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Mapping coral reef using photogrammetry technique: A preliminary study at Pulau Udar Besar, Sabah, Malaysia.

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Abstract

Mapping of coral reefs is useful for understanding, monitoring and tracking their development. However, studies on reef mapping in the Southeast Asian region are limited. The main objectives of this study were to 1) map the coral reefs using photogrammetry in order to create a 3D map of the reef, and 2) determine the coral growth forms and identify the corals to the lowest possible taxa from the images. Data collection was conducted on 19 and 24 January 2018. All images were captured by applying photogrammetry technique using a digital camera with waterproof housing. Image reconstruction process was performed in Agisoft Photoscan and Blender, using the structure-from-motion (SfM) algorithms to reconstruct the 2-Dimensional images into a 3D model. The reef map generated from Agisoft Photoscan is of medium quality. Coral growth forms were determined and identified to the lowest possible taxa through the images. From the images, free-living corals of the family Fungiidae were the most common coral observed in the study site. In conclusion, the output of this study shows that reef mapping is possible using a photogrammetry approach and images can be used to identify coral growth forms.

Keywords: Image reconstruction, 3D imagery, coral growth form, Kota Kinabalu

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Introduction

Conventional methods such as *in situ* quadrats, line transects and manta tows have been used for coral reefs surveys to determine the benthic community structure (Miller and Müller, 1999). In large reef areas, using conventional methods to determine the benthic spatial distribution is not practical when resources such as cost, time and personnel are a limitation (Ginsburg, 1994). As technology development improved with time, marine scientists began to use remote sensing technology to identify, map and assess coral reef ecosystem health, using satellite sensors, aerial and satellite photography, hyperspectral imagery, acoustic analyses, and bathymetric surveys (Clark et al., 1997; Mumby and Edwards, 2002; Eakin et al., 2010). This assists scientists and policy-makers in conservation planning and management purposes (Witze, 2016). However, mapping coral reefs with these advanced technologies may not always be practical due to certain limitations and disadvantages, for instance the expensive cost to obtain high resolution data from airborne hyperspectral data and remote sensing imagery, and sensors limitation in identifying the coral reef features (Cetin, 2004; Ventura et al., 2016).

To map a coral reef area with extensive details, the combination of photo-interpretation technique and intensive ground-truthing provides better results than remote sensing technology alone (Andréfouët, 2008; Scopélitis et al., 2010). It is a non-invasive and cost-efficient way to achieve better understanding, monitoring and tracking of coral growth (Chandler et al., 2005; Marre et al., 2019). Repetitive surveys with this technique can provide a database for monitoring coral reef development.

The aims of this study were to map a section of the coral reef of Pulau Udar Besar, Kota Kinabalu, using photogrammetry technique in order to create a 3D map of the reef, as well as to identify the growth form and the lowest possible taxa of the corals from the images. The study site was chosen due to the limited information of the island. Photogrammetry is defined as making measurements from photographs that can be used to construct 3D measurements from 2D images (Nisha, 2021). The output from this study can serve as baseline information for future reference.

Materials and Methods

Study Site

Pulau Udar Besar is located approximately 1.4 km from the Kota Kinabalu mainland as shown in Figure 1. There are no human settlements on the island. The study site was located at the western part of the island (6°04'48.4"N, 116°05'18.2"E). The fringing reef of the island extends up to approximately 0.1-0.2 km from the island.

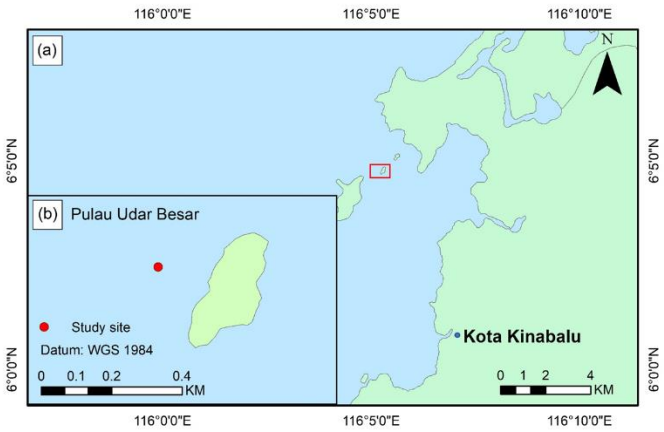

Figure 1. (a) Map of study area – Pulau Udar Besar, Kota Kinabalu, **(b)** Inset map shows the study site indicated by the red dot (Source: ESRI).

Field Survey

The sampling site was chosen based on LandLook Viewer imagery (https://landlook.usgs.gov/) and exploratory dives. Data collection was done over two days on the 19 and 24 January 2018, with two dives on each day. The sampling site did not extend deeper than 10 m depth, and was within 200 m radius of the island's coral reef extent. A quadrat of 10 x 10 m was placed on the seafloor by using a transect tape as a framework for the mapping. For the mapping approach, the benthic habitat was defined to include abiotic substrates (e.g., sand, rock) and biotic communities (e.g., coral) covering the seafloor.

Image Acquisition

The mapping was done by collecting images within the boundary of the 10 x 10 m quadrat using a camera (Olympus Compact Digital Camera, TG-3 Tough) in underwater housing, with Full High Definition (Full HD) resolution (1920 x 1080 pixels) settings. All images were taken manually to capture the best image and to minimize image distortion, and videos on Full HD (1920 x 1080 pixels) at 30 frame per second (fps), to ensure all area and angle of the coral reef were covered (Burns, 2017; Poncet and Quod, 2017). Slow and steady diving pace was important to avoid distorted images. The photogrammetry technique used in capturing the images were convergent and parallel. This is to optimize the overlap and parallax when capturing the images, and to increase point cloud from digital imagery. Convergent photos were used to capture each individual coral, while parallel photos were used to capture the overview of top view and side view of the coral reef (Morgan et al., 2017) (Figure 2).

Image Processing

Two types of software were used to process and produce the 3D map, which were Blender and Agisoft Photoscan Professional 1.4.3. The Blender software was used to convert videos into image sequences at 30 frames per second (fps). The Agisoft Photoscan was used to reconstruct photogrammetric captured images to generate a 3D model or data, in three primary stages: photo alignment, geometry building and texture building (Agisoft LLC, 2010).

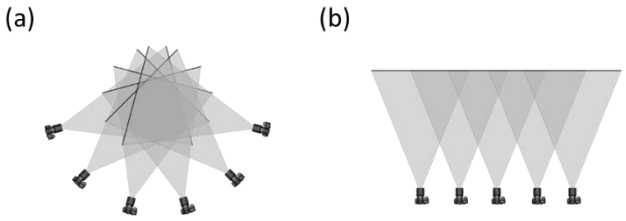

Figure 2. Convergent (a) and parallel (b) camera views (Source: Dietrich, 2014).

After converting the videos into images in Blender, all the images were exported to Agisoft Photoscan. Photoscan then aligned the series of photos using algorithms to automatically detect invariant features ("keypoints") which overlap in the images to create a system of geometrical projective matrices and determine the position and orientation of each camera position (Westoby et al., 2012). The software constructed the 3D geometry on the 2D image plane simultaneously based on the camera position and feature points in conjunction with the intrinsic parameters and focal length of the camera that were extracted from the metadata of each image (Stal et al., 2012). This process then created a sparse 3D point cloud from the projection and oriented images in a 3D space. The final phase of the geometry building was generating a dense point cloud, which in turn can be used to build a continuous surface or mesh. The resulting mesh was triangulated and rendered with the original imagery in order to build textured 3D mesh and create the final digital surface model.

Results

Reef Mapping

Approximately 48,088 images were acquired over the two-day survey. Only 11,021 images had good resolution and could be used for further analyses. All images were processed and analysed to remove blurred and distorted images. Total processing time took two weeks to complete a medium quality 3D model. It was not possible to generate a 10 x 10 m 3D map due to the incomplete image dataset, therefore, only a section of the reef reconstructed from 171 images generated on Agisoft Photoscan is shown in Figure 3.

Coral Growth Forms

The coral growth forms were determined from the images and when possible, the corals were identified following the descriptions of Veron (2000). The main coral growth form observed in the study site was free-living mushroom corals (family Fungiidae). Apart from free-living corals, submassive coral (family Poritidae) were also observed (Figure 4). Some of the coral growth forms that could be determined in Figure 4 are listed in Table 1.

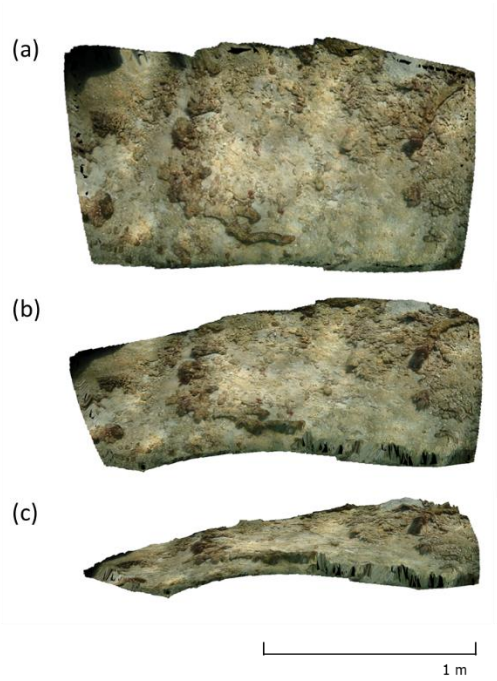

Figure 3. A section of the reef at Pulau Udar Besar in 3D: (a) top view, (b) perspective view, and (c) side view (profile). Scale represents 1 m.

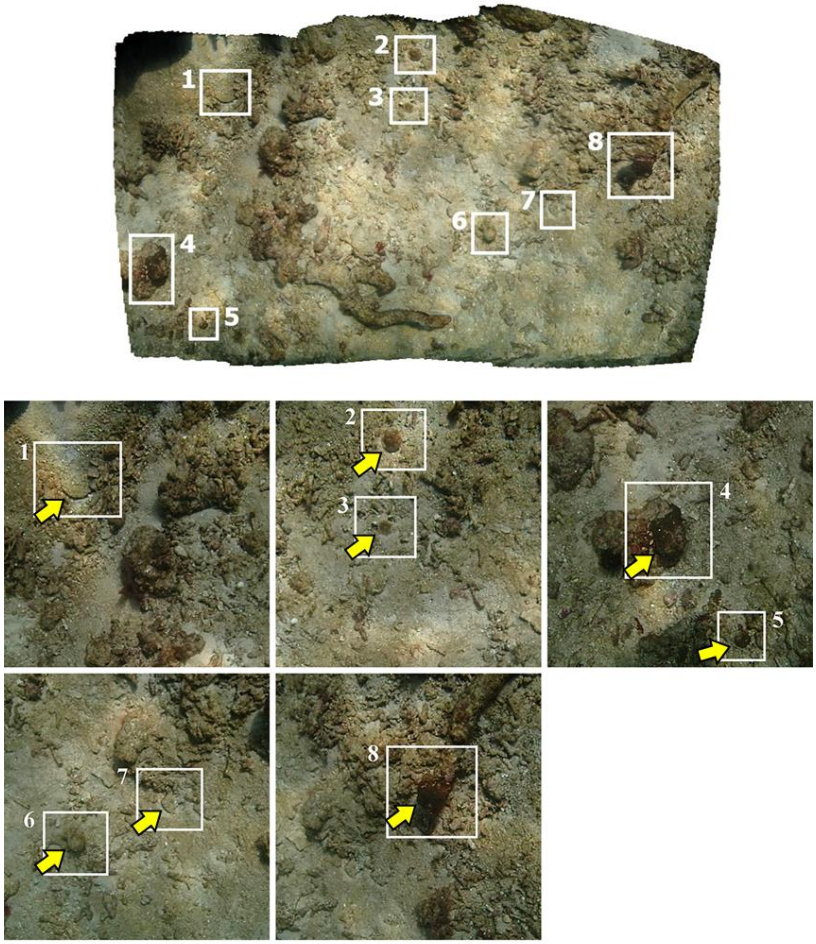

Figure 4. Few mushroom corals (Fungiidae) and submassive coral (*Porites*) could be seen among the sandy substrate and coral rubble, as indicated by the yellow arrows in the square boxes. The numbers correspond with the coral information in Table 4.

Table 1. Coral growth forms and taxa observed in Figure 4.

Box	Growth form	Family	Genera
1	Free-living	Fungiidae	-
2	Free-living	Fungiidae	-
3	Free-living	Fungiidae	-
4	Submassive	Poritidae	*Porites* sp.
5	Free-living	Fungiidae	-
6	Free-living	Fungiidae	-
7	Free-living	Fungiidae	-
8	Free-living	Fungiidae	-

Discussion

Mapping using photogrammetry

Photogrammetry can be defined as a type of science that makes measurements from photographs. The input to photogrammetry is photographs and the output is typically a map, a drawing, a measurement, or a 3D model of a real-world object or scene (Walford, 2017). This technique is commonly applied on aerial, and terrestrial subjects. Therefore, this study was conducted to experiment the use of photogrammetry for shallow benthic marine research.

Mapping the reef by applying photogrammetry technique requires basic underwater photography skill, good diving buoyancy control and the knowledge of using Agisoft Photoscan software in image reconstruction. One drawback of this mapping method is that it is only possible to be applied to clear water reefs or at reefs with good water clarity. The sampling site is situated near the coastal city Kota Kinabalu and Sepanggar Bay. Occasionally during the northeast monsoon, physical factors such as waves, wind and tidal force may affect underwater visibility around the sampling site due to high water turbidity from the resuspension of surface sediments (Gallagher et al., 2016; Heery et al., 2016). Hence, images will require additional editing to enhance image quality prior to the reconstruction step.

The study was conducted during the northeast monsoon and prolonged rainy season. Thus, cloudy weather was observed during the two-day survey. Insufficient natural light underwater was improved by setting the camera's ISO to auto to overcome the changing light conditions underwater. Flashlights and filters can also be used to enhance the colours of the corals when at deeper depth or low light situations.

In the early stages of image processing in Agisoft Photoscan, the parameter setting that controls the photo alignment procedure, particularly the estimation of camera position was set at medium accuracy that will cause the software to downscale the image by the factor of four. Nevertheless, it is still possible to discern the different coral growth forms and coral family, as can be seen in Figures 3-4. Despite the long hours of image reconstruction, the results however are promising as the corals could be visually identified from the images. In order to produce higher quality 3D models, it is recommended to use a computer with at least 16-64 GB RAM and high speed multi core CPU (3GHz+) to reduce image processing time (Agisoft LLC, 2020), and to capture in situ photographs closer to the substrate to increase the image resolution.

As the study was designed to experiment the application of photogrammetry technique underwater, other ground truth information such as ground control points, underwater markers as scale reference, waypoint data and other spatial information were not taken into account. Consequently, accuracy assessment is not available for this study due to the lack of such information.

Coral Reef at Pulau Udar Besar

The most common coral growth form observed in the study site were free-living corals. This may be due to their natural habitat adaptation, where they are not attached to a hard surface and are able to live on the substrate of sand or among coral rocks (Hardy et al., 2018). The second common growth form that can be found were submassive coral, such as *Porites* sp. (family Poritidae). They form mounds of colonies made of hundreds of polyps and are able to live in low-light conditions (Riddle, 2020).

Pulau Udar Besar lies just outside of the Tunku Abdul Rahman Park (TARP), in Kota Kinabalu. Most of the reef area at the study site was covered with rubble. This may be due to the effects from previous unsustainable fishing methods by fishermen. There were several small fishing boats surrounding the south of the island during the survey. Two blasts were also heard underwater during the dives, indicating blast fishing activity in nearby reefs. If the shallow area of the reef is decimated by repeated blasts, it will be very hard or even impossible for the reef to recover (Fox and Caldwell, 2006). Nevertheless, the output from this study provided some baseline information on the reef of Pulau Udar Besar, which could be used in comparison in the future to indicate whether the reef has improved or deteriorated.

The method and results of this study prove that reef mapping or monitoring activities do not necessarily need to use expensive technology. This exploratory research may create opportunities for volunteers to contribute to the mapping of reefs for monitoring and marine conservation purposes. Moreover, photographs that are taken can be used as a tool for education and to create public awareness about the importance of coral reefs.

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