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The Accuracy Evaluation of Unmanned Aerial Vehicle Technology for Different Coastal Terrain Mapping

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***Abstract*— Due to its societal impact, coastal area is one of the most important parts in a developing country. The low cost Unmanned Aerial Vehicle (UAV) system can be used for various applications including mapping of coastal area. The aim of this study is to evaluate the accuracy of Digital Elevation Model (DEM) and orthophoto accuracies obtained from UAV system based on different coastal terrain. In this study, a micro fixed wing UAV attached with a camera digital were used for digital aerial images acquisition on two different coastal terrains (i.e. cliff and sandy) at flying altitude of 300m. The root mean square error (RMSE) analysis was used to assess the planimetric accuracy of orthophoto based on Northing and Easting coordinates and height accuracy of DEM. In this study, the average of Easting and Northing RMSE value for Crystal Bay, Alai Melaka and Kampung Seri Pantai, Mersing Johor are ±0.024m and ±0.076mrespectively. Meanwhile RMSE values for height are ±0.132m and ±0.390m for both study area. It shows that Crystal Bay, Alai Melaka show the smallest RMSE value for both average Easting and Northing and height coordinates which indicates that it is the best coastal terrain (sandy) for accurate orthophoto and DEM. In conclusion, these results from the UAV system are sufficient for most civil engineering project according to map standard published by American Society for Photogrammetry and Remote Sensing.**

Keywords—UAV, Coastal Terrain, Coastal Mapping, Orthophoto, Digital Elevation Model

I. Introduction

Coastal is a type of area located on the seafront where it is important for tourism, fisheries, ports and many others. During monsoon season, the coastal areas are expose to erosion [1-3] and this may cause damage to mangrove, trees, marine animals and human’s life. According to [4], coastal areas are also prone to environmental hazards such as erosion and sedimentation processes. These may cause loss of coastal land and damages to infrastructures and buildings. Coastal erosion is a natural disaster occurring from the interactions between natural processes and systems. It is widely believed that erosion occurs continuously along the coastline due to combination of both natural and human factors. These include wearing away of land and removal of beach or dune sediments by tidal currents or rise in sea level [5-11], wave currents [12, 13], or climate changes [14-16]. In addressing this coastal erosion, there are several steps taken by the authorities such as the construction of the wave diversion, the renovation, the repair of the river estuary, the formation and maintenance.

Therefore, coastal mapping is one of the approaches to monitor the coastal area where the generated map can provides coastline information, land condition, coastal terrain, buildings and residential area. Moreover, the coastal map is intended to be frequently produced for coastal erosion mapping as reference material for stakeholders such as developers, local authorities, engineer and researchers to assist in decision making. A map is a representation and the reality of geography in the abstract, in which it is a mean to communicate and transfer the relevant geographic data in the form of visual or digital information as the end result. It can be seen that maps are not only used for positioning but also for surveillance, erosion monitoring, risk flooding area, erosion assessment and landslide.

In the 90's, total station instruments were introduced for the purpose of surveying [17]. The instruments were used to accurately observe the bearing and distance of lines and also to deliver 2D plan. The conventional ways of data collection, data processing and results were replaced by more effective techniques. There are several techniques in acquiring coastal map such as aerial photogrammetry using manned aircraft [18-21], remote sensing [20, 22], Light Detection and Ranging (LiDAR) [20, 23], Global Positioning System (GPS) [20, 24] and Terrestrial Laser Scanning (TLS) [25, 26]. These geoinformation technologies also assist engineers in protecting coastal erosion. Generally, remote sensing and aerial photogrammetry are widely used for mapping coastal erosion. Through remote sensing, the development of high resolution satellite imagery such as IKONOS, QuickBird and WorldView 2 enabled the mapping of coastal erosion. Similarly, high resolution satellite imagery from airborne or aerial images were obtained by utilizing several technologies (e.g. IKONOS, QuickBird, Spot and WorldView2) and manned aircraft technology [21]. However, there are some limitations of these techniques for obtaining aerial images. For example, according to [27], many countries in the tropical region are covered with clouds especially during the rainy and monsoon season, thus making it difficult to capture clear images. According to [28, 29], there are also limitations in using satellite and manned aircraft, which are high flight cost, low ground resolution and limited time frame. Hence, it is rather impractical to use these technologies to cover lower altitude and small area. Usually, project related to coastal erosion involves small area. Table 1 shows the summary of the comparison between four techniques namely manned aircraft, LiDAR, satellite image and UAV

TABLE I. COMPARISON BETWEEN MANNED AIRCRAFT, LIDAR, SATELLITE IMAGE AND UAV

Type / Feature	Manned Aircraft	LiDAR	Satellite Image	UAV
Flight Planning	Overlap and side lap need to be considered	More complex due to small strips and potential data voids	No	Overlap and side lap need to be considered
Flight restrictions	Must fly during day time and need clear sky	Less impact from weather, day/night, cloud condition	Most image in the tropical region cover with cloud	Must fly during day, clear sky time and under cloud
Cost estimation	Up to hundred thousand ringgit Malaysia	Up to hundred thousand ringgit Malaysia	Up to ten thousand	Up to thousand ringgit Malaysia
Production rate	Time consuming	Can be automate d and faster	Depend on satellite which passes through the area	Can be automated and rapid
Coverage Area	Cover large area and not practical to cover small area	Cover large area	Cover large area	Cover small area based on micro UAV and cover large area based on long endurance UAV

II. THE USE OF UAV FOR COASTAL EROSION

Coastal erosion occurring levels are also influenced by different coastal terrain. Steep coasts will experience higher erosion than sloping coasts. This is due to the ruptured waves occurring on a sloping coastline that will experience friction and weaken the waves to eradicate. This is in contrast to the steep coast because of the high energy of the waves. The UAV is the most suitable technique for monitoring and mapping the coastal area since it has been developed and progressed rapidly from year to year especially for mapping applications [30]. Consequently, UAV is the solution for low budget project with time constraints and few manpower rather than using satellites or manned aircraft with expensive flight costs, time consuming and weather-dependent data collection, restricted maneuverability, limited availability, limited flying time and low ground resolution in mapping process [28, 31]. Moreover, three dimensional models can be generated by using UAV image after performing digital image processing. The study area is situated in two different coastal areas. The first is Crystal Bay, Alai, Melaka which is located on the west coast of Peninsular Malaysia (Fig. 1). The second coastal erosion area is Kampung Seri Pantai, Mersing, Johor which is located in the east coast of Peninsular Malaysia (Fig. 2). The objective of this study is to evaluate the accuracy of different coastal terrain mapping by using UAV. The output of this study are digital terrain model (DTM) and orthophoto of this study.

Fig. 1. Study area of Crystal Bay, Alai, Melaka

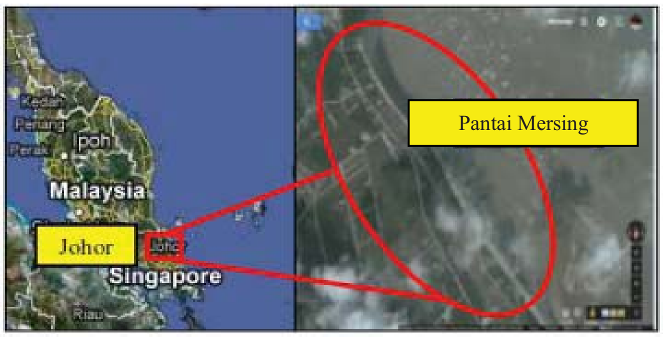

Fig. 2. Study area of Kampung Seri Pantai, Mersing, Johor

III. METHODOLOGY

UAV work process involves aerial images acquisition, establishment of Ground Control Points (GCPs) and Check Points (CP), image processing until production of orthophoto and digital elevation model (DEM) as shown in Fig. 3.

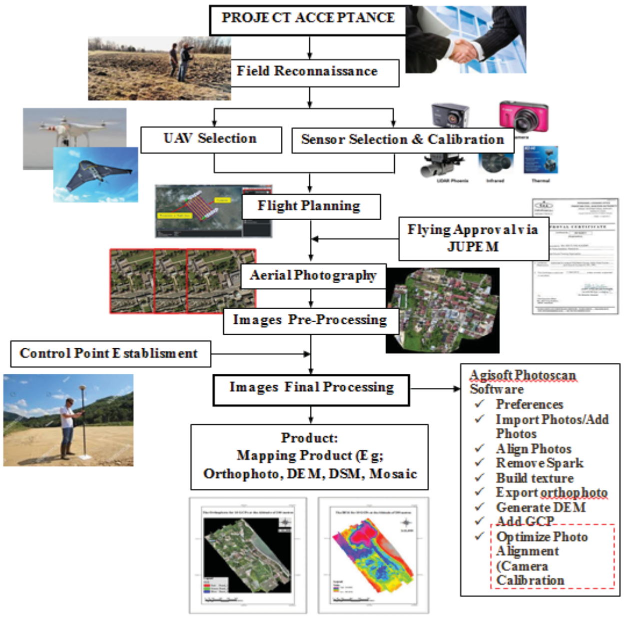

Fig. 3. UAV Work Process

There are several steps in producing coastal terrain mapping. This work process have been applied on coastal studies area at two different terrain namely cliff and sandy.

A. Instruments

In this study, Canon Powershot XS230 HS as shown in Fig. 4 was used in acquiring the coastal aerial images. This Canon Powershot XS230 HS has 14.0x optical zoom lens and other specification as shown in TABLE II. Micro fixed wing UAV known as Helang UAV as shown in Fig. 5 was used in acquiring aerial images of two real site study areas. The dimensions of Helang UAV have a wing span of 1680mm and 1180mm in length that are capable of flying at 300 meters height. TABLE III shows the specification of micro fixed wing UAV known as Helang UAV.

Fig. 4. Canon Powershot XS230 HS

TABLE II. CANON POWERSHOT XS230 HS DIGITAL CAMERA SPECIFICATIONS

Specification	Description
Maximum resolution	4000 X 3000 pixels
Effective pixels	12.10 Megapixel
Lens	14.00x zoom, f3.1-5.9, 28-392mm (35mm equivalent)
LCD size	3”
Sensor size	1/2.3", 460K dots/None
Sensor type	CCD
Dimensions	4.2 x 2.4 x 1.3 in. (106 x 62 x 33 mm)
Weight (Body)	218g including batteries
Shutter	15-1/3200
ISO	100-3200
Memory type	SD/SDHC
File Formats	JPEG (conforms to Exif 2.2), conforms to DCF2.0, DPOF, PRINT Image Matching III, AVI (Motion JPEG), with WAV(PCM), mono

Fig. 5. Micro Fixed Wing Helang UAV

TABLE III. HELANG UAV SPECIFICATION

Specification	Description
Weight	2-3 kg with Lithium-polymer battery
Dimensions	Wing span 1680mm, length 1180mm
Endurance	Up to 45 minutes
Payload	130g – 500g for one to three cameras
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 and autonomous
Camera stand	No flexible camera holder
Flight altitude	<450m

B. Aerial Images Acquisition

Image acquisition is an important step that needs to be completed in order to get the best aerial images. The flight planning needs to be settled beforehand to capture the aerial images. Several considerations need to be clarified during flight planning such as flying height, coverage of the study area, focal length, scale, percentage of the end and side lap. The important part depends on weather and time taken of aerial images of the study area which could affect the brightness of images. The best time to acquire aerial images is about from 8.00 am until 11.30 am in the morning. During the flight mission, two people were in charge namely the pilot and the ground crew. Autonomous UAV for image acquisition will be implemented for flight mission and landing. In autonomous mode, UAV will receive input from laptop or mission planner via radio modem and will be flown based on the starting waypoints until the end of waypoints. In this study, two flight lines were designed for the Helang UAV which covers two study areas with the dimension of 4 km x 2 km. Fig. 6 shows some of the aerial images acquired using the Helang UAV with flying height of 300 meters for Cyrstal Bay, Alai, Melaka. Similarly, Fig. 7 shows some of aerial images acquired using the Helang UAV at the flying height of 300 meters for Kampung Seri Pantai, Mersing, Johor. The format of the image is in Joint Photographic Experts Group (JPEG). All the images contain the GPS locations, flying altitude, and the time taken. All these information are embedded in the image because before flight mission, the UAV system need to lock the GPS in order to hold the position of the images captured during flight mission.

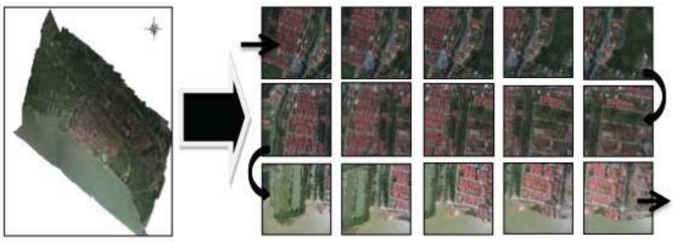

Fig. 6. Aerial Images of Micro Fixed Wing Helang UAV for Cyrastal Bay, Alai Melaka

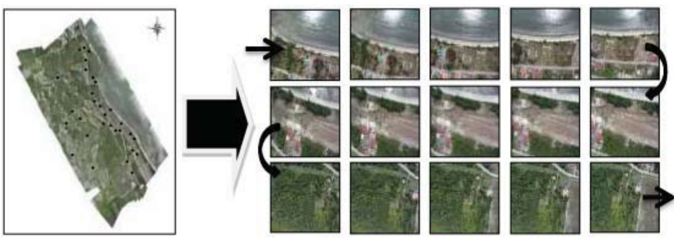

Fig.7. Aerial Images of Micro Fixed Wing Helang UAV for Kampung Seri Pantai, Mersing, Johor

C. Establishment of GCP and CP

GCPs are used during data processing to assist in geometry correction process in orthophoto mosaic in order to produce accurate map. Meanwhile, CPs is used for accuracy checking of the map produce using UAV. A minimum of five (5) GCPs required for Agisoft Photoscan Software. The GCP is the most important part that influenced the accuracy of orthophoto and DEM. The exact number of GCP is required for a good quality of photogrammetric results to be established. (Gómez-Candón et al., 2014;Tahar, 2013)

The GCPs and CPs collected using GPS observation through rapid static technique. This technique can provide the position information includes Easting, Northing and Elevation, X, Y and Z or in latitude, longitude and height (ϕ, λ and H). Its accuracy is up to 10 centimeter level. This observation technique only takes around 20 to 30 minutes per GCP and CP. The base station will be observed through static technique that gives accuracy at millimeter level. A base station was used for network as reference station. Fig. 8 shows the distribution of GCPs and CPs for the two coastal studies area.

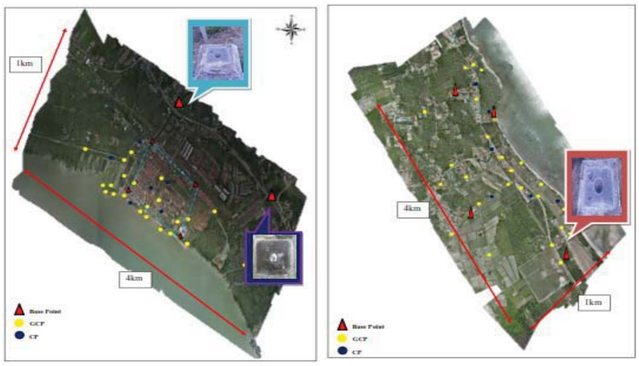

Fig. 8. GCPs and CPs distribution for two coastal studies area

D. Aerial Images Processing

Fig. 9 shows the flowchart of the aerial image processing using Agisoft Photoscan Pro software from creating new project until the production of orthophoto, DEM and Google Earth format.

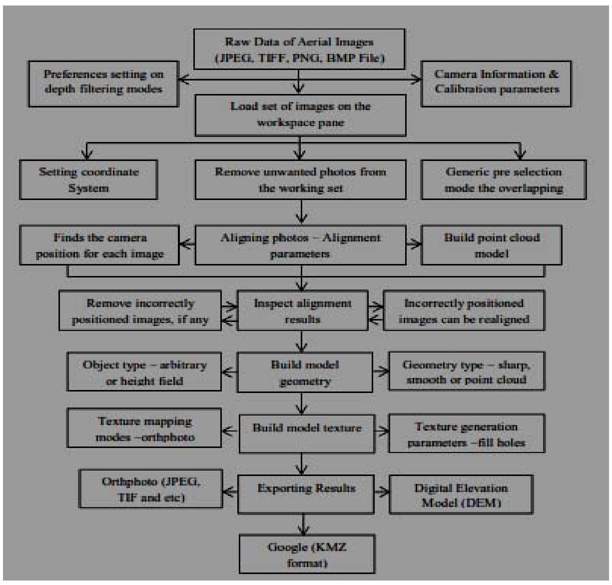

Fig. 9. Aerial Images Processing

IV. RESULTS AND ANALYSIS

There are two primary results produced in this study which are the orthophoto and DEM. Generally, DEM shows the elevation value meanwhile the orthophoto shows the planimetric position which is the Easting and Northing. DEM posting shall be the minimum allowed by the data and shall not exceed 1 meters as a performance standard (Ambercore, 2008). The orthophoto accuracy which includes the planimetric coordinate (Easting and Northing) shall not exceed the RMSE value 1 meter for scale of 1:40, 000. Both orthophoto and DEM results were used to produce the coastal map. Fig. 10 and Fig. 11 shows the orthophoto and DEM for Crystal Bay, Alai Melaka.

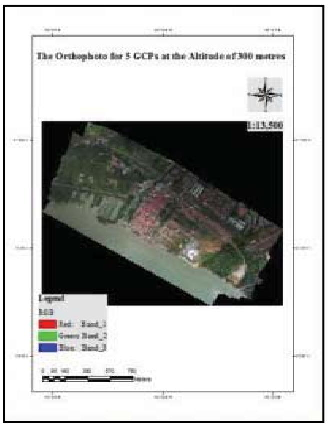

Fig. 10. The orthophoto for Crystal Bay, Alai Melaka

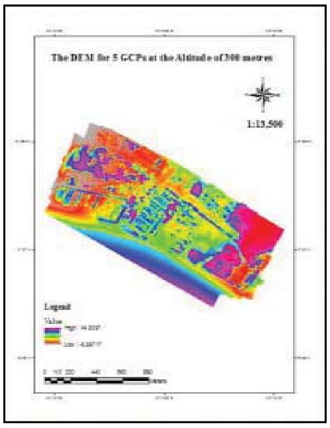

Fig. 11. The DEM for Crystal Bay, Alai Melaka

Based on these figures, UAV is capable for producing high resolution aerial images. Low altitude also beneficial to aerial images Helang UAV as it gives clear images from existing cloud. With this technology of Helang UAV, any local authorities, government agencies and private company can use this technology for mapping and hazards assessment. Fig. 12 and Fig. 13 shows the orthophoto and DEM for Kampung Seri Pantai, Mersing Johor.

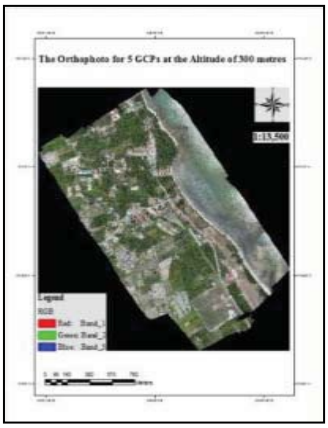

Fig. 12. The orthophoto for Kampung Seri Pantai, Mersing Johor

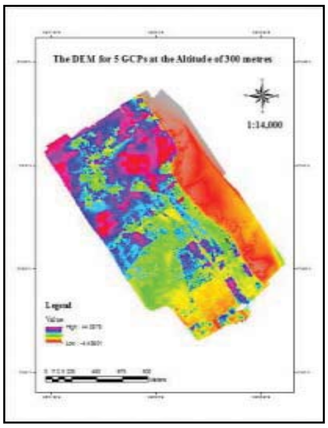

Fig. 13. The DEM for Kampung Seri Pantai, Mersing Johor

As shown in Fig. 10, and 12, the produced orthophoto commonly showed the entire natural landed features. This indicates that better orthophoto can be produced if GCPs are utilized during image processing process for these two coastal studies areas. Based on that figures, it can be seen that orthophoto for Crystal Bay, Alai Melaka and Kampung Seri Pantai, Mersing, Johor were successfully produced. Fig. 11 and 13 shows that the DEM for both study area were also successfully produced. All the height area is shown in purple color while the flat area is shown in yellow color. It shows that it has slightly different DEM due to different coastal terrain of these two coastal studies areas. Fig. 14 shows the bar graph of root mean square error (RMSE) graph for northing, easting and height for Crystal Bay, Alai Melaka and Kampung Seri Pantai, Mersing Johor.

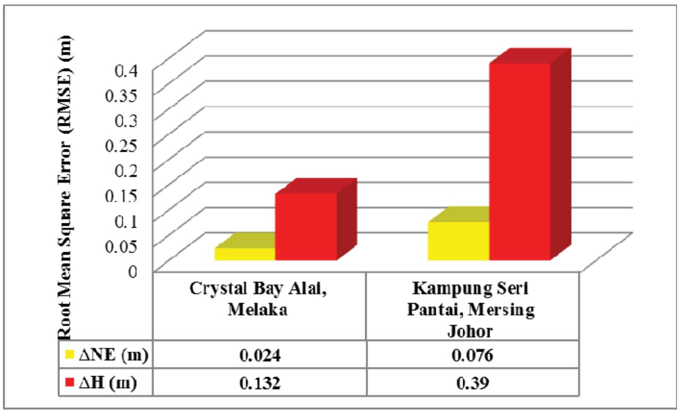

Fig. 14. RMSE graph for both coastal studies areas

The average of Easting and Northing RMSE value for Crystal Bay, Alai Melaka and Kampung Seri Pantai, Mersing Johor are ±0.024m and ±0.076mrespectively. Meanwhile RMSE values for height are ±0.132m and ±0.390m for both study area. It shows that Crystal Bay, Alai Melaka show the smallest RMSE value for both average Easting and Northing and height coordinates which indicates that it is the best coastal terrain (sandy) for accurate orthophoto and DEM. TABLE IV shows the accuracy finding based on previous research work especially using data source of aerial images.

TABLE IV. ACCURACY FINDINGS BASED ON PREVIOUS RESEARCH WORK

No.	Researchers	Findings	Application
01	Gomez et al., 2013	Studied was carried out at the flat terrain with the dimension of 12.5m x 12.5m. The results showed the spatial resolution (pixels from 7.4 mm to 24.7 mm for 30, 60 and 100m flying height)	Agriculture purpose in Wheat
02	Udin et al., 2012	In planimetry accuracy, a submeter ±0.555m and ±0.624m were obtained for X and Y coordinates respectively. Meanwhile the RMSE for Z coordinates is ±1.117m.	River mapping

03	Al-Tahir et al., 2011	The main problems still to be addressed are the vibration of the system, the payload capability and the integration of all sensors.	Natural Disasters
04	Tahar, 2013	The achievable positioning accuracy are ±2.3cm (Easting), ±2.9cm (Northing) and ±8.7cm (Height) at the altitude of 80m.	Large scale slope mapping
05	Eisenbiess, 2009	The laser DSM and the UAVDSM can be fitted together with a mean offset of less than 1cm and a standard deviation of 6cm for image resolution.	Archeological Site

V. CONCLUSION

This study has successfully evaluated the accuracy of unmanned aerial vehicle system for two different coastal terrains. The accuracy of the main outputs namely orthophoto and DEM are different due to the environment and earth surface of the study area. The RMSE shows differences in accuracy evaluation of the two coastal areas where the sandy coastal area of Crystal Bay, Alai Melaka has better accuracy compared to the cliff coast of Kampung Seri Pantai, Mersing Johor. The best large scale mapping for coastal area is influenced by the coastal terrain landscapes. Therefore, this micro UAV can provide accuracy up to centimeter level with correct method and procedure of image acquisition and processing for producing large scale coastal mapping. In future studies, this study will expand analysis using UAV LiDAR as a platform to capture coastal data. The comparison of coastal map products between UAV attached with compact digital camera and UAV LiDAR will be performed to determine the level of differences.

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