneath the wing of the Cropcam UAV. The photographic session was conducted for three days and a series of digital images were acquired for each session. The digital images were acquired at an approximate 60% overlap and 30% sidelap. Since the format of the digital camera is small then the ground coverage is small too. Many small format aerial photographs were acquired using several flight lines and session. After each flight session, the digital images were downloaded into the notebook at the ground control station. Fig. 6 depicts an example of a strip of the aerial photograph acquired using the digital camera. Fig. 7 depicts all the acquired aerial photographs assembled to form a single image known as uncontrolled mosaic.

Fig. 5 Study area (UTM, Johor, Malaysia)

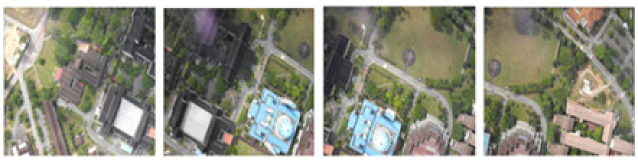

Fig. 6 A strip of aerial photograph of the study area

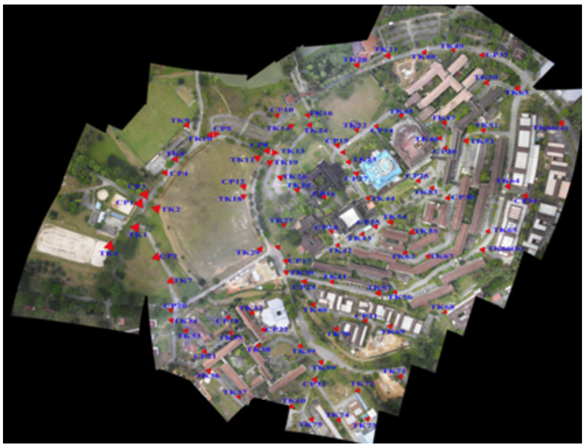

Fig. 7 Uncontrolled mosaic

B. Establishment of Ground Control Point and Check Point

In photogrammetry, it is a common practice that the ground control point (GCP) is established after the aerial photography session. There are several methods that can be used to establish the GCP such as traversing and Global Positioning System (GPS). In this study, the rapid static technique of GPS was used in establishing the GCP and check point (CP). For this study area, many GCPs and CPs were established. The check points (CPs) are used for accuracy assessment.

C. Calibration of Digital Camera

In order to achieve accurate results in photogrammetry, normally the digital camera need to be calibrated. There are many methods that can be used for camera calibration such as laboratory method, plumbline, on-the-job and self-calibration bundle adjustment method. The method of camera calibration is carried out based on the particular or specific application. In this study, a test field was built and it is a 3D test field which consist of 36 targets that are fixed with retro-reflective target. The test field was used to calibrate the Pentax A40 Optio digital camera. For the purpose of calibration, 10 photographs of the test field were acquired from five (5) camera locations (Fig. 8). The focus of the digital camera was set at infinity focus and the automatic function was disabled. At each camera location, two photographs were acquired where one is in landscape position and the other one is rotated 90 degree from its' original position i.e portrait position. During photography the camera flash is switched on and a piece of tissue paper was used to filter the flash so that sufficient amount of light will be transmitted. If the flash is not covered then the retro-reflective target will suffer 'over saturated' which might causes deterioration of the calibration results. In the calibration process, convergent photographs were employed where the optical axis of the digital camera must always pointing towards the centre of the test field and the dimension of the test field should occupy the entire format of the digital camera as much as possible. The convergent configuration must be employed to strengthen the geometry and with the purpose to recover focal length successfully [6]. The photography session was carried out within short period. In this study, the photographs of the test field were acquired after the process of acquiring the aerial photographs

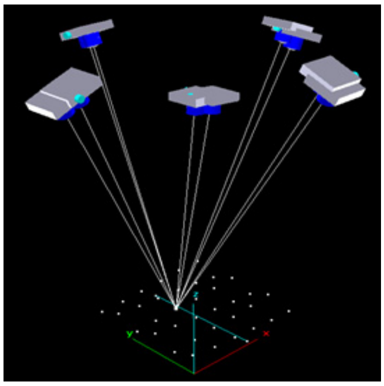

Fig. 8. Calibrating the digital camera

D. Processing Aerial Photograph

In this study, the Erdas Imagine image processing software was used to process the digital images of the small format digital images. The software was used to produce digital orthophoto and digital map. In the software, the 3D stereoscopic model was setup within short period of time. Then on screen digitizing was carried out from the stereoscopic model to produce digital or vector map. The next step is to generate DTM and finally generate digital orthophoto. The vector map produced from digitizing the features and the orthophoto could be exported to other format such as CAD and GIS formats.

V. RESULTS

From this study, two sets of results were produced. The first result comprised of camera calibration parameters obtained from calibrating the digital camera and the second result comprised of orthophoto and map of the study area produced from the image processing software of the study area.

A. Calibration of Digital Camera

Table 1 shows the estimated interior orientation parameters together with their standard deviation of the calibrated digital camera. The camera calibration parameters consist of the focal length (c), principal point offset (xp, yp), radial (k1, k2, k3) and tangential (p1, p2, p3) lens distortion, "affinity"(b1) and different in scale factor (b2). From the results, it was found that the lens distortion parameters k1 and k2 are significant due to the value of the standard deviation is better from the determined parameters. The same phenomenon also applies to the b1 parameter. In photogrammetry, it is quite common practice to use the focal length (c) and principal point offset (xp, yp) in the solution to produce accurate results and the lens distortion parameter could be used also to improve the quality of the results.

TABLE 1
CAMERA CALIBRATION PARAMETERS

Parameter	Value	Std Deviation
c (mm)	7.4753	4.511e-003
xp (mm)	-0.0930	2.670e-003
yp (mm)	0.1264	2.700e-003
k1	4.17626e-003	1.004e-004
k2	-9.22072e-005	2.088e-005
k3	2.63634e-006	1.411e-006
p1	2.05459e-004	1.802e-005
p2	-6.14004e-004	1.841e-005
b1	1.94918e-004	3.866e-005
b2	7.89334e-005	4.294e-005

B. Orthophoto and Map

In this study, there many aerial photographs are acquired using the high resolution digital camera and UAV. However, not all of them are used in producing the orthophoto. Aerial photographs that fulfilled the condition of 60% overlap and 30% sidelap are selected. In this study, as a start initially two aerial photographs were selected and processed using image processing software and individual orthophoto was successfully produced. Also in the same software the digital terrain model (DTM), a stereomodel in three dimensional (3D) was successfully produced. Fig. 9 depicts the digital orthophoto and digital map of the selected aerial photographs.

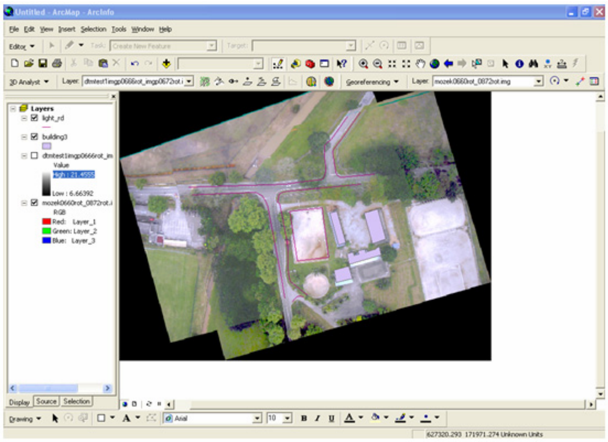

Fig. 9. Orthophoto and map of the selected aerial photographs in ArcGIS software

After successfully processed the two selected aerial photograph, all the photographs were processed as a strip and a block of aerial photograph. Unfortunately, the final orthophoto produced based on all the aerial photographs are not promising since the UAV does not follow the planned flight line (i.e suppose to be a straight line) as shown by the footprint in Fig. 10. In the same Fig. 10, it depicts the actual flight path and it is clearly seen that crabbing occurred during the process of photography. Even though the UAV is expected to follow a straight line, it suffers crabbing due to the wind speed. Fig. 11 depicts the orthophoto of the whole study area and many discontinuities can be clearly seen in it. This orthophoto could not be used for GIS application. If no crabbing occurs then there is possibility that better orthophoto could be produced. In this study, the individual orthophoto which covers small area can still be utilized for GIS applications.

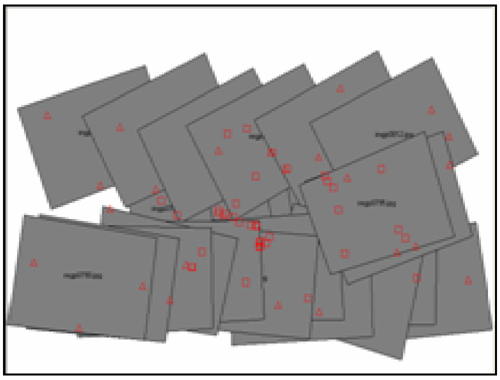

Fig. 10. Footprint of the actual path of the UAV

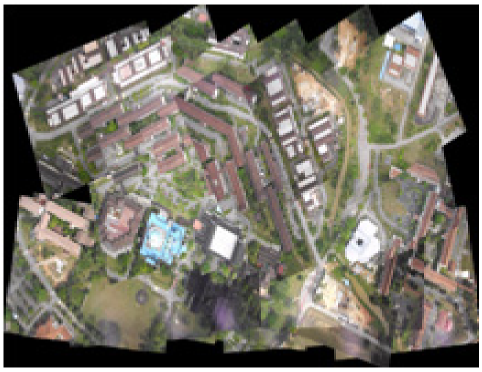

Fig. 11. Orthophoto for the whole study area

VI. CONCLUSIONS

From this study, it was found that the UAV can be used as a platform to acquire aerial photograph of the study area using the small format digital camera. The acquired images are sharp and clear. Also the acquired digital images of the study area were successfully processed to produce digital orthophoto and digital map. Hence, there is no doubt that the combination of the UAV and the digital camera could be used and explored further for GIS application, mapping and other applications. However, user must aware that the area covered by the digital camera is very small. For accuracy assessment, the accuracy achieved by the small format digital camera is at sub-meter level.

In this study, it is proven that the small format digital camera can be used in aerial photogrammetry, however, the digital camera needs to be calibrated whether after aerial photography. The user should also aware that the small format digital camera could not produce high accuracy. Finally, it can be concluded that the small format digital camera has the potential to be used in aerial photogrammetry especially if the project area is small, requires not high accuracy and when the budget is limited.

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