# Developing a method to grasp coral reefs through remote sensing technology

by
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## Abstract

Due to the effects of land reclamation for harbors, etc. and development activities such as sea route dredging, as well as the global influence of an increase in the seawater temperature, etc., coastal coral reef sea areas around the world are exposed to risks such as bleaching and coral disappearance, which may be accompanied by a damaging effect on the diverse living things inhabiting the coral reef, the fisheries industry, sightseeing and the disaster prevention functions of the coral reef. For Madreporaria alone, which is the main reef-building coral, there are 839 species on the IUCN red list. For that reason, in the case that development activities are conducted in coral reef sea areas, it is important to evaluate the impact, and to consider avoidance, minimization and corrective measures with regard to the impact. Here, using two types of remote sensing technology, a means of accurately understanding the coral distribution in coral reef sea areas will be introduced. The first is (1) a technology for understanding coral distribution using high resolution multispectral satellite imagery, and the other is (2) a technology for performing a 3D analysis of coral reef and understanding coral distribution using underwater video footage. (1) is able to accurately understand and analyze wide-area coral distribution and coverage in coral reef sea areas at a scale of tens of $km^2$. (2) is able to specifically understand and analyze the terrain of coral reef in an area extending approximately ten meters in every direction, and the distribution of individual corals and seaweed. As an example, we will report the results taken from Okinotorishima in Japan. Okinotorishima is a shallow island measuring approximately 4.5km east-to-west, 1.7km north-to-south and with a depth of less than 10m. For the understanding of coral distribution from the satellite imagery in (1), it was possible to analyze the coral distribution and coverage with 80% classification accuracy as a result of obtaining satellite imagery of the entire island and applying coral coverage guidance data based on image clustering and field surveys. By obtaining satellite imagery for several years and conducting the same analysis, we were able to understand the change in the coverage area over the years. For the underwater video footage analysis in (2), video footage was taken of knolls in the coral reef in an area extending ten or more meters in every direction, and we were able to make a three-dimensional understanding of the coral distribution using a 3D analysis. Also, as a result of classifying the coral in a part of this area, classification accuracy of 80% or more was obtained. These technologies can be considered as useful tools to quantitatively understand the influence of development activities such as sea route dredging and the effects of prevention measures such as coral transplanting.

***Keyword:*** multispectral high resolution satellite imagery, underwater photography, coral reef, coral classification

## 1. Method

### 1.1 Satellite imagery coral classification process

In this study, high resolution satellite imagery IKONOS GeoEye-1 (resolution of 0.5m) was used in the multispectral satellite imagery. The years of photography were 2006, 2011, 2012 and 2017, which are recent years in which there is little noise due to clouds and high waves, etc.

The flow of coral coverage analysis using satellite imagery is shown in Figure 1.

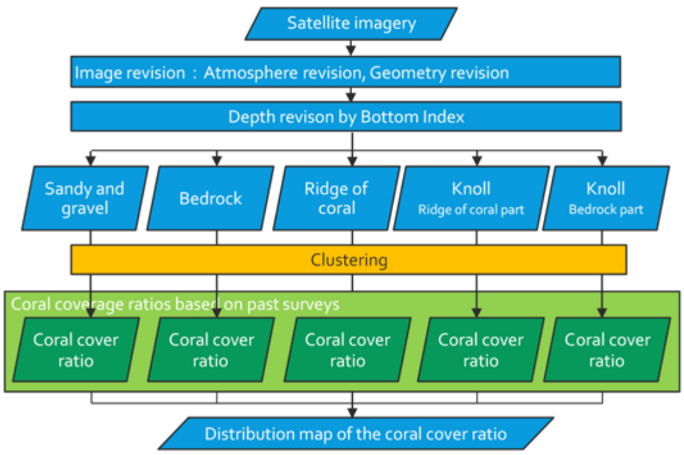


Figure1 Satellite imagery coral classification flow

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First, for pre-processing of the satellite imagery, atmospheric correction using dark pixel subtraction and geometric correction using geographic coordinates as reference points were performed. Then, the bottom index was calculated, and the calculated bottom index image was overlapped with the satellite imagery to divide the image into individual bottom quality divisions using existing bottom quality divisions. Unsupervised classification (clustering) was performed on the image after sectioning off the bottom quality divisions. A coral coverage distribution map for each class after classification was produced by applying the coral coverage after overlapping the existing coral study results with the 2006 satellite imagery taken at the same time. Regarding the satellite imagery classification results from other years (2011, 2012 and 2018), the coverage was automatically applied using the relationship between the image data from each class according to the 2006 analysis results and the coral coverage.

### 1.2 3D analysis and coral distribution analysis process using underwater video

The flow of the investigation and analysis is shown in Figure 2. In the field survey, divers took underwater video footage in the survey target area. In this study, the photographs were overlapped in order to prevent any gaps in the images of the knolls in Okinotorishima in an area extending about ten meters in every direction. Two types of photography processing were performed, namely, mosaic-type and orthographic-type using 3D imaging. The mosaic type forms a plane figure for the entire survey target area by pasting together the characteristic points of the overlapping images in the divided background images. 3D image processing forms a 3D shape using SfM (structure from motion). Then, from the produced 3D model, an orthographic projection is made on any surface to produce an orthographic image. Finally, for the automatic classification of coral, coral distribution is confirmed using object base classification. In this study, there were 2 classifications (coral and non-coral) and 7 classifications (branch-like coral, other coral, dead coral, seaweed, bedrock, giant clam and other).

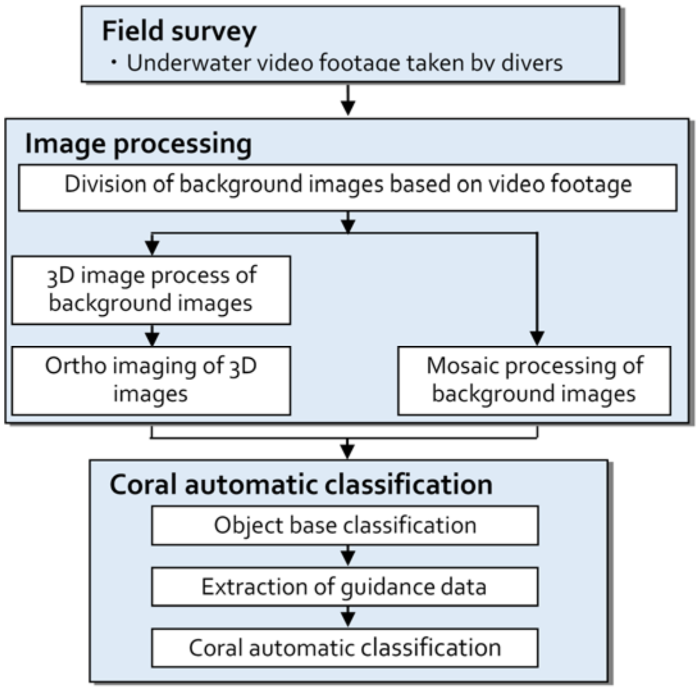


Figure 2 Underwater video footage analysis

## 2. Results and Discussion

### 2.1 Satellite imagery coral classification results

The coral coverage distribution map and the transition in coral area calculated therefrom are shown in Figure 3. Based on this analysis, in the approximately 11 years between 2006 and 2017, it was confirmed that the coral area reduced by roughly half.

A verification of the accuracy of the multispectral satellite imagery analysis was performed using the results of the analysis of 2012 satellite imagery and the 2013 to 2014 field survey results. The image classification accuracy verification results are shown in Figure 4, Figure 5, Figure 6 and Table 1.

As for the accuracy of the coral coverage analysis results based on satellite imagery in contrast with field verification data, the accuracy in an RMSE (root mean square error) evaluation was approximately ±3%, and the overall accuracy was 80% with a Kappa coefficient of 0.7 (substantial).

The cost of performing the coral distribution analysis was, in the case of an analysis area of 10km$^2$, approximately 20,000 dollars for coral classification by satellite imagery, whereas the cost in order to obtain the same accuracy from a visual inspection performed by divers is calculated to be 200,000 dollars, so an understanding can be gained with about 1/10th of the cost.

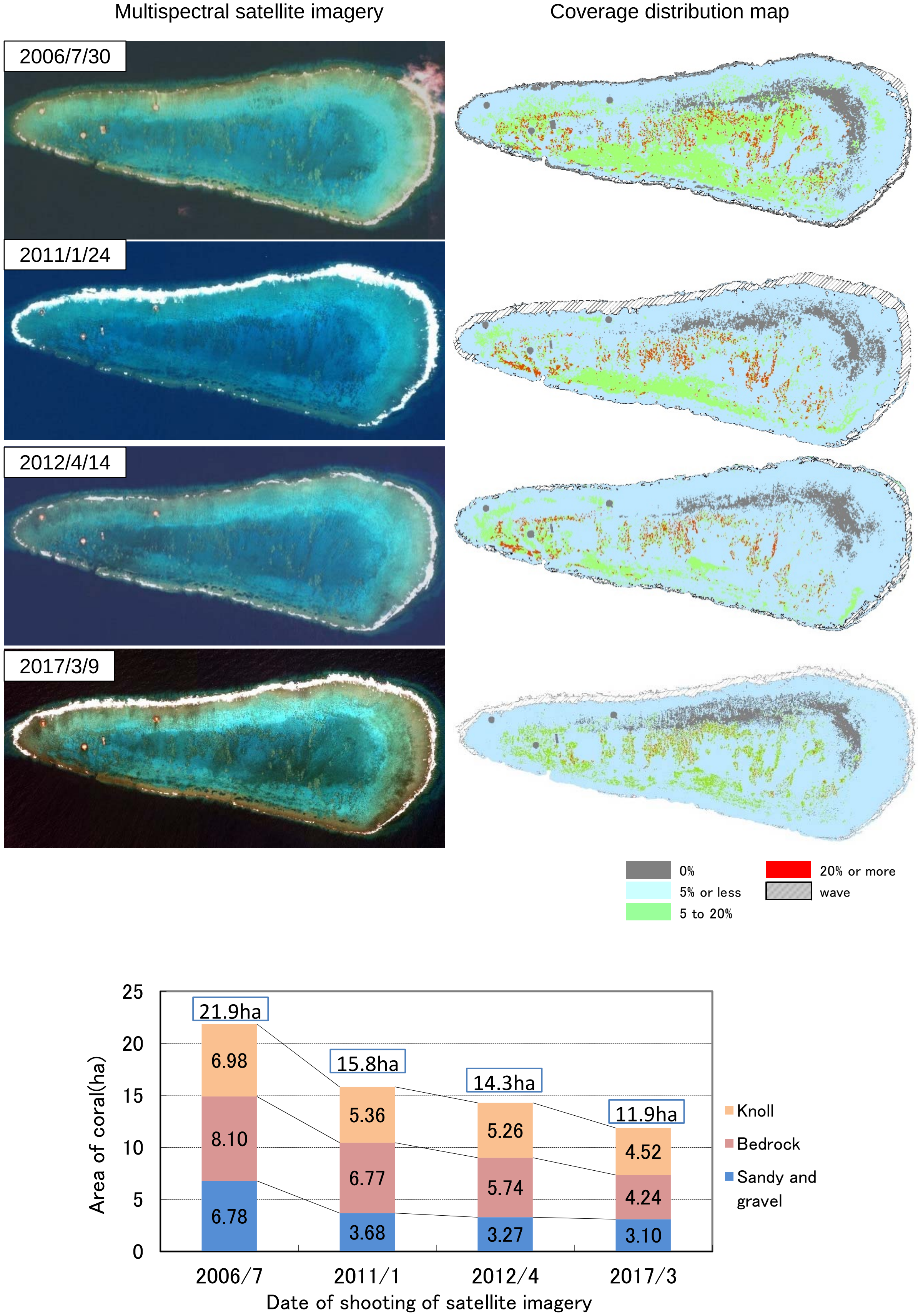


Figure 3 Coral coverage analysis results (example of Okinotorishima)

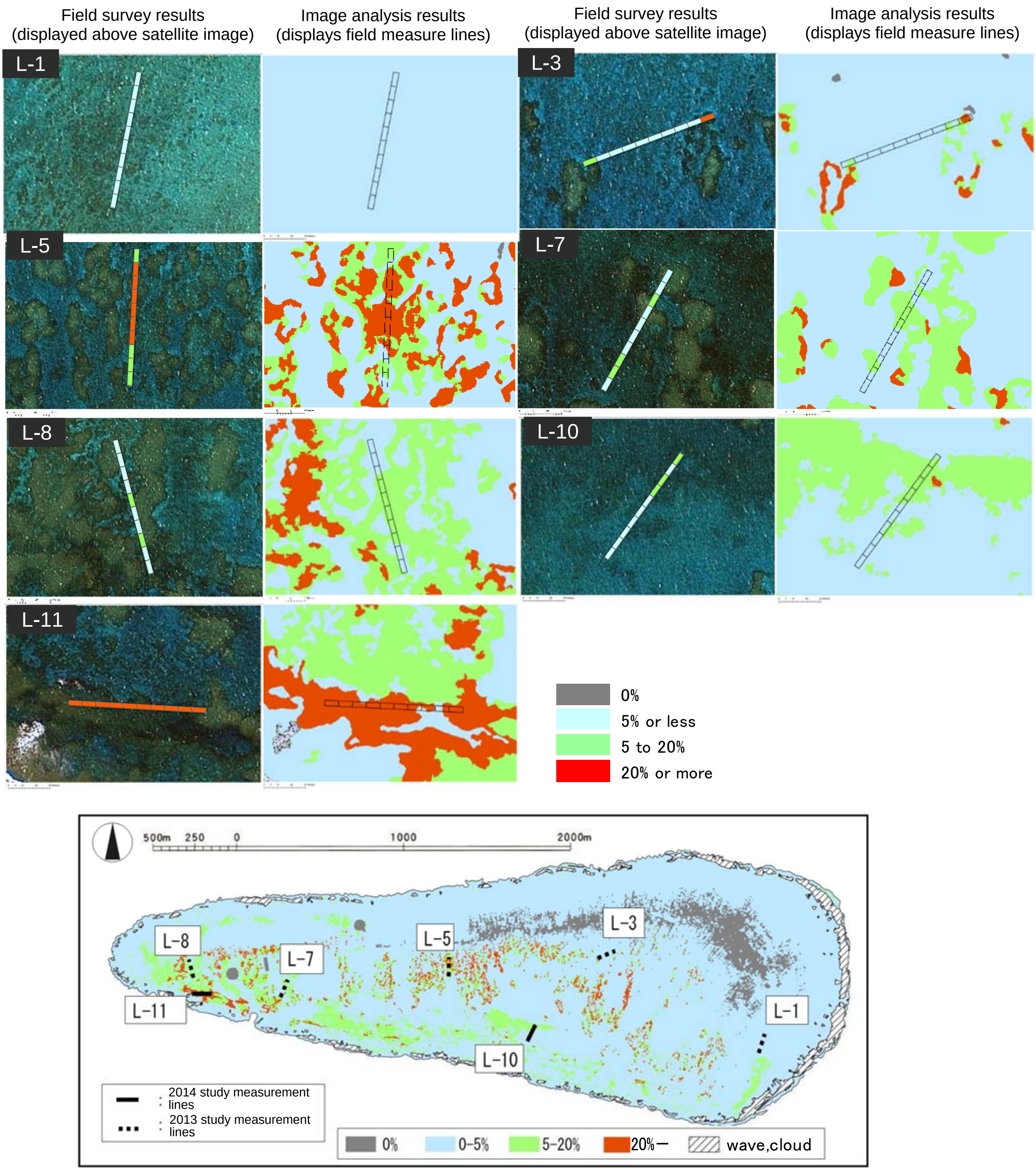


Figure 4 Coral coverage field survey results and comparison with satellite imagery analysis results
(Field survey: 2013 and 2014; Satellite image: 2012)

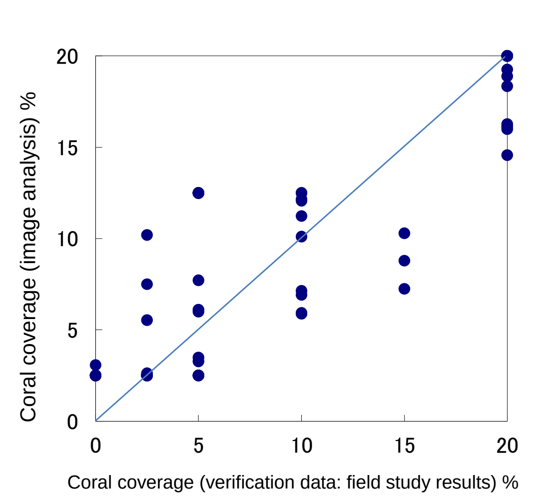


Figure 5 Comparison between coral coverage verification data and image analysis results (2012 satellite imagery, 2013/2014 field surveys)

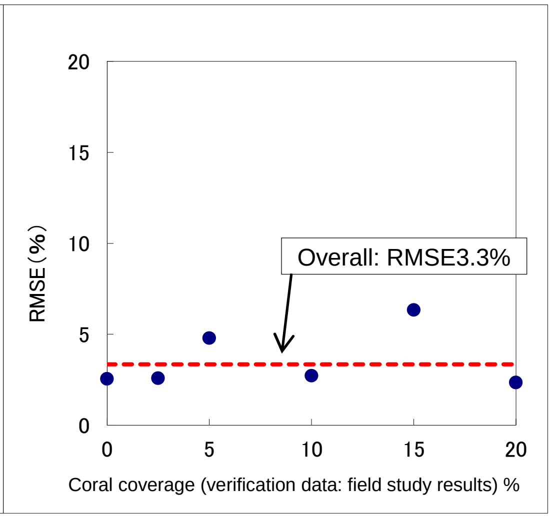


Figure 6 Calculation errors in image analysis results (RMSE) (2012 satellite imagery, 2013/2014 field surveys)

*1. Coral coverage based on image analysis shows the total value (average) of the coverage information in all images (40 images) in a 4m x 10m observation area.

*2. Coral coverage based on a field survey and image analysis is the data needed to show the scope of the change. For that reason, in order to calculate errors in the analysis, a comparison and error calculation is performed after setting an integer value for the coverage, as shown below.
Coverage of 1% or less⇒0%, 1 to 5% or less⇒2.5%, 5 to 20%⇒12.5%, 20% or more⇒20%

Table 1 Classification accuracy verification results
(2012 satellite imagery, 2013/2014 field surveys)

| Overall accuracy | Kappa coefficient |
|---|---|
| 80% | 0.7 (substantial) |

### 2.2 Results of 3D analysis and coral distribution analysis using underwater video

Figure 7 shows examples of coral coverage classifications after performing a 3D analysis of underwater video filmed in Okinotorishima. As the Figure shows, by performing a 3D analysis, it is possible to understand the classification of coral in specific parts of knolls, as well as their size and distribution. Next, a coral classification analysis of the image was performed by making it an ortho image. The results of verifying the interpretation accuracy of these images are shown in Table 2 and Figure 8. In the case of using 2 classifications, for both the mosaic image and the ortho image, an accuracy of 80% or more for automatic coral classification was obtained. On the other hand, when using 7 classifications, the accuracy of automatic coral classification with the ortho image was 40-60%, so issues were seen in terms of practicality. The causes of incorrect classifications are unclear images, and misunderstanding dead corals and scarce corals, etc.

Therefore, from now on, it is considered to be important to give attention to acquiring images that facilitate classification by means of closeup photography and the use of lighting when photographing shaded areas, for example. Furthermore, it is considered to be important that the cost of analysis is reduced by creating a model to obtain the same analysis accuracy from multiple images rather than analyzing each image, as we did in this study.

The cost of coral distribution analysis, in that case that the scope of analysis covers 1ha, the cost of coral classification analysis using underwater video is approximately 11,000 dollars, whereas the cost in order to obtain the same accuracy from a visual inspection performed by divers is calculated to be 110,000 dollars, so an understanding can be gained with about 1/10th of the cost.

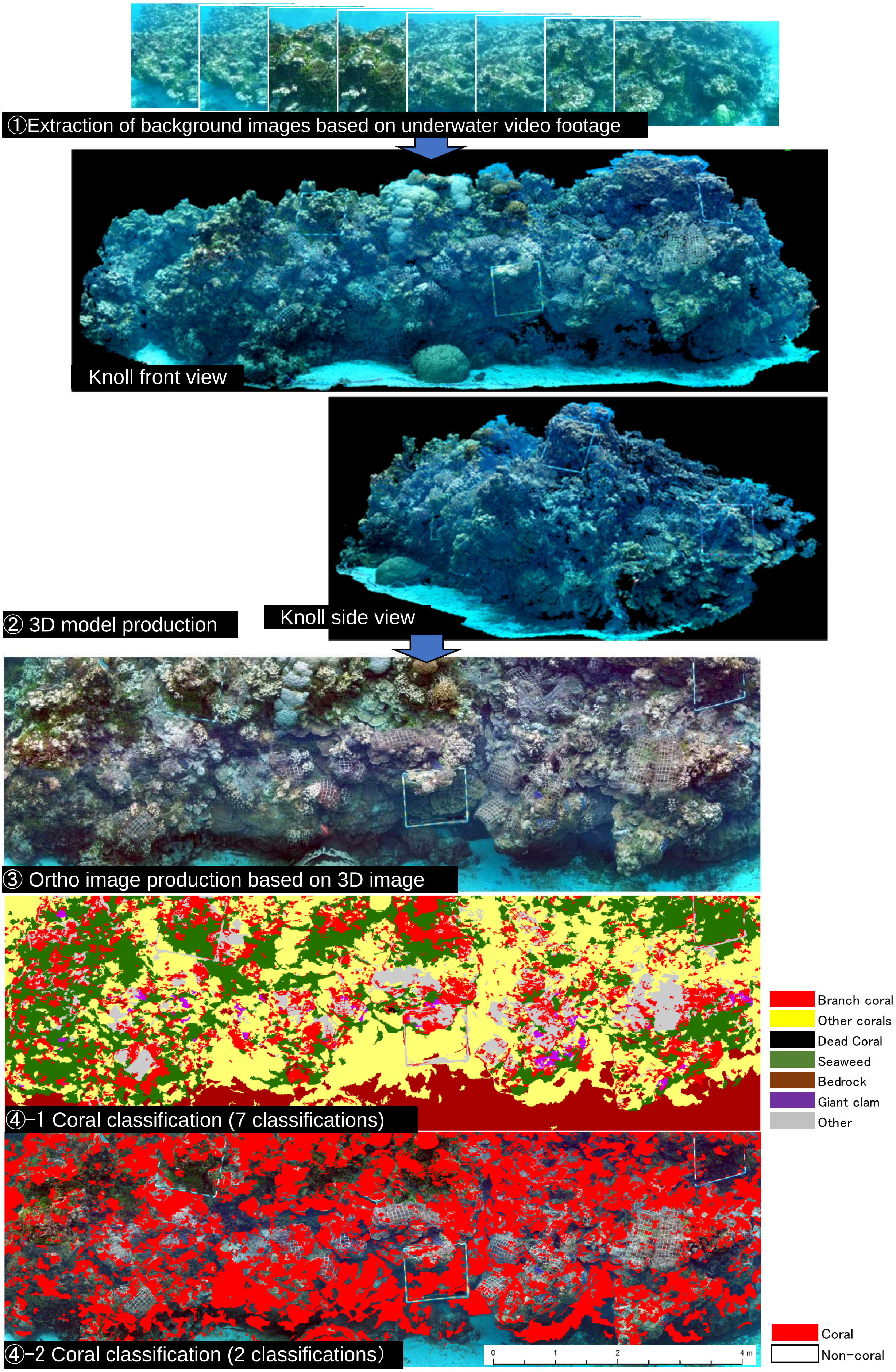

Figure 7 3D model and ortho image production, and coral classification examples

Table 2 Accuracy verification results

| No. | Image | Image scale | Guidance data | Guidance classification item | Year and location | Automatic classification accuracy | |
|---|---|---|---|---|---|---|---|
| | | | | | | 2 classifications | 7 classifications |
| 1 | Mosaic imaging | Approx. 30m$^2$ | Applied to each image | Color, pattern, scale, etc. (20 types) | Measurement line L-5 FY 2015 Seabed Complete image | 80% | - |
| 2-1 | Orthographic imaging | Approx. 50m$^2$ | Applied to each image | Addition of depth conditions gained from orthography in color, pattern, scale, etc. (23 types) | A3_1 FY 2016 Knoll vertical plane Complete image | 85% | 68% |
| 2-2 | | Approx. 30m$^2$ | | | A3_2 FY 2016 Knoll vertical plane Complete image | 87% | 68% |
| 2-3 | | Approx. 50m$^2$ | | | A10_1 FY 2016 Knoll vertical plane Complete image | 72% | 60% |
| 2-4 | | Approx. 20m$^2$ | | | A10_2 FY 2016 Knoll vertical plane Complete image | 76% | 57% |
| 3-1 | Orthographic imaging | Approx. 50m$^2$ | Applied to each image | Addition of color and pattern conditions (47 types) | A10 FY 2017 Knoll vertical plane Complete image | 87% | 55% |
| 3-2 | | | | | A10 FY 2017 Knoll vertical plane Sections with large amounts of seaweed | 91% | 63% |
| 3-3 | | | | | A10 FY 2017 Knoll vertical plane Sections with large amounts of dead coral | 84% | 44% |
| 3-4 | | | | | A10 FY 2017 Knoll vertical plane Sections with large amounts of bedrock | 85% | 63% |
| 3-5 | | | | Same as No. 2 (23 types) | A10 FY 2017 Knoll vertical plane Complete image | - | 51% |

*Accuracy colors: Stronger blue color denotes higher accuracy, Stronger red color denotes lower accuracy
*2 Classifications: Coral, non-coral; 7 Classifications: Branch-like coral, other coral, dead coral, seaweed, bedrock, giant clam, other
*Automatic classification accuracy = Area correctly classified by means of automatic classification/total area

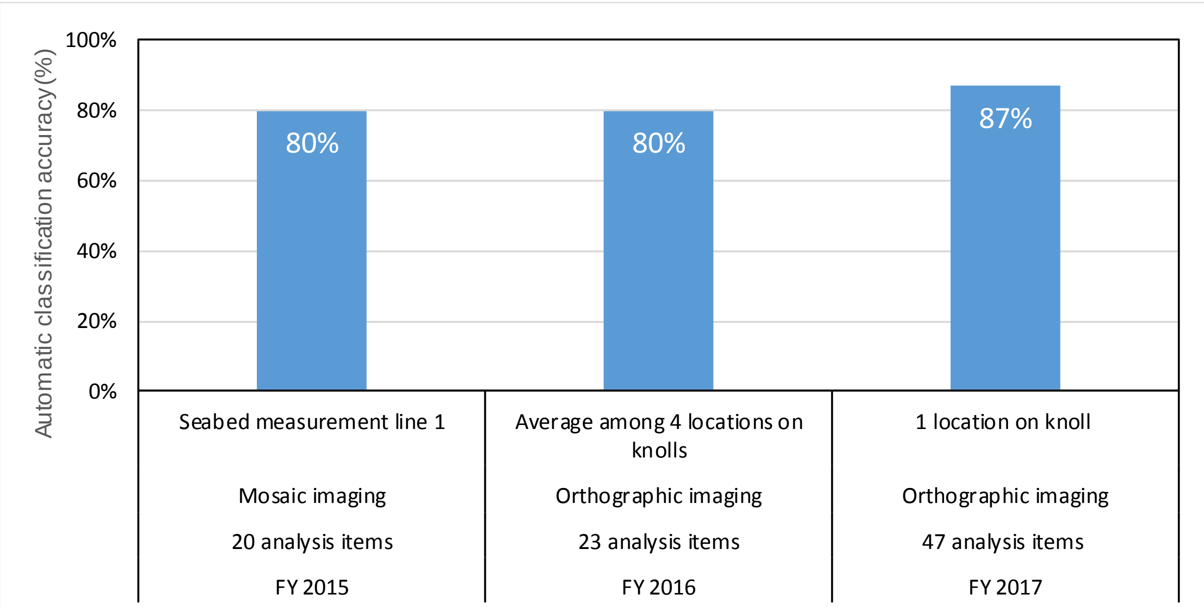


Figure 8 Comparison between coverage survey results and satellite imagery analysis results

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