

Mapping Coral Reefs of Phi Phi Island Using Remote Sensing and GIS for Integrated Coastal Zone Management

Sarawut Ninsawat and Nitin Kumar Tripathi

Space Technology Application and Research Program (STAR) and
Integrated Tropical Coastal Zone Management Program
Asian Institute of Technology
P.O. Box 4, Khlong Luang, Pathumthani 12120, Thailand
Tel: 66-2-524 6392, Fax: 66-2-524 5597
Email: nitinkt@ait.ac.th; st018536@ait.ac.th

Abstract

The Coral reefs in Thailand are important as attractive tourist place because of the variety of coral. This research is aimed at developing the approach of using fused image of high spatial resolution and multispectral, Panchromatic and LISS III sensor of IRS-1D, for making coral habitat map. The mixing habitat could be better distinguished through high resolution 5.8 m. Study of benthic features with higher precision, ground survey for training area is required and only a limited number of areas can be investigated. Therefore, it seems necessary to take advantage of the increasing number of sites surveyed by the monitoring organizations (ReefCheck, GCRMN etc.) for a fruitful exchange. Water column correction is used to eliminate the influence of the depth before supervised classification using ten classes from multivariate classification of field survey for training area. The result of classification, is the habitat type image, is then identified in term of quality of coral reef. The rule for identification habitat zone map use the ratio of percentage cover of live coral and dead coral followed by the standard rule of Coral reef maps in Thai water made by Phuket Marine Biological Center (PMBC). In the study area, four zones of the reef habitat, except in "Good zone" and "Damaged zone", are explored from the remote sensing data processing techniques and modeling.

Keywords: Coral reefs, Image Fusion

Introduction

Coral reefs are considered to be the oceanic equivalent of the tropical rainforest in term of their biodiversity, complexity and net primary production. Interconnected coastal ecosystems composed of coral reefs and mangroves, seagrass beds, beaches, estuaries and marine water have historically been the basis for subsistence, security and culture of local people throughout the developing world. (Kenchington, 1985). From a remote sensing point of view, coral reef boundaries are probably the easiest of these to map. The next level of challenge is to distinguish the condition

zones of the reef (e.g. Damaged reef zone, Good quality reef zone). For management purposes, such information may be used in a similar manner to that of 'coral reef zone maps'.

Integrated coastal zone management (ICZM) has been proposed as a comprehensive, interdisciplinary and adaptive approach for addressing complex issues concerning the conservation and sustainable development of coastal resources. It encompasses dynamic processes related to planning, assessment, community participation, co-management and evaluation. Such decision-making approaches must reflect the complex and interconnected dynamics of coastal ecosystems. Islands are inherently coastal environments and, as such, require a high degree of integrated coastal management (Cicin-Sain, 1993).

We are most interested to identify zone of healthy and non-healthy coral reefs of Phi Phi Island. We are most interested in the spectral distinction between healthy and dead coral. Coral's health can be measured in a number of ways. Brown and Howard (1985) reviewed seven accepted measures of coral health: 1) growth rate; 2) metabolism; 3) biochemistry; 4) reproduction; 5) behavioral response; 6) disease; or 7) loss of zooxanthellae. The loss of zooxanthellae appears to be the only remotely detectable measure of coral health, as it results in a distinct loss of color and therefore change in spectral reflectance (Holden and LeDrew, 1998). Incorporated with GIS, these enhanced maps of coral reefs are powerful visual tools for display and communication and can be readily understood by coastal zone planners and the general public alike.

The ecosystem of coral reefs is known as the most complex and diverse ecosystem. Thus, the mixing of habitat always happens with the view of remote sensing. The potential of high spatial resolution multispectral images Landsat 7 ETM+, SPOT 5, IRS-1D for coral reef mapping is now quite well understood. There is convergence in the accuracy achieved when mapping broad classes of bottom type in coral reef environments

using these sensors. Since the launched of IRS-1D, which improved panchromatic spatial resolution of around 5 m. As a result, it is very interesting to use the spatial resolution at 5.8 m. for mapping coral reef, which are the most complex and diverse ecosystem. In this study, the approach of merged LISS-III and PAN sensor, the payload of Indian Remote Sensing satellite IRS-1D, was evaluated for coral reef mapping considering cost-factor. Fortunately, with the benefit of both of sensor are more compatible than Landsat TM/SPOT PAN, the merged image can reduce the effect of radiometric error from the image fusion process. And both of IRS-1D sensors are already corrected by basic geometric correction with path orientated.

Field survey is essential to identify the habitats present in a study area, to record the locations of habitats for multispectral image classification (i.e. creation of habitat maps) and to obtain independent reference data to test the accuracy of resulting habitat maps. Ground survey technique for training area based on image pixel size is required and only a limited number of areas can be investigated. Therefore, it seems necessary to take advantage of the increasing number of sites surveyed by the monitoring organizations (ReefCheck, GCRMN etc.) for a fruitful exchange. This study adjusts the standard method of ReefCheck organization, which is used by volunteer around the world, for the purpose of remote sensing of coral reef.

One problem with remotely sensed measurements is that the atmospheric path between object and sensor but the special problem when trying to derive quantitative information about underwater habitats is the confounding influence of variable depth on bottom reflectance (Ahmad and Neil, 1994). Water column correction algorithm has been employed to enhance the image (Green *et al.*, 2000; Mumby *et al.*, 1998; Siregar *et al.*, 1995; Moritorena, 1996). This algorithm has not been widely adopted in terms of mapping shallow water (Mumby *et al.*, 1998). This algorithm is based on an axes rotation to calculate a parameter that is not depth dependent. Any variation perpendicular to the principal depth variation is assumed to be due to differing bottom cover types.

Method

The field data was collected around Phi Phi islands on April 2002. The mapping objective focuses on major habitat types (health and non-health coral were separated, then the survey methods should be simple, quick and able to cover large areas. These techniques are probably best suited to most satellite remote sensing operations. The survey technique is based on image pixel size and condition of SCUBA diving that was used for underwater field survey. For this study, the pixel

size of PAN image is 5.8 m but if field survey is performed once station for represent one pixel, it will use so much time for an adequate number of sites and with the safety reason of SCUBA diving, diver should avoid to change pressure often that will interfere the blood system. Thus, The technique is base on an 11.5 m length and record data every 0.5 m. One field survey station will be used to represent two pixels (Panchromatic pixel size is 5.8 m). Three field workers operate for each station. One filed worker sets the line for survey, another is the data recorder and the third swims on the water surface to record location by GPS with waterproof pack. In this study, we adjusted the standard method of ReefCheck organization, which is used by volunteer around the world, for the purpose of remote sensing of coral reef. This method assesses the benthic community of coral reefs; only the type of reef category is noted at equidistant points along the line (every 0.5 m). Four living biotic features and seven substrata types were record as shown in Table 1. Additional data were also recorded during field survey such as location, depth and water visibility. The cover of each category is calculated by the ratio of number of points per category to the total number of points.

Living biotic feature	Substrata
Live hard corals	Coral rock
Live soft corals	Dead coral
Macro algae	Sand
Sponge	Silt/Clay
	Rock
	Rubble
	Other

Table 1: Types of living biotic feature and substrata.

The statistical analysis was performed with field data. In this study, cluster analysis was used for classify habitat type. The similarity (or dissimilarity) between each pair of sites can be determined using a similarity coefficient. The square euclidean distance used as a dissimilarity coefficient, this is probably the most commonly chosen type of distance. It simply is the geometric distance in the multidimensional space. The joining or tree clustering method uses the dissimilarities or distance between objects when forming the clusters called Hierarchical classification. In this study, the rule for joining each cluster use Ward's method. In short, this method attempts to minimize the sum of square (SS) of any two clusters that can be formed at each step (Ward, 1963).

The percentage cover of coral reef state and substratum is calculated to integrate the same cover type after classified by habitat type. Three main cover types are composed of (1) live coral, (2) dead coral and (3) substratum. Each cover type is calculated by the summation of the percentage cover of habitat type in each group as shown in table 2. The percentage cover of coral reef state and substratum are interpreted to make reef habitat zone map that give the information about the quality of coral reef in that area. First, the substratum area, which has percentage cover of substratum more than 75, was extracted from the all set. Then, the reef habitat zone map is identified by the ratio of live coral and dead coral of rest area. The rule for identification is based on the coral reef map of Thailand made by PMBC for ICZM purpose as shown in table 3.

Coral state and substratum type	Habitat type in each group
Live Coral	HC, SC
Dead Coral	DC, CR
Substratum	RK, RB, SD and SI

where

HC = Hard coral RK = Rock
 SC = Soft coral RB = Rubble
 DC = Dead coral SD = Sand
 CR = Coral rock SI = Silt

Table 2. The habitat type belonged to each coral state and substratum cover type.

Ratio of % live coral and % dead coral	Zone
≥ 3:1	Very good
2:1	Good
1:1	Moderate
1:2	Damaged zone
1: ≥3	High damaged

Table 3. Criteria for reef habitat zone map.

Both LISS-III and PAN images were geometrically corrected and the effects of variable depth were removed using method of Lyzenga (1981). This algorithm is based on an axes rotation to calculate a parameter that is not depth dependent. Any variation perpendicular to the principal depth variation is assumed to be due to differing bottom cover types. The ratio of attenuation coefficients was derive from image itself by series of groups of pixels were selected from the imagery that had the same bottom type but different depths (approximately 122 pixels). Areas of submerged sand are good because they are fairly recognizable to an interpreter without much field experience. Blue and green of LISS-III sensor were selected for water column correction because good penetration of water that should be visible band.

Merging information from different image sensors involves two distinct steps (Chavez and Bowell, 1988). First, the digital images from both sensors are geometrically registered to one another. Next, the information contents -spatial and spectral- are mixed to generate a single data set that contains the best of both sets. First, the LISS-III data are digitally enlarged by a factor of four in both directions to generate a pixel size similar to the PAN data. These results are smoothed with a 3 by 3 low-pass filter to eliminate the blockiness introduced by the digital enlargement (Chavez *et al.*, 1984; Chavez, 1986). Next, control points of both image are interactively selected to register the LISS-III data onto the PAN data (that is, the LISS-III was the slave and the PAN image was the master). In this study the method used to merge the information contents of both data sets were the Intensity-Hue-Saturation (IHS) method.

Masking for interested area is very useful and necessary. Terrestrial area and deep-water area were masked to increase the accuracy of classification. A combination of image processing and manual digitizing were used to make a mask band. And then the supervised classification was performed with fused image and water column corrected band from LISS-III image. Mahalanobis distance classifier used ninety-eight points of classified field data from multivariate classification and ancillary information for training area. The result of image classification is in raster format that will be transformed to vector shape file format for data input of a GIS.

Results and Discussion

Subsequently, the multivariate classification, Cluster analysis, of field data was performed. The objective of the cluster analysis is to determine which objects are similar and dissimilar and categorize them accordingly. The result of cluster analysis showed that type of habitat could be reduced to ten classes. The final grouping of clusters, also called the final partition, is the grouping of clusters, which will, hopefully, identify groups whose members share common characteristics. Therefore, the spectral resolution of satellite sensor could be discriminated by characteristic of each class. After classify field data, the class characteristic was determined by the average of the percentage cover of living biotic type and substrata. The percentage cover of coral reef state and substratum was calculated to integrate the same cover type after classified by habitat type. Three main cover types are composed of (1) live coral, (2) dead coral and (3) substratum.

In this study, we emphasized on coral health. Therefore, the name of habitat will derive from the habitat characteristic of field data not include geomorphologic information for labeling. Based on clustering analysis, the field data was classify into ten

habitats. Four habitats are classified to substratum type, because the percentage cover of non-living biotic feature is more than 75. The following is the characteristic of habitat type in this study.

Due to the water column correction was performed for LISS-III image data, which composed of two visible bands and two near infrared bands. The pair of spectral band should be visible band which penetration of water better than near infrared band. Therefore, band 2 (Green) and band 3 (Red) were selected to calculate coefficient attenuation between both bands. Exponential attenuation of radiance with depth linearised for bands 2 and 3 using natural logarithms. Figure 1 shows the plot of transformed band 2 against transformed band 3 for a sand substratum at various depths, which correlation coefficient of both bands is very high ($r = 0.91401$). Base on 122 pixels of sand but difference depth from field survey. The calculation coefficient attenuation of band 2 and band 3 gave a value 0.917. Subsequently, the new image, which is independent of the depth, was generated.

$$\text{DIV index} = \ln(L_2 - L_{s2}) - (0.917 \times \ln(L_3 - L_{s3})) \text{ Eq. 1}$$

where

L_2, L_3 are the pixels radiance in band 2 and 3,

L_{s2}, L_{s3} are the average radiance for deep water in band 2 and 3,

To combine the information contained in high spatial resolution IRS-1D PAN and multispectral LISS-III data, fusion methods have to be used to benefit from both. Ideally, the method used to merge data sets with high spatial resolution and multispectral should not distort the spectral characteristics of the multispectral data. Not distorting the spectral characteristics of the data is important for calibration purposes and for ensuring that targets that are spectrally separable in the original data are still separable in the merged data set. A basic assumption was used by this method that the PAN data was very similar to the first principal component data. The correlation coefficient between the PAN data and the intensity band was quite high ($r = 0.872$). Therefore, the PAN data can replace the intensity band in the retransformation of the data back into the original image space. Figure 2 shows the resulting fused image of PAN and LISS-III image data that become multispectral, composed of three bands, and high spatial resolution data (5.8 m.), which gave more detail than original LISS III image data at same area as shown in Figure 3.

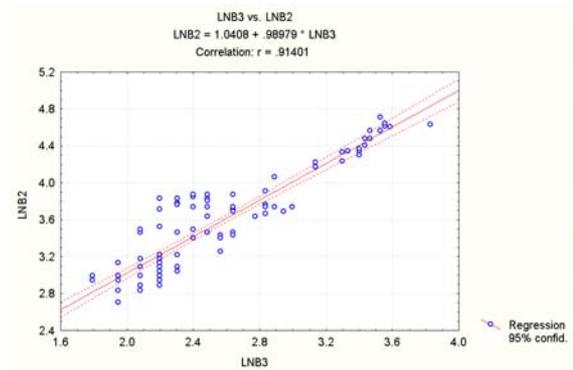


Figure 1: Bi plot of logarithm of band 2 and 3 for a sand substratum.

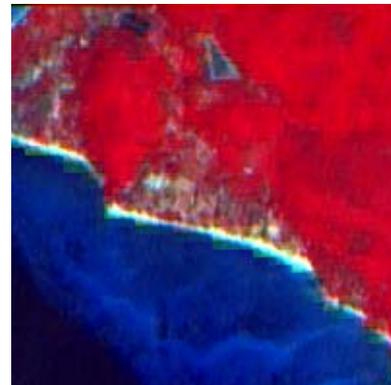


Figure 2: Fused image of PAN and LISS-III image with IHS fusion method (resolution 5.8 m.).

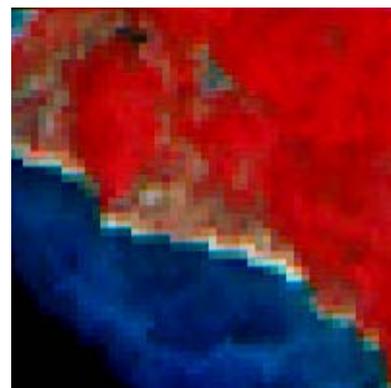


Figure 3 LISS-III image data (resolution 23.5 m.).

In order to evaluate quality of the classified image was used kappa coefficient method. It is a measure of agreement between the classified image and referenced data. In this case, sixty points of field survey data were used for the independence reference data. Except habitat 10, substrata silt zone was not used for accuracy, because of unavailable of field data for accuracy assessment. Accuracy of the classified image using the error matrix is given in Table 6. An overall accuracy of

76.67 % was determined by dividing the total number of correctly classified spectra (the sum of the count along the major diagonal) by the total number of spectra considered in this study $[10+4+4+5+4+4+5+6+4)/60=46/60=0.7667]$. The producer’s accuracy for each group can be found along the bottom of the matrix, and the user’s accuracy can be found along the right side of the matrix. In addition, Kappa coefficient also was calculated by the error matrix. A Khat value of 0.7348 was achieved in this study. A value of 0.7348 would imply that the classification process was avoiding 73.48 percentages of the errors that a completely random classification would generate.

Lot of factors might have contributed to this such as the delay in the time of ground truthing and the time when the satellite image was taken, and the water column correction algorithm may not remove the effects of water attenuation completely. However, this overall accuracy of classification is quite high. Therefore, the habitat type image could be accepted assess and monitor coral reef ecosystem.

The GIS is not only a normal digital map, but also has efficient of data base management that will useful for further analysis. The database from multivariate classification of field data could add to each class. Therefore, the analyses of percentage cover of live coral, dead coral and substratum was used to generate the reef habitat zone map by the ratio of live coral and dead coral. However, the substratum could be extracted from the all set before calculated that ratio. The rule for identification is based on the coral reef map of Thailand made by PMBC for ICZM purpose. Although the rule to generate the reef habitat zone map have many standard but it should easy to understand for all people not only the people who work with Coastal zone management, but also the people who interesting in this marvelous ecosystem such as the tourist, SCUBA diver. In the

study area, four zones of the reef habitat, except in “Good zone” and “Damaged zone”, were explored from this identification.

Conclusions

Both LISS-III and Panchromatic sensor were fused together to generate multispectral and high spatial resolution image data. Through the high spatial resolution image, the mixing habitat could be more distinguished. The image processing technique for water column correction was performed because of water column influence. The spectral radiances recorded by a sensor are therefore dependent both on the reflectance of the substrata and on depth. These two influences on the signal will create considerable confusion when attempting to use visual inspection or multispectral classification to map habitats. The result of water column correction generated depth invariant index of band 2 and band 3 with the rationale that both of bands are visible band the water penetration is more than Infrared band. The depth invariant index was independent of depth.

This study adjusts the standard method of Reef Check organization, which is used by volunteer around the world, for the purpose of remote sensing of coral reef. Therefore, the advantage of the increasing number of sites surveyed from the fruitful exchange of data could be taken. Some adjustment was done to match methodology and satellite sensor. Also for the reason of safety in SCUBA diving was one important thing to design the survey method. An 11.5 m. line transect was used to represent two pixels of PAN data for training area. Subsequently, the cluster analysis was performed with field data to generate ten classes. Attributes in each class were performed to make class label.

Class	%HC	%SC	%DC	%FS	%SP	%CR	%RK	%RB	%SD	%SI	%OT	Total
1	33	3	8	0	0	2	0	15	39	0	0	100
2	14	11	48	0	0	17	0	4	6	0	0	100
3	93	0	1	0	0	1	0	3	1	0	0	100
4	0	0	43	0	0	0	0	3	53	0	0	100
5	13	6	5	0	0	10	0	45	21	0	0	100
6	23	0	0	0	0	65	0	6	6	0	0	100
7	0	0	1	0	0	4	0	2	93	0	0	100
8	0	0	0	0	0	1	0	99	0	0	0	100
9	0	0	0	0	0	0	96	0	4	0	0	100
10	0	0	0	0	0	0	0	0	0	100	0	100

Table 4: Classes from the classification of field data.

Class	%Live coral	%Dead coral	%Substratum
1	36	10	54
2	25	65	10
3	93	3	4
4	0	43	57
5	20	15	65
6	23	65	13
7	0	5	95
8	0	1	99
9	0	0	100
10	0	0	100

Table 5: The percentage cover of live coral, dead coral and substratum in each habitat type.

Classification using the fused image and depth invariant index based on classified field data and some ancillary information were used for mahalanobis classifier. This generated habitat type image without any unclassified pixel. The overall accuracy assessment with sixty points of independent reference field data was 0.7667, Khat value of 0.7348 was achieved in this study, which indicated that the habitats types identified in this study are reliable. However, the misclassification in the deep water and steep slope area still are the problem of this study. The rationale that the overall accuracy was quite high because of data for accuracy assessment around that area was very less.

In this study, remote sensing data products were integrated with field information in GIS for analysis and application. The result of classification was exported to GIS for further analysis. The reef habitat zone map was prepared using the ratio of percentage cover of live coral and dead coral to generate the quality zone of coral reef around that area. The rule to generate the quality zone depends on the standard rule of Coral reef maps in Thai water made by PMBC. The four zones were found in this study area, except “Good zone” and “Damaged zone”. The distribution of live coral, dead coral and substratum area were also displayed using five ranges of percentage cover.

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