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1 author:

Rozaimi Che Hasan
UNIVERSITI TEKNOLOGI MALAYSIA

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Rozaimi Che Hasan

UTM Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia (UTM), Jalan Semarak 54100 Kuala Lumpur, Malaysia,
rozaimi.kl@utm.my

Abstract. Coral reef plays important role for marine biodiversity of our coastal areas. The need of spatial knowledge and extents of these habitats is a fundamental step in assessing the impacts of anthropogenic activities and establishing marine protected areas for conservation purposes. In Malaysia, coral reefs are mostly found along the coastal and shallow water regions includes Pulau Langkawi (northern part of Peninsular Malaysia) where these areas are known to attract tourists and contribute to the economic incomes to the locals. The study here presented analysis from two types of acoustic sonar data collected at Northern region of Pulau Langkawi, Malaysia namely; (1) acoustic data from RoxAnn echosounder, and (2) acoustic image from side scan sonar, to identify and predict coral reef habitats. In this study, both acoustic data were acquired simultaneously from a single survey vessel and therefore permits two types of analysis; (1) comparison of two dataset, and (2) combination of data, for remote acoustic habitat classification. First, habitat map was produced using RoxAnn classification which utilised the information from the first echo return (E1) and second echo return (E2). Additionally, depth data was also produced from the RoxAnn to be used for further analysis and classification. Secondly, in-house software was developed to process raw data from side scan sonar and to generate image of the seafloor (mosaic). Finally, supervised classification was performed using all dataset (E1, E2, depth and mosaic) to generate coral reef habitat map. The results showed that both the RoxAnn and side scan sonar described different acoustic information from seabed types. All these dataset were then useful to generate map of coral reef spatial distribution using supervised classification technique. Furthermore, coral reef habitats found to have high backscatter intensity shown in the mosaic - agreed with the classification results from the RoxAnn system. Combination of dataset from multiple acoustic sources is seen to be useful in identifying and mapping coral reef habitats at the study area where this could minimise manual and other conventional methods.

1. Introduction

Knowledge of coral reef is essential as it plays significant roles for our marine ecosystem. Coral reef supports diverse marine species including fish and provides food and shelter to other marine flora and fauna species [1]. The declining of coral reef habitats due to anthropogenic activities has call for urgent protection [2]. In Malaysia, detail information of coral reef distribution and their extents are still not completely available due to the difficulties and huge cost in gathering complete information of the seafloor habitats. A proper technique and approach is then needed to systematically acquire and predict the distribution of coral reefs without heavily depending on conventional methods (i.e. divers) where it is normally time consuming and costly.

Satellite remote sensing and underwater acoustic approaches are the two most common techniques applied to identify and map coral reef. Although satellite remote sensing technique could provide large coverage, high turbidity of water especially on the west coast of the Peninsular Malaysia has limits its full capability (i.e. failed to penetrate to seabed surface). By contrast, acoustic methods such as multibeam sonar, side scan sonar and single beam echo-sounder are some of the systems that could be utilised without having this limitation [3]. Additionally, most of these acoustic sensors not only produce depth data, but also seafloor reflectance level (i.e. intensity) from seabed surface which can be an important proxy to discriminate different seabed habitats such as for remote detection of coral reef [4, 5].

The main goal of this study is to analyse acoustic signal from two systems (single beam echosounder and side scan sonar) that could potentially be used to produce spatially explicit map of coral reef. This paper presented initial results and analysis from acoustic survey campaign in Malaysia coastal water. Firstly, dataset from both systems were process and analysed independently. Then, results from both dataset were combined to construct map of coral reef.

2. Methods

2.1. Data collection

This study was carried out at northern region of Peninsular Malaysia, located at Tanjung Rhu, Langkawi on 18th, 19th and 29th of June 2013 (Figure 1). The study site included three small islands (Pulau Gasing, Pulau Pasir dan Pulau Dangli) with areas of 2.25 km^2. For the single beam echosounder system, a RoxAnn GD-X unit was used to acquire seabed data. Positioning was completed using a GPS receiver (WGS84 datum) and all data were recorded into a computer. Apart from depth information, RoxAnn system has the built-in acoustic seabed classification process that is capable to characterise types of seabed. The classification system in RoxAnn utilised first echo (E1) and second echo (E2) returns as parameters to distinguish between seabed types. To use the classification feature, RoxAnn system needs to be calibrated prior to the actual survey. This prior information is similar as training data used for supervised classification. Classification process were using these two variables (E1 - roughness and E2 - hardness) from the calibrated data to predict new set of data observed. To achieve this, two main classes were used; reef and non-reef. The reef and non-reef classes were identified using a mini underwater video camera and using these calibration values, classification can be made to the entire measurements during the survey operation.

A side scan sonar Imagenex Model 872 YellowFin was used to investigate seabed types by providing image of the seafloor (mosaic). The side scan sonar used frequency of 330 kHz with transducer beam widths of 1.8° (along track) and 60° (across track). Positioning was also achieved using a GPS receiver (separately with RoxAnn system) linked to the data acquisition software. eXtended Triton Format (XTF) [6] raw data was generated from the side scan sonar data for further processing and analyses.

2.2. Data processing

Depth data from RoxAnn was processed and reduced with sea level variations using the tide data observed at the nearest tidal station. All RoxAnn data was exported into ASCII data consisted of E1, E2, predicted class, depth and their locations (latitudes and longitudes). As the data from RoxAnn (E1, E2 and depth) were sparse, the author applied spatial interpolation to these variables to generate full coverage dataset. This process was achieved using Matlab programming software and was finally exported to ESRI ASCII raster grid image (5m pixel size).

To process side scan sonar data, the author have developed in-house software (UTMSonarProcess) in Matlab. The software is capable to process data recorded from side scan sonar in XTF file format to produce raster image (ESRI ASCII raster grid). First, UTMSonarProcess convert the raw XTF data into Matlab format. This will extract important information especially the amplitude data (port and starboard sides) and also the GPS location for each ping. Two XTF data packets were extracted; XTFPINGHEADER (time and GPS locations) and XTFPINGCHANHEADER (slant range, number of sample and amplitude data). Next step involved with smoothing the GPS data to exclude any blunders with navigation data. The geographic positions were then projected into a plane system in Universal Transverse Mercator (UTM) format (UTM Zone 47 North).

By using the heading information in XTFPINGHEADER and the slant range in XTFPINGCHANHEADER packets, position were computed for all amplitude samples (assuming flat seafloor). Backscatter intensity returns, I (measured in decibels (dB)) which describe the seabed roughness and hardness, was then derived using the amplitude and gain value (in XTFPINGCHANHEADER) using Equation (1) as follows;

$$I = 20 \text{ x } \log_{10} (\text{amplitude}) - \text{gain} \qquad (1)$$

For compatibility with RoxAnn dataset, the pixel resolution of the side scan mosaic was also set to 5m. The mosaic was then exported to the ESRI ASCII grid format for further analysis particularly to be combined with RoxAnn dataset. A correlation measure using Pearson's linear correlation coefficient (R^2) were applied to quantity relationship between different acoustic products.

2.3. Classification

For classification, a well-known classification technique, Maximum Likelihood Classifier (MLC) was applied to produce coral reef habitat map. MLC is a parametric supervised classification approach that has been widely used in many remote sensing applications. For each class obtained from training data, it computes mean and covariance matrices and assumes that the probability density function is a normal Gaussian distribution. Unknown sample data will be classified to the class that has the highest membership probability. Since the ground data was limited in this study (i.e., the ground data was only used for RoxAnn calibration), the predicted classes from the RoxAnn acoustic seabed classification was used as the training data for the classifier. These data were then randomly separated into 50% for model development and 50% for the validation process.

Figure 1. Study site at North of Langkawi Island, Peninsular Malaysia (not to scale). The site included three small islands from left (Pulau Dangli, Pulau Gasing and Pulau Pasir).

3. Results and discussion

Acoustic seabed classification using RoxAnn single beam echo sounder was able to predict coral reef locations (Figure 2). The distributions of the reef classes were mainly found closed to these islands (i.e. surrounding) rather that off the islands. However, full coverage of coral reef map was not achievable as the RoxAnn data was very sparse. By contrast, the mosaic produced from the side scan sonar was able to generate almost 100% acoustic coverage, although no information was available about the seabed types. However, the mosaic was useful in explaining the spatial distribution of the coral reef. Surprisingly, there were some agreements between the distributions of coral reef predicted using RoxAnn with the intensity levels produced from the mosaic. These classes were predicted where the mosaic was having high backscatter intensity values (e.g. areas around the three islands) and less at the areas with low intensity levels (i.e. middle part of the study area). There were possibilities that hard surfaces from the hard coral habitats had increased the scattering levels and finally produced unique pattern in the side scan mosaic. Lower intensity levels were predominantly related to the soft seabed surface such as fine sand and mud. The characteristics of these seabed surfaces will have huge potential to be incorporated into acoustic classification that could be useful to remotely identify seabed habitats.

In terms of correlation between datasets, all the RoxAnn products have high correlation coefficient between each other (Table 1). As E1, E2 and depth were highly correlated (correlation coefficient=1), there will be possibility that these dataset might presenting similar information for seabed classification. By contrast, mosaic was less correlated with E1, E2 and depths, meaning that side scan sonar and RoxAnn captured and presented different seabed information. This suggests that both system can be used together to extract different seabed characteristics which will be very useful for the classification process.

Applying supervised classification (mosaic, E1, E2 and depth) using RoxAnn predicted class (50% separated sample as the training data) achieved 85% accuracy. Almost 70% of the reef class was predicted and mapped around or close to the three islands. This distribution agreed with the spatial location of reef class for RoxAnn as well as the mosaic from the side scan sonar (i.e. areas with high backscatter intensity levels). The advantage of this technique is the ability of constructing full coverage coral reef map as compared to the sparse classification results from the RoxAnn system (Figure 2b). This demonstrates how two acoustic systems could be combined to improve the detection of coral reef at shallow water. Even though the map was produced using a basic classification technique (i.e. MLC), there is potential that the dataset could be used with more advanced prediction technique such as machine learning which will be the focus of the author's future research.

In this study, both acoustic sensors were deployed simultaneously with the advantage of reducing time and cost during data acquisition. However, designing survey line and spacing needs to be done properly as it will determine final product. For example, survey line for single beam echosounder cannot be too large because it will affect the results of the interpolation to generate full coverage of E1, E2 and depth – large separate point will produce poor interpolation. At the same time, for the side scan sonar, increasing slant range (large separation of survey line) will increase the coverage. To satisfy an optimise data gathered from both acoustic sensors, the survey line was set at every 50m and the results shown that for this distance, it was sufficient to perform spatial interpolation (i.e. RoxAnn dataset) as well as to maximise the side scan sonar coverage.

Table 1. Correlation coefficient (R^2) between mosaic, E1, E2 and depth.

	Mosaic	E1	E2	Depth
Mosaic	1	0.00597	0.005969	0.006027
E1	0.00597	1	1	0.999998
E2	0.005969	1	1	0.999998
Depth	0.006027	0.999998	0.999998	1

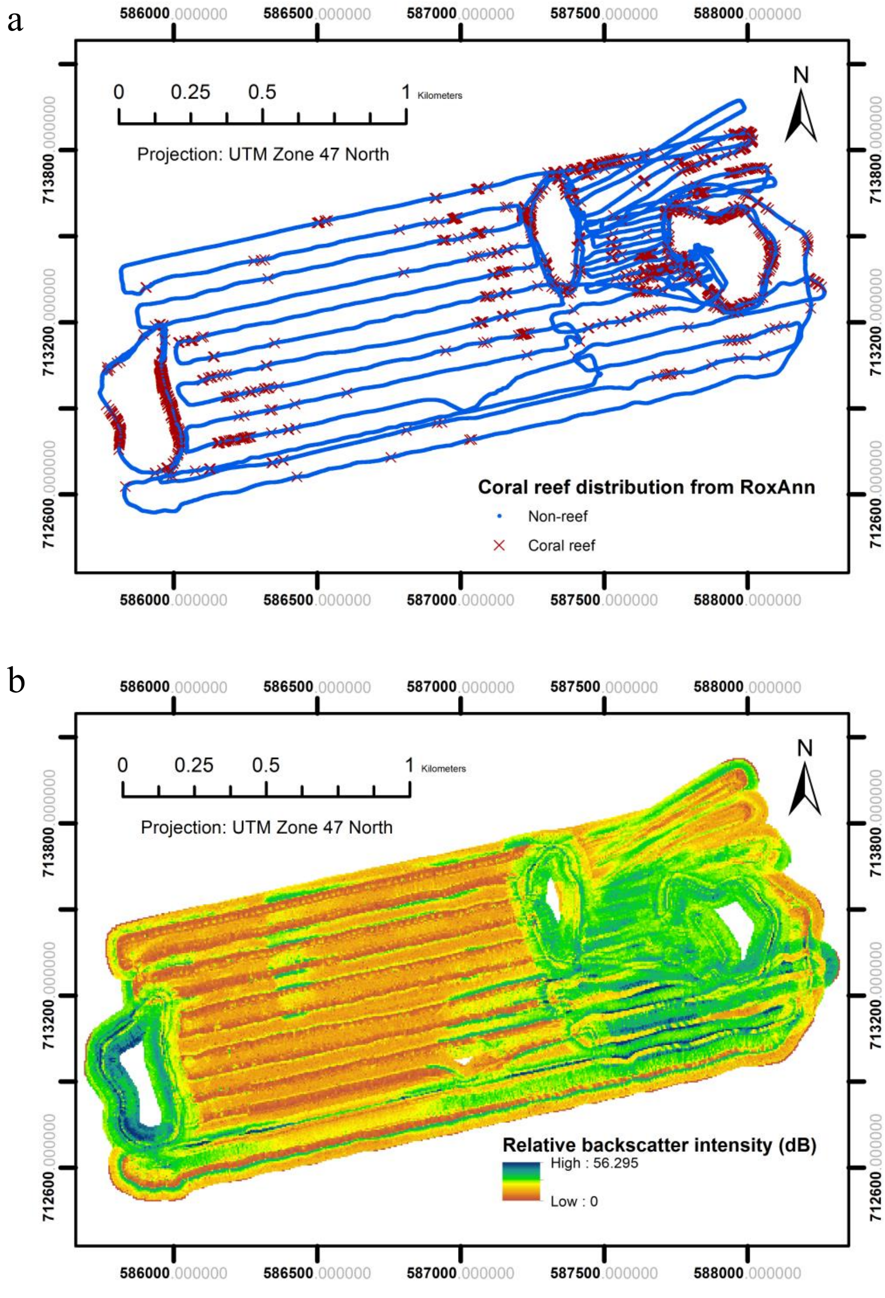

Figure 2. Results from RoxAnn seabed classification (Figure 2a) and mosaic of side scan sonar (Figure 2b). Two classes are used for RoxAnn system (Reef and Non Reef) where values in the mosaic are based on relative backscatter intensity (dB).

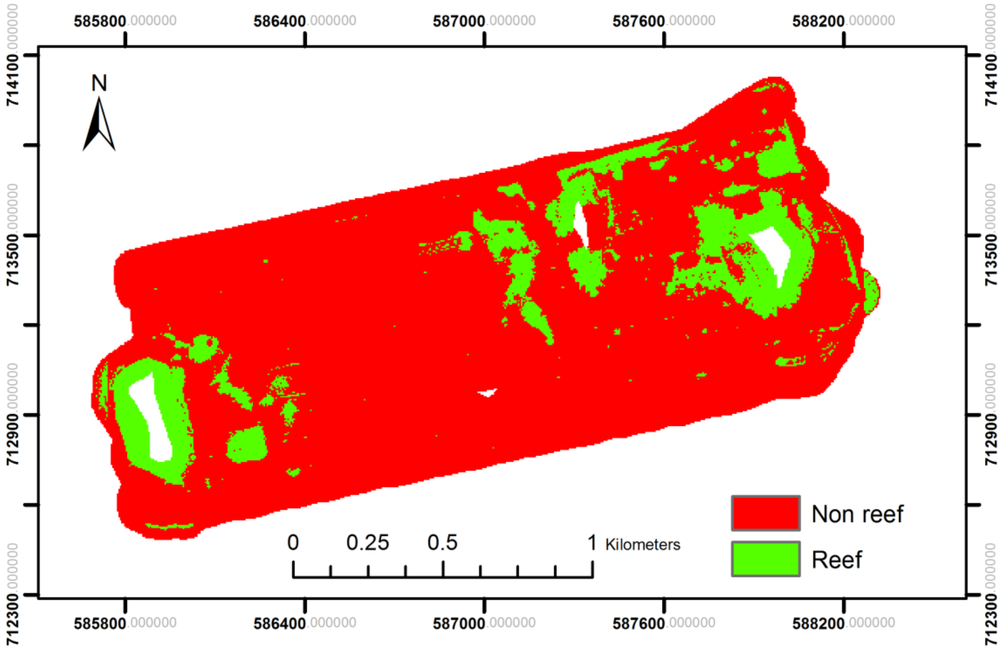

Figure 3. Coral reef map derived from supervised classification of E1, E2, depth and mosaic from the side scan sonar

4. Conclusion

Identification of marine habitats is vital for related agencies and policy makers to protect marine flora and fauna from man-made activities. Mapping these habitats via underwater acoustic is seen as one of the approaches that could provide important baseline information for the conservation strategy, monitoring and planning. This study demonstrates the effectiveness of combining data from multiple acoustic sonars for the purpose of seabed habitat identification particularly mapping the coral reef distributions. Although producing sparse dataset, the author demonstrated how combination of RoxAnn single beam acoustic classification with mosaic from side scan sonar is capable to produce a full coverage coral reef map. In-house software developed to process the side scan sonar data has shown that it is sufficient to generate image of the seafloor (i.e. mosaic) where it could then be further applied in a classification process.

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