The 2010 Taiwan Bathymetric Lidar Survey of Penghu and Dongsha Atoll

Peter Tian-Yuan Shih [1], Dushan Arumugam[2], Shihan-Wern Shyue[3], Ya-Hsing Chen[4], Hui-Jung Wang[4],Jie-Chung Chen[5], and Jia-Hsun Chen[6]

[1]Professor, Natural Hazard Mitigation Research Center, National Chiao Tung University, Hsinchu, Taiwan.
Tel: + 886-3-5712121#54940; Fax: +886-3-5716257; E-mail: tyshih@mail.nctu.edu.tw

[2]Technical Manager, Geomatics Data Solutions, Surrey, Canada
Tel: + 1-604-755-7672; Cell: +1-778-551-1509; E-mail: Dushan@GeomaticsDS.com

[3] Associate Professor, National Sun Yat-sen University Department of Marine Environment and Engineering. Tel: + 886-7-5255067; Fax: +886-7-5250102; E-mail: swshyue@faculty.nsysu.edu.tw

[4]Dupty Engineer, Natural Hazard Mitigation Research Center, National Chiao Tung University, Hsinchu, Taiwan.
Tel: + 886-3-5712121#55283; Fax: +886-3-5714125; E-mail: yshina@gmail.com

[5]Section Chief, Ministry of Interior, Taipei, Taiwan.
Tel: + 886-2-23565270; Fax: +886-2-23976875; E-mail: moi5383@moi.gov.tw

[6]Staff, Ministry of Interior, Taipei, Taiwan
Tel: + 886-2-23566104; Fax: +886-2-23976875; E-mail: moi1240@moi.gov.tw

Abstract

Bathymetric lidar systems utilize green laser, which can penetrate water and scatter on the sea floor, to collect shallow water depths. Comparing with sonar based sounding technology, airborne laser hydrography is featured with high efficiency and particularly suitable for areas with shoals and other risks for boat navigation. In 2007, Dongsha atoll was designated as the 7th Marine National Park of Taiwan. The habitat of various marine lives is highly related with the depth and the seafloor topography. Penghu is an outlying island archipelago and an important tourist attraction. Dongsha atoll and some area of Penghu were selected for surveying with bathymetric lidar.

Equipped with an AHAB Hawkeye II lidar system installed on a SA-226T aircraft, the survey was conducted in August and September of 2010. The survey area is about 500 square kilometers for Dongsha, and about 415 square kilometers for Penghu. The point density for both areas is about 3.5 meter by 3.5 meter. In addition, an area of 20 square kilometers located in the east portion of the atoll is also surveyed with 2x2 meter resolution at lower flying height.

This paper outlines the data acquisition, processing, and validation of this survey. Based on the cross check between the overlap of flight lines and cross flight lines, the result meets the requirement of IHO (International Hydrographic Organization) 1b specification.

1. Introduction

The sonar instruments, either single or multi beam, on board of ship or boat, are the major current technology for bathymetric mapping. It offers potentially higher spatial resolution, and also better depth accuracy. However, for the area with shallow water or risky navigation environment, airborne bathymetric lidar has the advantage of higher efficiency, and much better navigation feasibility.

In order to explore the airborne bathymetric lidar technology, and collect the detailed sea floor terrain information of Dongsha atoll, Ministry of Interior of Taiwan supported a project utilizing this technology for mapping Dongsha atoll, and a portion of Penghu. This project has two major objectives. The first is to evaluate this technology, and develop strategy on adopting this technology for future shallow water area mapping. The other is to establish sea floor terrain information for various marine researches in Dongsha, and potential engineering applications in Penghu.

The geographic location of Penghu and Dongsha related to Taiwan is shown in Figure 1. While Penghu is close to Taiwan, Dongsha atoll is located 480 km southwest of Kaohsiung. Penghu is composed of many islands, as shown in Figure 2. In 2007, Dongsha atoll was designated as part of the Marine National Park of Taiwan. The shape of Dongsha atoll is nearly a perfect ring (Figure 3). The diameter of this ring is about 25 kilometers. Dongsha is the only constantly above water land in Dongsha atoll. The highest elevation is about 7.8m. The length of Dongsha is 2800m, and width 865m (MNPH, 2010).

Penghu is composed of more than 90 islands. The land area is about 127 square kilometers. Ma-Gong, the capital of Penghu, is about 140 km from Kaohsiung. Penghu is featured with both unique geological and marine settings. One area in southern Penghu composed of four islands is under evaluation of becoming a part of the Marine National Park.

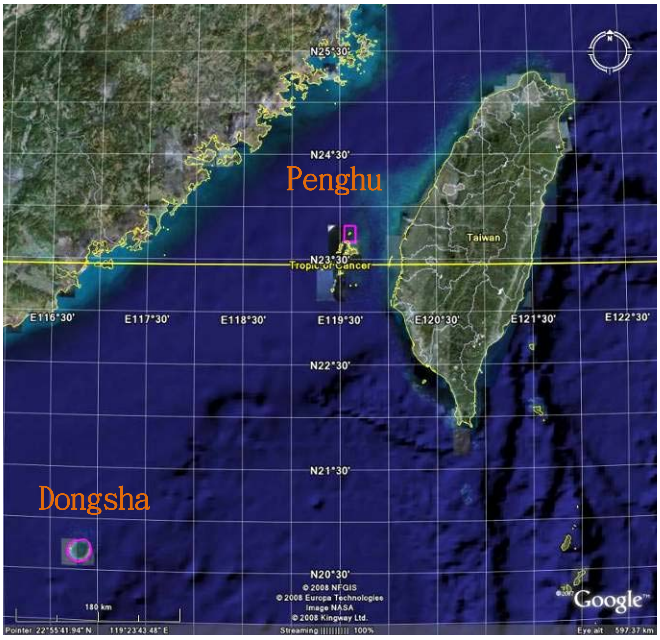


Figure 1: The Geographic Location of Dongsha, Penghu, and Taiwan

Figure 2: Penghu

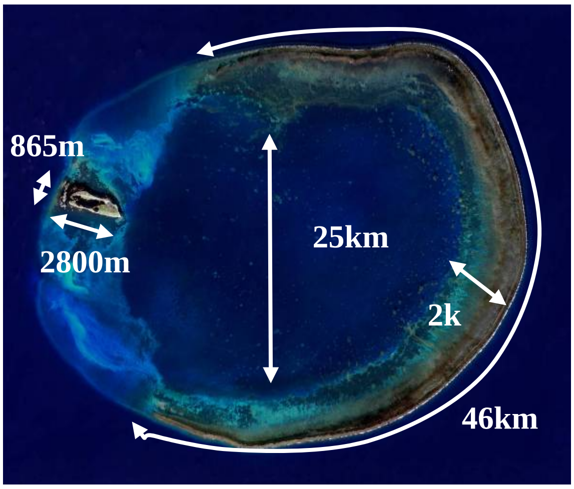


Figure 3: Dongsha Atoll (MNPH, 2011)

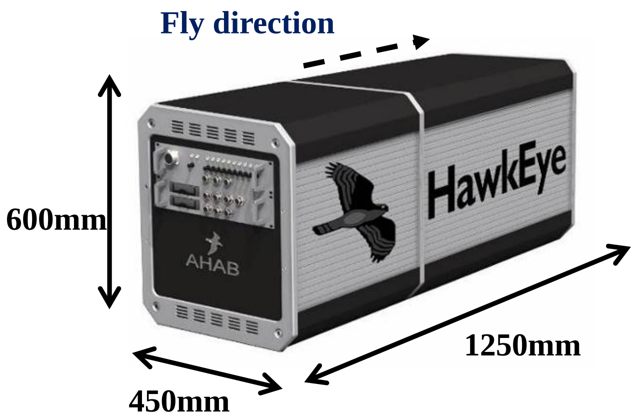
2. The Bathymetric Lidar Operation

The initialization of the mission planning started in December of 2009. In the planning, the selection of airborne platform was a major issue. Due to the complexity in importing a surveying aircraft from overseas, great efforts were put on the evaluation of domestic airborne platforms, both fixed wing and rotating wing. Several constraints from the airborne bathymetric lidar instrumentation, namely, the floor area on plane required, the cooling capabilities, the flying speed, and the power capacity of the aircraft, ruled out all the commercially available options in Taiwan. While the government owned Beech King 200 and 350 aircrafts are good candidates, their busy schedule prevented further arrangement. As the result, a dedicated aircraft was imported into Taiwan for the bathymetric lidar mission.

2.1 Hawkeye II

This survey was conducted with an AHAB HawkEye II lidar system installed in a SA-226T aircraft. Hawkeye II system uses airborne laser that detects sea bottom in shallow coastal waters (<50 m). There are four channels, including an infrared channel, two green channels, and one channel for Raman scatter. The HawkEye II system simultaneously collects 4 kHz bathymetric, 64 kHz topographic lidar soundings and digital images acquired at 1Hz covering the lidar scanned area (Figure 4). IDE UI-2250SE digital camera was chosen to be used with 1200x1600 pixel resolution and the focal length is 12 mm. Full waveform information is stored for the bathymetric laser (Henrik, 2006).

The laser fired from HawkEye II maintains the angle from nadir, which is close to 20º. It can avoid the reflection from the sea surface directly. The viewing of HawkEye II system principle is shown in Figure 5.



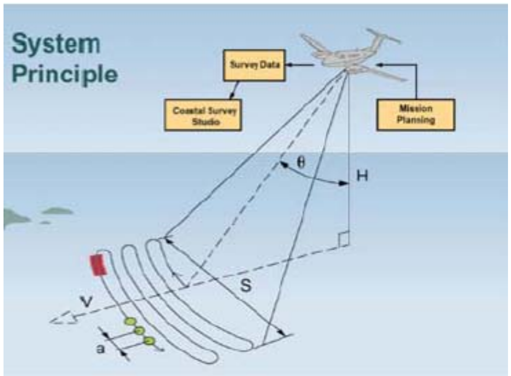


Figure 4：HawkEye II system (AHAB, 2006)   Figure 5：HawkEye II system principle

2. Flight plan

The targeted survey areas of this project are Penghu and Dongsha. Survey area and planned flight lines of Penghu are shown in Figure 6. The test flight and the calibration verification were all carried out in Penghu. Survey parameters of Penghu are shown in Table 1. A temporary base of operations for processing and validating the data was located in Kaohsiung, which is about 200 kilometer from Penghu.

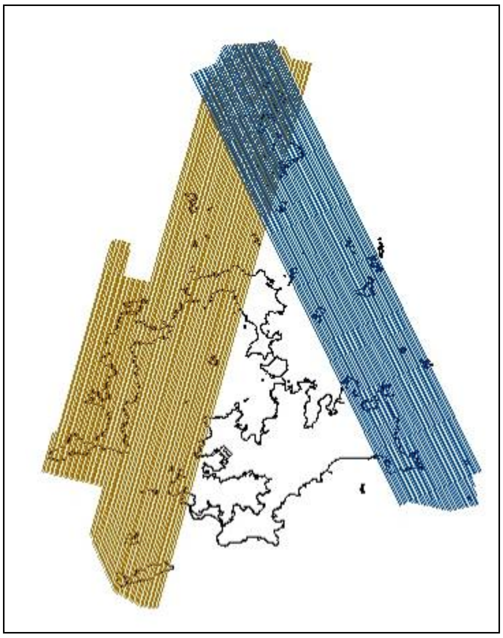


Figure 6：Planned flight lines of Penghu

Table 1：Survey parameters of Penghu

Spot spacing	3.5×3.5 m
Flight altitude	400 m
Survey speed	150 knots
Swath width	160 m
Sidelap	20%
Survey area	415 km^2
Total flight lines	118
Fly hour	19hr (from Magong Airport)

The survey of Dongsha will include the complete atoll and extend out to 50m water depth or laser extinction, whichever comes first. Survey area and planned flight lines are shown in Figure 7. Dongsha Airport is used as the base of operations for the survey of Dongsha Atoll. A temporary base of operations for processing and validating the data were also located on Dongsha.

The point density for both areas is about 3.5x3.5 m. But, an area of 20 square kilometers located in the east portion of the atoll is also surveyed with 2x2 m resolution at lower flying height. Survey parameters of Dongsha are shown in Table 2.

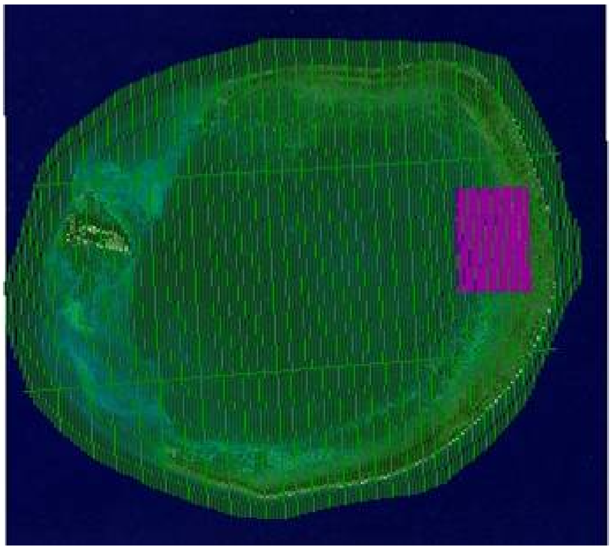


Figure 7：Planned Flight Lines of Dongsha

Table 2：Survey parameters of Dongsha

Spot spacing	3.5×3.5 m	2×2 m
Flight altitude	400 m	300 m
Survey speed	150 knots	150 knots
Swath width	160 m	120 m
Area	506 km^2	20 km^2
Total flight lines	183	35
Fly hour	22 hr	6 hr

3. Data Acquisition

The HawkEye II system arrived Taiwan in August, 2010. Two calibration flight were conducted, one in the beginning and one by the end of this surveying. The surveying flight lines are shown in Figure 8, and 9. In Dongsha, the flight lines were oriented to a north-south direction for minimizing the effects of sun glint. The survey area is about 500 square kilometers for Dongsha, and about 415 square kilometers for Penghu.

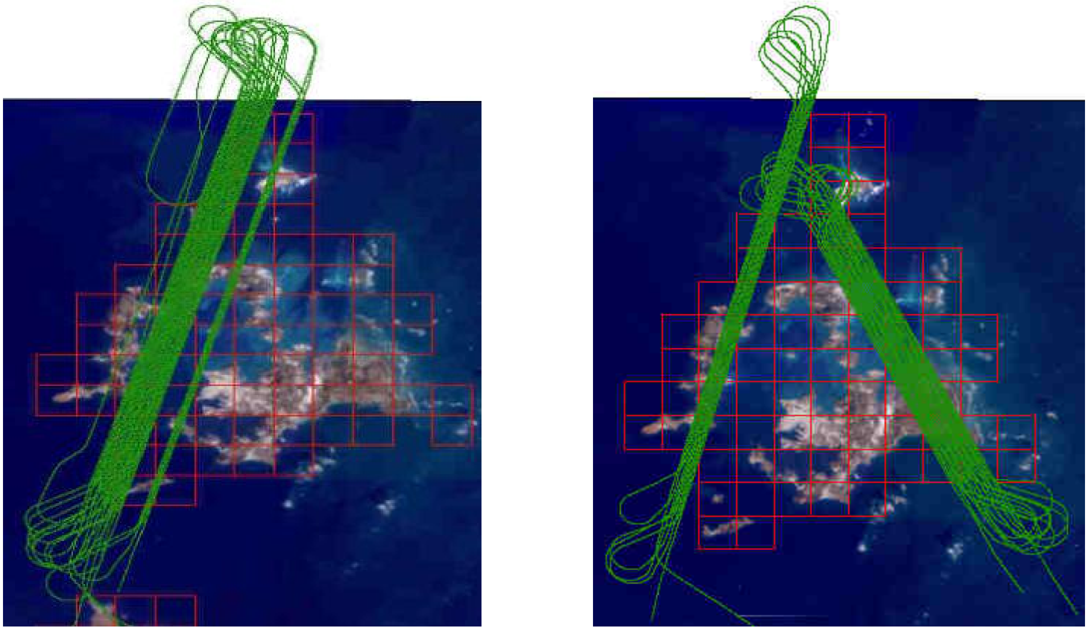


Figure 8: Penghu Flight Lines

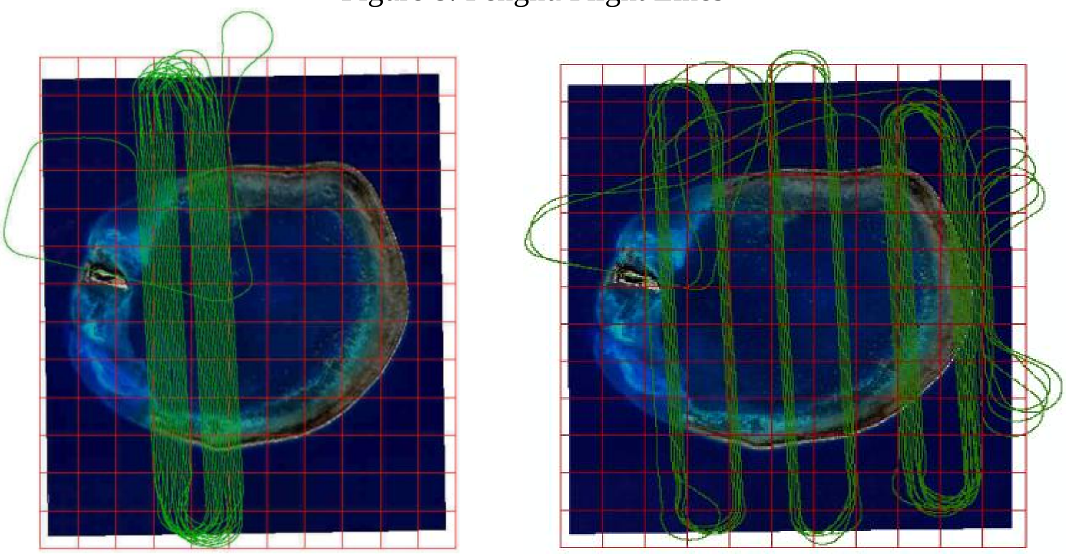


Figure 9: Dongsha Flight Lines

4. Data Processing and Validation

During the period of data acquisition, on site data processing is conducted in Kaohsiung and Dongsha temporary base. The data analyst solved and reviews the lidar point clouds and then made decisions of re-fly or adjust the flight plan depending on the situation. The data post-processing and validation is held in National Chiao Tung University's laboratory.

4.1 Calibration and Position processing

The first part of calibration is the internal calibration of the unit itself and is carried out in the manufacturer's laboratory. This calibration allows for errors within the HawkEye unit itself, which include the laser alignment, internal scanner angle, latency between components, etc. The second part is conducted and verified in the field and is concerned with errors in orientation, particularly between the inertial motion sensor and the center of the scanning mirror.

Boresight calibration area is located in western Penghu, as shown in Figure 10. The survey area is about 0.5km^2 of flat ground and about 2.2km line over sea.

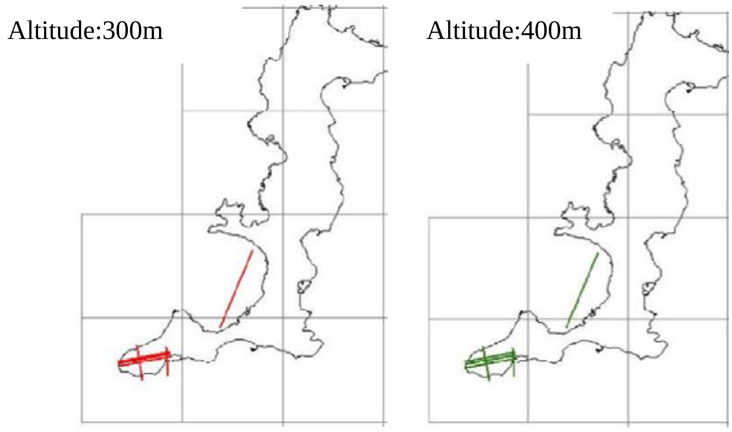


Figure 10：Calibration Flight lines

There are four existing GPS base stations in Penghu (Figure 11). CIME, WIAN, HUSI and JIBE are e-GPS tracking stations owned by National Land Surveying and Mapping Center, Ministry of Interior. Two additional stations, 4921 and 6407, are set up temporarily for this project. The sampling rate of these stations is all 1Hz.

In Dongsha, there is one existing station, TNSM, set up by Ministry of Interior. Two GPS stations, MNPH-01 and MNPH-08, are set up temporarily for this project. Top view of three GPS stations is shown in Figure 12.

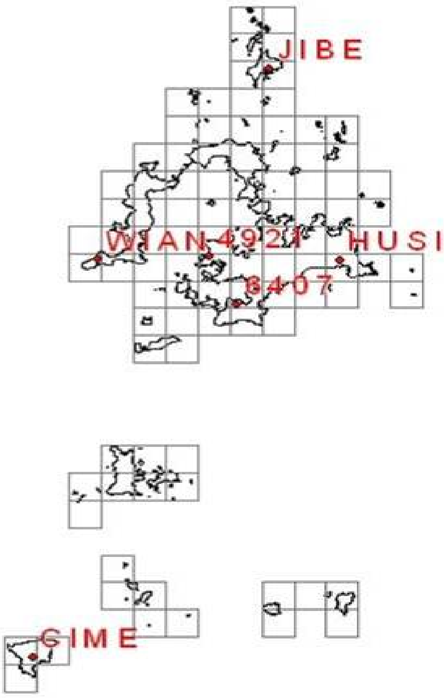


Figure 11：GPS Base Stations of Penghu Figure 12：GPS Base Stations of Dongsha

The first step of data post processing is combing the GPS base stations, GPS data of aircraft and IMU data and then solving the track with POSpac MMS5 software. The following step is merging data from GNSS, inertial, laser bathymetry and laser topography LIDAR data collections with AHAB Coastal Survey Studio (CSS) to solve for the point cloud with full waveform by each flight. The procedure is shown in Figure 13.

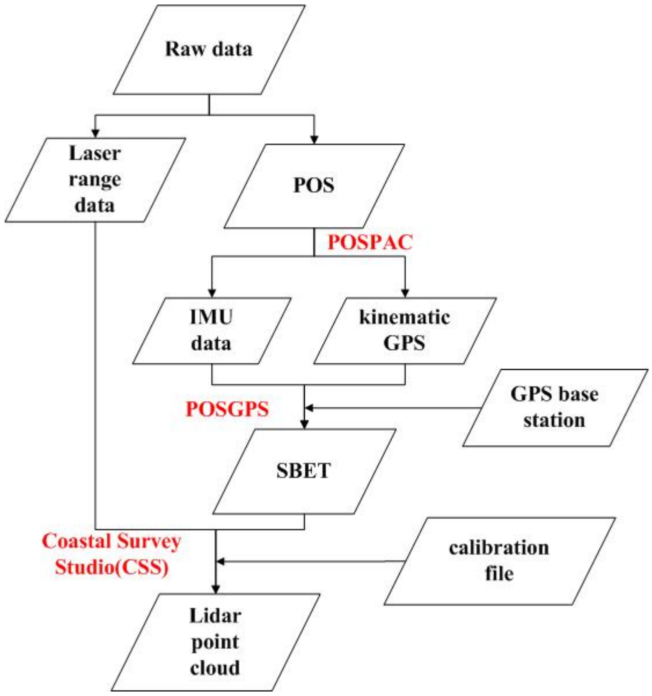


Figure 13：Data Processing Flow

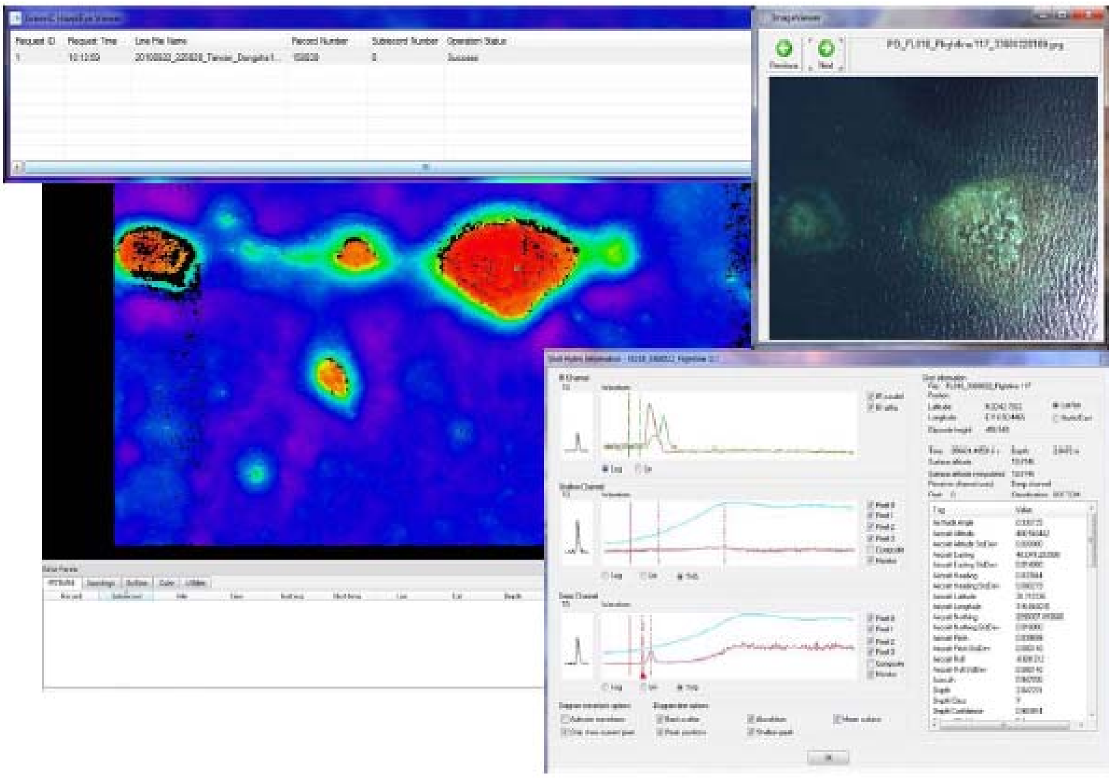


Figure 14：Data editing with GreenC HawkEye Viewer

4.2 Data editing

Data is processed with AHAB's Coastal Survey Studio (CSS, Isaksson, 2009), IVS Fledermaus (IVS3D, 2009) and GreenC (GDS, 2010) software packages. CSS processing uses the position and orientation information, along with the lidar return and waveform information to compute 3D positions of each data point in ellipsoid height. The data points is then reviewed and cleaned in Fledermaus while viewing the associated waveform and digital camera imagery with GreenC HawkEye Viewer (Figure 14).

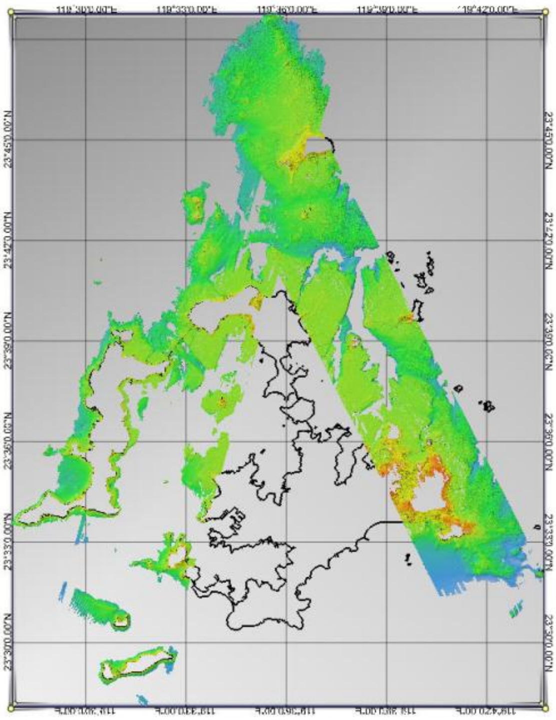


Figure 15：Lidar Coverage in Penghu

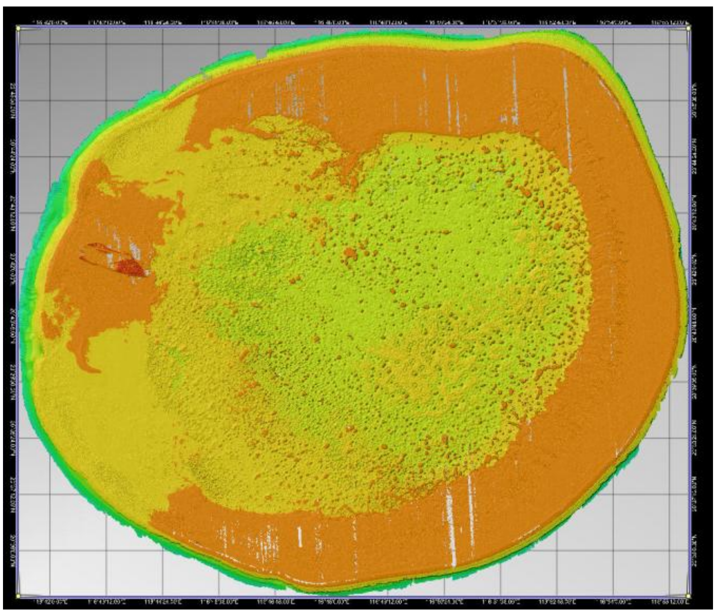


Figure 16：Lidar Coverage in Dongsha

4.3 Result

All the measurements are produced in ellipsoid height system. The coverage is shown in Figure 15, 16 respectively for Penghu and Dongsha. While the Penghu data set is heavily influenced by the water turbidity induced by typhoon, the limitation of current bathymetric lidar system in very shallow area and the sun glint, caused some data gap in Dongsha.

4.4 Internal accuracy assessment

The internal accuracy assessment is conducted with the overlap and cross lines to the survey lines. Crosscheck in Fledermaus applied for generating the difference statistics for comparing survey line data with a reference set of data. Several cross lines were flown in Penghu and Dongsha as shown in Figure 17. The intersection angle between the normal lines and cross lines are about 60º in Penghu and 90 º in Dongsha. A sample of the overlap from the parallel and cross lines is shown in Figure 18.

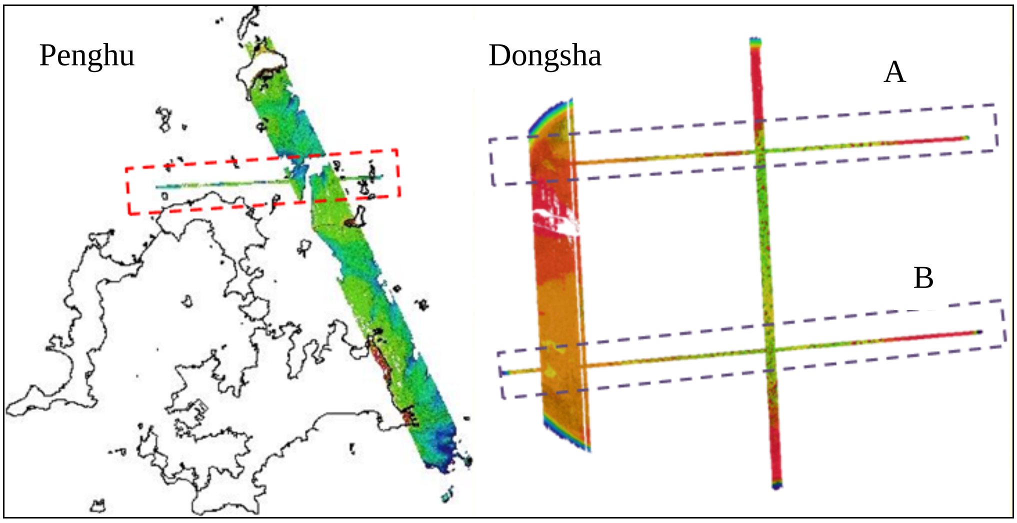


Figure 17：Cross Lines in Penghu and Dongsha

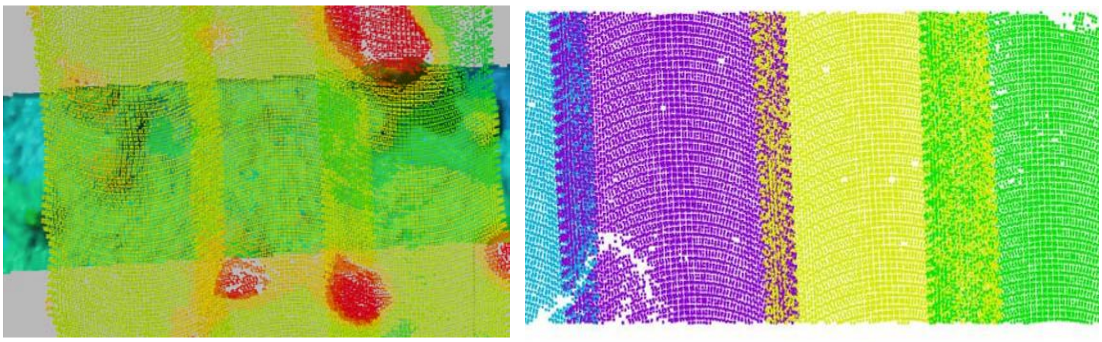


Figure 18：Overlap from Cross Line (left) and Parallel Line (right)

4.5 Sonar validation survey

Both the multibeam and single beam echo sounders were used for validation survey. Due to the navigation condition in Dongsha Atoll, only single beam system was used in that area. The instruments used in the single beam sonar survey are shown in the Table 3. The spacing between the survey lines are about 40m, and the interval of cross lines is 1km in Penghu and 500m in Dongsha for internal accuracy check. In order to be sure that the sonar surveyed area is overlapped with the lidar surveyed area, sonar survey was conducted after the lidar survey. Due to the delay of the aerial survey, the sonar survey was heavily influenced by the seasonal windy weather. A part of the Sonar survey in Dongsha is shown in Figure 19. Along the sonar line, more details of the terrain can be revealed due to the higher spatial resolution, as shown in Figure 20.

Table 3：The instruments of sonar survey

Name	Type/Accuracy	Photo
GPS system	Leica GPS System 500 Vertical accuracy：±5mm+1ppm	
	Trimble 5700 system Vertical accuracy：±5mm +2ppm	
Bathymetric survey	ODOM Hydrotrac echo sounder Depth accuracy：0.01m±0.1% depth The range of echo sounder：0~200m	
	TSS-320B heave compensator Measure range：±10m accuracy：>5cm RMS	

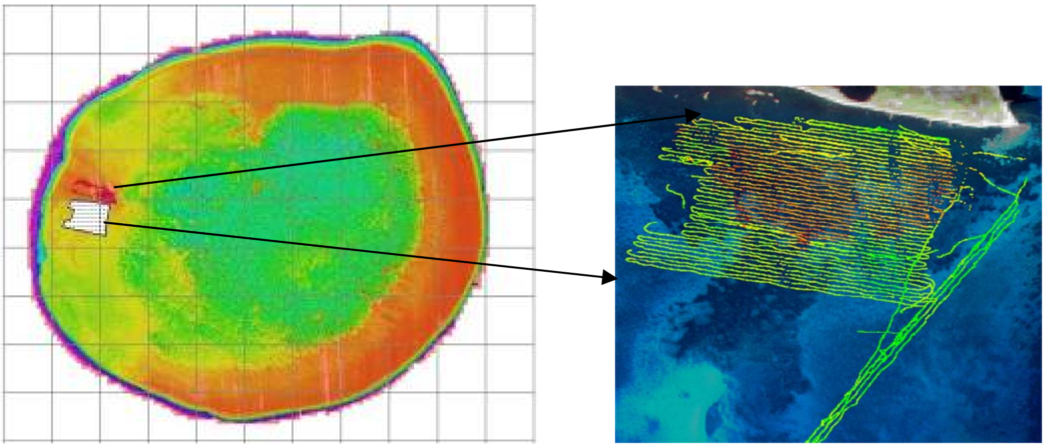


Figure 19：Sonar Survey Area of Dongsha

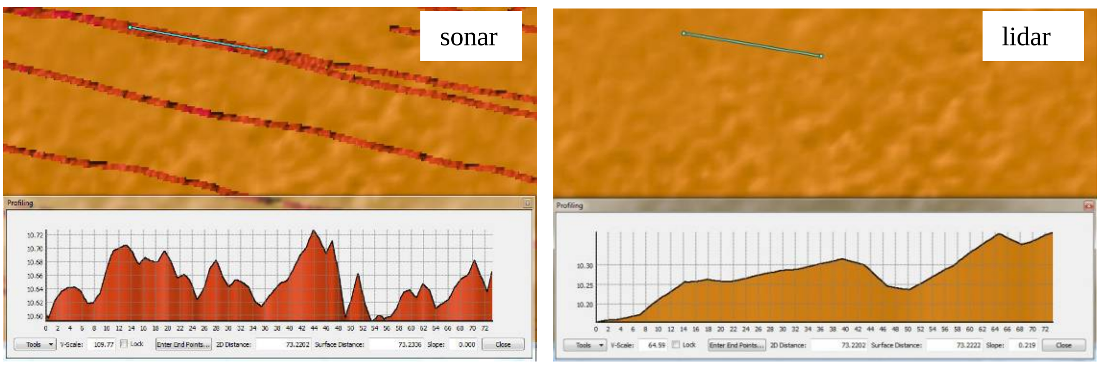


Figure 20: A Sample Profile

5. Discussion

Although the data validation is not finalized yet, the preliminary assessment shows fairly promising result. Flying schedule is constrained by ambient conditions, such as weather, water quality, flying conditions and ATC flying permissions. In this project, thanks to the fully support and cooperation of all involved parties, the result is very good in Dongsha. But the qualities of Penghu data are not as good as Dongsha because of two typhoons passing by. Overall, Bathymetric lidar provided an efficient alternative to sonar for mapping and monitoring shallow water coral reef ecosystems.

Acknowledgment

The authors are deeply indebted to Coast Guard Administration, particularly Dongsha Headquarter, Marine National Park Headquarter, Air Force, Civilian Aviation Authority, Daily Air, Naval Meteorological and Oceanographic Office, and many others. Without their generous support, this mission would be impossible. The authors also wish to express their sincere gratitude to Miss Almudena Perez-Gonzalez, Mr. Jonas Gunnarsson, and Mr. Sean Maguire, for their great contribution to the survey.

References

MNPH, 2010, Dongsha Atoll, Marine National Park Headquarters, http://marine.cpami.gov.tw/chinese/index.php?option=com_content&view=article&id=80&Itemid=47, last accessed：2011-03-12.

GDS, 2010. GreenC Solutions User Manual, Geomatics Data Solutions.

Isaksson, A., 2009, Coastal Survey Studio Mark II Manual Version 2.X, Airborne Hydrography AB.

IVS3D, 2009. Fledermaus Reference Manual, Version 7, Interactive Visualization Systems Inc.

Henrik, K., 2006. HawkEye II Technical Description, Airborne Hydrography AB.