A generic approach for photogrammetric survey using a six-rotor unmanned aerial vehicle

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Abstract. This paper discusses a rapid production of slope mapping using multi-rotor unmanned aerial vehicle (UAV). The objective of this study is to determine the accuracy of the photogrammetric results based on novel method of multi-rotor UAV images as well as to analyze the slope error distribution that are obtained from the UAV images. This study only concentrates on multi-rotor UAV which also known as Hexacopter. An operator can control the speed of multi-rotor UAV during flight mission. Several ground control points and checkpoints were established using Real Time Kinematic Global Positioning System (RTK-GPS) at the slope area. Ground control points were used in exterior orientation during image processing in sequence to transform image coordinates into local coordinate system. Checkpoints were established at the slope area for accuracy assessment. A digital camera, Sony NEX-5N was used for image acquisition of slope area from UAV platforms. The digital camera was mounted vertically at the bottom of UAV and captured the images at an altitude. All acquired images went through photogrammetric processing including interior orientation, exterior orientation and bundle adjustment using photogrammetric software. Photogrammetric results such as digital elevation model, and digital orthophoto including slope map were assessed. UAV is able to acquire data within short period of time with low budget compared to the previous methods such as satellite images and airborne laser scanner. Analysis on slope analysis and error distribution analysis are discussed in this paper to determine the quality of slope map in the area of interest. In summary, multi-rotor UAV is suited in slope mapping studies.

1. Introduction

There are several operational UAVs for civilian remote sensing applications, such as photogrammetric recording of archeological sites [1], precision agriculture [2], Global positioning system (GPS) remote sensing measurements [3], hyperspectral, thermal remote sensing and rangeland monitoring [4], detection of mines and explosives, scanning rooftops for break-ins and finding lost children or hikers, shooting action scenes for movies, inspection of chemical or industrial plants. The integration between digital camera and UAV has become more famous among researchers from various disciplines [5]. A model of rotary-wing UAV was explored in 1980 for photogrammetry work. Reference [3] and [6] mentioned that the demands of aerial photogrammetry have increased especially after the development of design, research and production of UAV platform.

The cost of UAV is much lower compared to aircraft or terrestrial equipment. Micro UAV has potential in forest and agricultural applications [2,5]. It is because UAVs are more flexible and are able to obtain data in any weather condition. 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 [8,9]. The disadvantages of UAVs include payload limitation, small coverage for one image, increasing numbers of images that need to be processed, and large geometric distortion. Due to the current technology, most of UAVs are installed with the autonomous pilot chip. The autonomous UAV features include attitude stabilization, velocity and position control, rotor speed control, waypoint guidance as well as automatic take-off and landing.

Many researchers have studied the problem of low cost slope mapping using satellite images [10,11,12]. However, in this paper, we have done it differently by generating slope map using unmanned aerial vehicle (UAV) instead of the traditional methods of using satellite images. Hence our method is promised to be more efficient than the previous method. UAV has unlimited time to fly at the same area in one day compared with the satellite images which depend on the specific time to capture images at the same area. Therefore, UAV is more efficient compared to the previous method of using satellite images. In contrast, UAV offers the best solution in most applications that require a highly accurate result with low budget, time constraint and less manpower [13,14].

In this study, multi-rotor UAV or known as Hexacopter UAV was used as an image acquisition platform. One digital camera, Sony Nex-5N with 16.1 megapixels was used as tools for image acquisition. Camera mount was installed at the bottom of UAV to embrace digital camera during flight mission [15]. Multi-rotor UAV has potential in acquiring data at the slope areas which are complex and diverse in nature, and many slope areas have different slope angles and height. In order to produce an efficient and fast production of slope map results, reliable new technique derived from unmanned aerial vehicle can be used. The main objectives of this study are to assess the capabilities of UAV in mapping slope area and to analyze photogrammetric results and slope error distributions obtained from UAV images. The analysis was carried out using Photomod 5.0 and ArcGIS 9.3.

2. Flight Preparation
In this study, MKTool software was used to design flight path which covered the whole study area. An operator captured an estimated coordinate of the study area before flight path designing stages. There are several parameters needed to be clarified before designing flight path. The parameters are proposed flying height, coverage study area, camera focal length that will be used during flight mission, required scale, percentage of end lap, and side lap. These parameters can affected the results of image acquisition during flight mission. Before capturing images from an altitude, pixel size of the images should be considered in order to determine the size of one image by using fixed focal length [15].

MKTool software required user to enter the waypoints coordinates. The flight design was based on the flying height and coverage area that need to be covered during flight mission. Afterward, navigation file was sent to flight control board via wireless modem. Figure 1 describes an example of MKTool software and computer with radio modem used in this study. Based on figure 1a, the red point shows the exposure station of digital camera to capture images on the ground and the blue line shows the flight line of UAV. MKTool software can monitor the condition of UAV during flight mission for example; UAV altitude, UAV attitude, battery status and UAV speed. Figure 1b shows a computer with radio modem that was used during flight mission. During flight mission, radio modem was used as the bridge for communication between UAV and ground station monitor. An operator can monitor the UAV activities from the ground station computer and prepare for any circumstances. In this mission, UAV takes about 10 minutes to cover the whole study area. The launching and landing operations are manually control by an operator to prevent any damages on the UAV especially during landing operation.
3. Image Acquisition and Processing

UAV raw images were processed by using photogrammetric software, which is known as Photomod. Photomod is one of the powerful software in aerial image processing. All acquired images need to go through all photogrammetric operations such as interior orientation, exterior orientation, aerial triangulation and bundle adjustment. Interior orientation requires the camera parameters and these parameters were obtained from the camera calibration results. The parameters are focal length, principal distance for x and y, radial lens distortion, tangential lens distortion, and affinity. 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 point 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, the 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. Tie points are responsible for orientating, tying all images in the strips and arranging all images similar as in the flight mission. GCPs are used to project the images into local coordinates. GCPs were established by using real-time kinematic global positioning system (RTK-GPS). Aerial triangulation is performed after exterior orientation and the accuracy of aerial triangulation is analyzed by using root mean square equation. There are two main products produced after the photogrammetric process; digital elevation model (DEM) and digital orthophoto (DO). These products are explained in the result and discussion section.

4. Results and Discussions

Two primary results were produced in this study; DEM and DO. DEM and DO were generated after they went through all photogrammetric process. DEM is generally based on the elevation value while DO consists of planimetric position Easting and northing coordinates. The final DO can be obtained after mosaic operation by using individual orthoimages for each model in the photogrammetric block. An accurate assessment of DEM and DO 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 new 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 in the whole study area and the analysis results were discussed in figure 2. All checkpoints 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.
Based on figure 2, it can be seen that the RMSE for planimetric coordinates is recorded as +0.216 meter in which each coordinates recorded as Easting is +0.113 meter, Northing is +0.184 meter and Height is +0.697 meter. It can be concluded that planimetric coordinates gives better accuracy compared to height. The reason of large error on height may be caused by systematic focal length error with the different undulation at the slope area. Therefore, height error contributes a large error in total RMSE for all coordinates. The error for each coordinate is studied in detail to identify the slope area that has a large error in photogrammetric results. Slope map is produced from DEM in the study area. Slope map is classified into nine classes in sequence to analyze the slope angle of the study area. Figure 3a illustrates the classification of 4 classes of slope e.g. <10° (gentle slope), 11°-20° (moderate slope), 21°-30° (steep slope), >30° (very steep slope). Figure 3a also demonstrates the slope map of the study area. It can be seen that, most of the big slopes can be discovered along the road. It is because most of slope has been excavated for the road construction. Figure 3b shows the result of slope analysis generated from the study area. It was found that most of the slope in the study area recorded a result of gentle and steep slope. This might be because of the new development in the study area that involves building construction.

Each slope class was analyzed to identify which slope class contributes large error in RMSE. This analysis was carried out based on each coordinates, for example easting (X), northing (Y) and height (Z). Figure 4 describes the result of slope error analysis of the study area. The line graph shows the error for each slope class for example gentle slope, moderate slope, steep slope and very steep slope. Theoretically, each slope interval will leads to the accuracy of photogrammetric results such as digital orthophoto or digital elevation model because camera lens has its own limitation to capture various types slope features. Based on figure 4, each slope class was examined to determine the error distribution of the study area. The analysis for X coordinates shows gentle slope records the minimum slope error while moderate slope record the maximum error. The analysis for Y coordinates shows gentle slope records the minimum slope error while steep slope records the maximum slope error. The analysis for Z coordinates shows gentle slope records the minimum slope error while steep slope records the maximum slope error.
There are several checkpoints used at each slope class in order to obtain the slope error on each slope class. It was found that, X coordinates recorded slope error below than 0.1 meter for all slope classes, Y coordinates recorded slope error below than 0.2 meter for all slope classes while Z coordinates recorded slope error below than 0.5 meter for all slope classes except for steep slope class reached about 0.7 meter. However these errors are too small until centimeter level. It was found that Z coordinates for all slope class record the highest slope error. This might be caused by the limitation of camera lens at the semi-undulated area. This condition might be caused by a systematic focal length error during flight mission or inconsistent altitude during flight mission. Therefore, it can be concluded that Z coordinates contributes big slope error for X, Y and Z coordinates and further study on these slope error needs to be carried out in the future.

5. Conclusion
Multi-rotor UAV raw images were successfully produced a slope map in the area of interest with highly accurate results. In this study, it was identified the slope error distribution for each coordinates for slope mapping references. X and Y coordinate give a better results compared with Z coordinates. This case might be caused by limitation of camera lens in capturing slope area. Therefore, it can be concluded that multi-rotor UAV can be used for slope mapping studies, especially for slope data acquisition in natural hazard analysis. This study has proved that UAV is more efficient compared with satellite images because UAV can fly under cloud cover with low altitude while satellite images can only be captured from the space which thousand kilometers from the earth. UAV can also fly at the same area without any time limitation, satellite images on the other hand, need to follow the revisit time to capture the images at the same area. Based on the RMSE result, multi-rotor UAV is capable of providing an accurate photogrammetric result for the other related applications. Slope analysis graph shows that UAV can produce an accurate slope map into different slope classes. In addition, it could be seen that the novel method using multi-rotor UAV can produce a slope map that is ready-to-use for decision making. These results are very useful for multi-criteria decision making in the slope stability risk study. In the future, this study will be expanded to produce a slope stability risk map of the tested area by using a few parameters including slope map, aspect map and elevation map. This study has potential in hazard mapping study especially at prone area that requires a frequently monitoring system.

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