

Underwater Photogrammetry Application for Coral Reef Mapping and Monitoring

Agung Budi Cahyono^{#1}, Andreas Catur Wibisono^{#2}, Dian Saptarini^{*}, Rizki Indra Permadi⁺,
Yanto Budisusanto^{#3}, Husnul Hidayat^{#4}

[#] Department of Geomatics Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia
E-mail: ¹agungbc@geodesy.its.ac.id; ²andreaswsurveyor@gmail.com; ³yanto_b@geodesy.its.ac.id; ⁴hidayathusnul@yahoo.co.id

^{*} Department of Biology, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia
E-mail: dianssa@yahoo.com

⁺⁴ NPC-Lab, Surabaya, Indonesia
E-mail: npclab@gmail.com

Abstract— Underwater mapping techniques such as underwater photogrammetry is one of the latest trends in survey techniques in mapping coral reefs. The underwater photogrammetry technique uses a non-metric camera in 3D reconstruction of coral reefs that will produce photo maps up to in 3D. This article explains how the process of data acquisition to the process of producing coral reef photo maps. The study area used surface terrain of coral reefs with dimensions of 25 m long and 2 m wide at depths of less than 5 m. Acquisition of photos using a type of waterproof sport-fisheye camera with automatic data processing to rendering using the Structure from Motion (SfM) algorithm. This platform was chosen because it is easy to obtain, quite inexpensive and practical in its operation. In addition, it has a good quality of lowlight, affordable, and have large FoV. For maximum image quality, the camera calibration is done with the average error obtained from camera calibration is equal to 1.10 pixels. Geodetic measurements are also carried out on the control points in the modelling process. Data was processed using 822 photos for photo orientation with overlap rate of > 75%. The result is a 1: 100 scale photo map with a Ground Sample Distance (GSD) value of 0.395 m. The 3D models of coral reefs are well-formed although the resulting image still has some weaknesses, for example, the appearance of colours that depend on the level of water clarity and the camera filters used.

Keywords— coral reef; mapping; underwater photogrammetry; monitoring.

I. INTRODUCTION

Coral reefs are often called the rainforests of the sea, both due to the vast amount of species they harbor, and to the high productivity, they yield. Aside from the hundreds of species of coral, reefs support extraordinary biodiversity. The coral reef is one of the seabed features that has several essential functions, such as tourism and protection. The process of rehabilitating and observing coral reefs is still somewhat tricky, several new methods have been appearing, but still have less impact. The coral reef is massive sediment of calcium carbonate, has produced by the coral star with a mixture of calcareous algae and other calcium carbonate-producing organisms. The existence of coral reefs as marine biodiversity, the main spotlight in the world [5]. Indonesia's coral reefs reach 39,583 km² or approximately 45.7% of a total of 86,503 km² of reef area in the coral triangle region, with the highest peak biodiversity including 590 species of

coral and 2,200 species of reef fish. However, it was reported that the existence of coral reefs was threatened, many threats come from local threats [1]. The coral reef has several functions, such as tourism, fisheries, protection, and biodiversity. The function can produce a negative impact when disturbed. If the amount of coral reef was decreased, the abrasion shall be increased and forming any damage to the coastal area.

There are some research and method that has been developed for coral reef monitoring. The method, such as Line Intercept Transect (LIT) which produced data with high detail needs a longer time and scuba diving equipment [2]. Underwater photogrammetry for comparing with the result has been granted from traditional snorkeling when the traditional method has been restricted from endurance and stamina snorkels [3]. Mapping the coral reef field can use

close-range photogrammetry with structure from the motion method for calculating the roughness value of the coral reef and the relation with mass transfer in the ocean.

Technology photogrammetry with Structure from Motion (SfM) it was an evolution from computer vision, where combined mathematical science with the technique until resulted 3D model and identification from the object as visual [4]. Application form photogrammetry has been developed to several functions, one of applied is seabed feature, such as shipwreck and coral reef. With the SfM method, the coral reef can be imaging the structure in the 3D model, so can provide high-resolution underwater imagery that can be further processed into various purposes. This research will analyze and apply the underwater photogrammetry for coral reef coverage and geometric analysis from a model that resulted. Coral coverage is cover from the surface with stony coral. Indonesia was located at the center of the coral triangle, which is a reef area with the highest marine biodiversity in the world. Indonesia's coral reefs approximately 45.7% of the total reef area in the coral triangle area [12]. Reported that from a combination of local threats and due to changes in temperature and bleaching, almost 45% of Indonesia's coral reefs are in high threat to very high If coral reef damage is worsening and no coral reefs produce limestone sediment, the function of coral reefs as breakwaters will be reduced because of deeper water and intensive abrasion. Based on Government Regulation no 60/2007, the government already has an ecosystem conservation program related to fish resources, conservation, and monitoring of coral reefs. But in the implementation still has constraints and limitations in resources and technology, such as image data from underwater photogrammetry. The main problems of this research are how to create a map of coral reef from image data and assessing accuracy for applying this method for coral reef monitoring.

II. MATERIALS AND METHOD

The study location is in Pasir Putih Beach, Situbondo, East Java with geographical coordinates $7^{\circ}40'20.91''$ - $7^{\circ}40'0.7''$ S and $113^{\circ}50'37.53''$ - $113^{\circ}53'21.30''$ E. The main instrument for image collection is a camera action. This platform was chosen because of its ease of use in operation. Besides, it has a good quality of lowlight, affordable, and have large FOV. Image collection was captured using camera action Gopro Hero 4 Silver 12 MP and ground measurements for georeferencing and accuracy testing were conducted using Total Station GTS Topcon and GPS Geodetic Topcon Hyper Pro. Hardware was used consist of a marker, roll meter, calibration chessboard and notebook MSI GP62 MVR.



Fig. 1(a) Field equipment and (b) Control Point measurement

A. Data Collection

The collection of data is done for supporting the data in this research. The need for primary data from the direct measurement to made research can be done. The data required in this research include photos of data, sea control points, and ground control in the coastal area and infield calibration data. The photos data are used to generate a photo map, and while the control point measurement data is used as the georeferenced point on the model.

B. Coral Reef Modelling

The first phase begins with the modelling of coral reefs using the SfM method. The modeling should do the selection of the image that will be used, the image that the user should have overlaps more than 75%. Photos from the calibration process in the field must be processed, to obtain intrinsic and extrinsic parameter values. The result of the parameter value will be used to calibrate the geometric of the model so that the corresponding model is produced outside the effects of distortion from the camera. Point form measurement of control points both from Total Station and GPS Geodetic should be processed and applied to the model for the control point.

C. Geometric observations

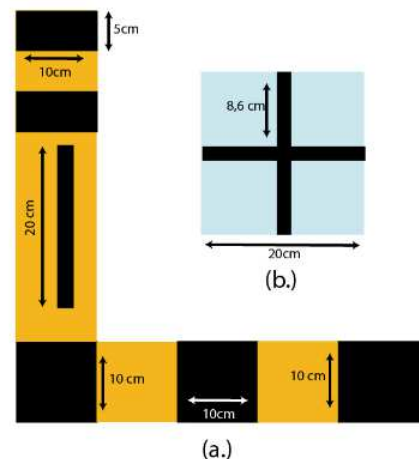


Fig. 2. Type marker: L (a) and K (b)

At this stage, the resulting model will be analyzed using 2 measurements, particularly test on marker L and marker K. Determining the error weight of each measurement, which there are several points test samples used. Dimensional of the marker model as follows:

From the final model, it is then measured on the segment of the marker. Then, the results are compared to the original size. From the difference, measurement resulted from the adjustment of the error value of the geometric model and will be tested for confidence level of data next stage.

III. RESULT AND DISCUSSION

A. Camera Calibration

This research used model camera fisheye (GoPro 4 Hero). The fisheye projection is based on the principle that in the ideal case, the distance between an image point and the principal point is linearly dependent on the angle of incidence of the ray from the corresponding object point. To

reconstruct the projection of an object, point into the hemispherical image, the object coordinates and image coordinates must refer to the same coordinate system [9]. Therefore, first, the object coordinates which are known in the superior coordinate system must be transformed into the camera coordinate system with the following transformation equations:

$$\begin{aligned} x_c &= r_{11} \cdot (x - x_0) + r_{21} \cdot (y - y_0) + r_{31} \cdot (z - z_0) \\ y_c &= r_{12} \cdot (x - x_0) + r_{22} \cdot (y - y_0) + r_{32} \cdot (z - z_0) \\ z_c &= r_{13} \cdot (x - x_0) + r_{23} \cdot (y - y_0) + r_{33} \cdot (z - z_0) \end{aligned} \quad (1)$$

Where X_c, Y_c, Z_c are object point coordinates in the camera coordinate system. X, Y, Z are object point coordinates in the object coordinate system. X_0, Y_0, Z_0 are coordinates of the projection center. r_{ij} is the element of the rotation matrix.

All the following considerations refer to the Cartesian camera coordinate system. Figure 3 illustrates the principle of the fisheye projection graphically. For a 180-degree fisheye lens, an object point's ray with an angle of incidence of 90 degrees is projected onto the outer border of the circular fisheye image [9].

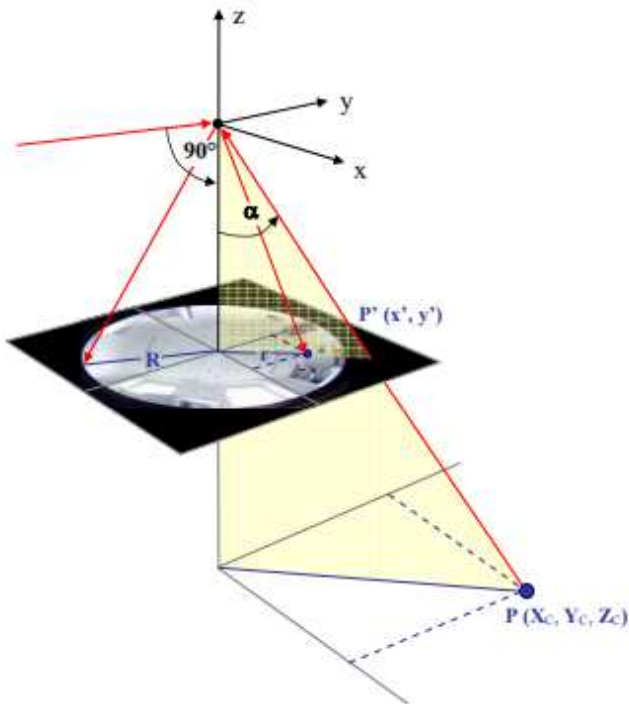


Fig. 3. Geometric relationship

This means that the resulting image point has the maximal distance to the optical axis. The relation between the angle of incidence and the resulting distance of the image point from the principle point is constant for the whole image. Consequently, the following ratio equation can be set up as the basic equation for the fisheye projection: Here are some results from data collection for camera calibration:

$$\frac{\alpha}{r} = \frac{90^\circ}{R} \quad \text{where} \quad r = \sqrt{x^2 + y^2} \quad (2)$$

- Where
- α : angle of incidence
 - r : distances between image and optical
 - R : image radius
 - x', y' : image coordinates

The angle of incidence α is defined by the coordinates of its corresponding object point X, Y, Z and the exterior orientation parameters. For the fisheye projection, the image radius R replaces the principle distance of the central perspective projection as a scale factor. In equation (2) the image coordinates x' and y' are still included in r . To obtain separate equations for the single image coordinates, another ratio equation becomes necessary.

The photo data is then selected and used to obtain values from intrinsic and extrinsic parameters from modeling the coral reef required calibration parameter.

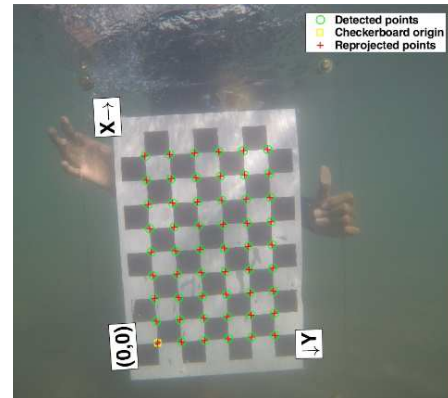


Fig. 4. Calibration checkboard

The average error obtained from calibration is equal to 1.10 pixels, following the value of the error of each photo used in the calibration process:

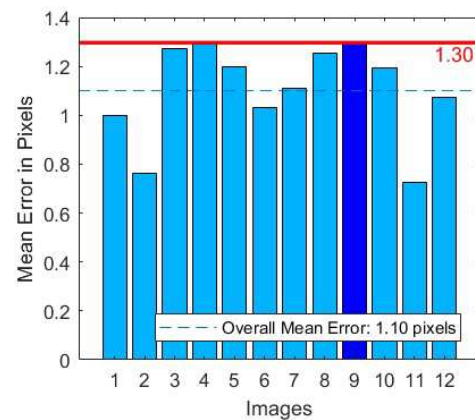


Fig. 5. Pixel Error

The largest error value is at 1.30 pixels and the smallest one is 0.7 pixels. Following depiction of the position of the camera in a space model:

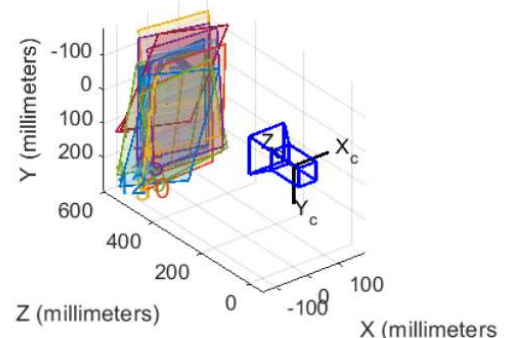


Fig. 6. Space Model Error Orientation

Below the result of calibration:

TABLE I
CALIBRATION PARAMETER

| Parameter | Value (mm) |
|-----------|-------------|
| f | 2.386 |
| Xo | 127.758 |
| Yo | -22.551 |
| K1 | 0.206547 |
| K2 | 0.243842 |
| K3 | -0.138373 |
| P1 | -0.00230718 |
| P2 | 0.000911211 |

From processing resulted in that error rate 1.10 pixel from 12 photos which have been used for calculating calibration. By previous studies due to fisheye cameras [8,9], the calibration results will be challenging to reach values below 1 pixel; moreover, it is used on objects underwater.

B. Control point

The coordinate of the control point was used as the orientation point and the geodetic value for generating the model. Control Point in this research was used from the measurement of total station and GPS Geodetic. The location of the GPS control point is on the left side of the Pasir Putih road and the right side of the Pasir Putih beach.



Fig. 7. GPS Control Point Location

For the value of control for import into model follow as below:

TABLE II
CONTROL POINT GPS GEODETIC

| Point Name | Easting(m) | Northing(m) |
|------------|------------|-------------|
| BM 1 | 812164.164 | 9148850.426 |
| BM 2 | 812157.878 | 9148839.131 |

From the results obtained from the measurements on the ground using GPS Geodetic, then measuring the detail points used as sea control points using the Total Station, and the calculation of detail points is carried out. The calculation method uses the parameter alignment method. Following are

the results of the calculation at the control points on the model:

TABLE III
CONTROL POINT TOTAL STATION

| Point Name | Easting(m) | Northing(m) |
|------------|------------|-------------|
| A | 812061.258 | 9149013.493 |
| B | 812065.605 | 9149015.508 |
| C | 812070.814 | 9149016.241 |
| D | 812075.751 | 9149018.178 |

The resulting point is 4 points from the parameter alignment. The depiction of the point is in the form of a polygon extending perpendicular to the coastline. The resulting error value is included in the accuracy interval of the geodetic GPS specification (± 3 mm) so that both points can be used as a reference measurement of the Total station. Test point using marker K as in figure 4., the measurement from test point refers to the model result. Below documentation of the following points:

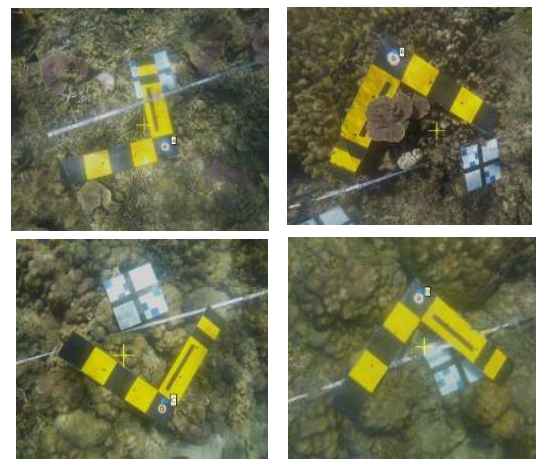


Fig. 8. Marker test point

C. Photo data of coral reef

Data was processed using 822 photos for photo orientation, with overlap rate of $> 75\%$ in order to obtain the model of coral reefs are intact formed lanes form a straight line following.



Fig. 9. Example of coral reef photo; (a) Type of Acropora Tabulate (ACT); (b) Type of Coral Foliose (CF)

The 3D model that has been produced is then processed further to produce a Photomap. The resulting photo map is the following:

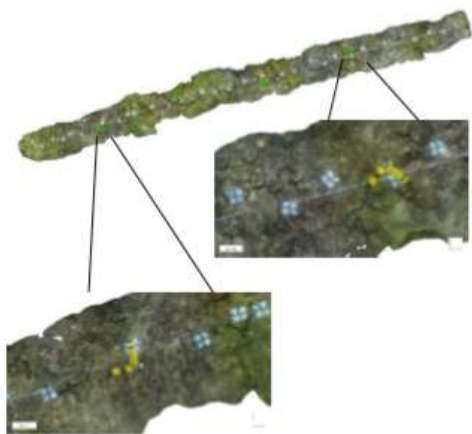


Fig. 10. Photomap and Control Point

The results of the manufacture produce a longitudinal area parallel to the coastline with dimensions of 25 m x 2 m. The parameter that has been used for the created model using the high setting for all step and described below:

TABLE IV
MODELING PARAMETER

| Parameter Name | | Value unit |
|----------------|---------------|------------|
| 1 | Sparse Cloud | 662.364 |
| 2 | Dense Cloud | 36.541.885 |
| 3 | Faces texture | 7.309.002 |

The 3D model that is formed can then be converted into the DEM form and produces a depth range that ranges from 2.62 m to 2.42 m. Colour gradation is a guide in reading the depth of the model produced.

D. 3D model of Coral Reef

This last activity is to get a form of Digital Surface Model (DSM) to be able to see the surface in 3D. The 3D models that are formed can then be changed into Digital Surface Model (DSM) shape and produce a range of depth i.e., ranged from 2.62 m to 2.42 m. Colour gradation is a guide in reading the depth of the model taken.

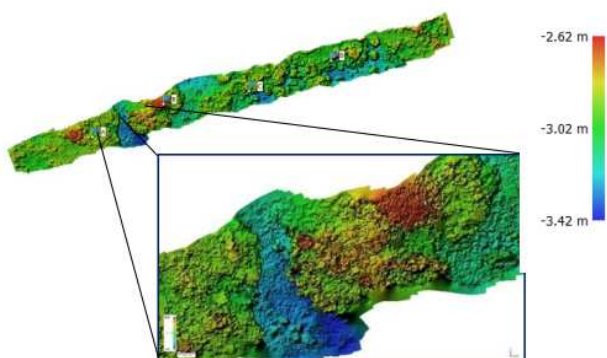


Figure 11. Digital Surface Model

Figure 11 shows the red area is the shallow depth area was at a depth of -2.62 m, while in the area in blue indicates the number 3.42 m.

IV. CONCLUSIONS

This research has produced a map with a photogrammetry underwater method. The mapping of coral reefs using the SfM underwater photogrammetry algorithm method was successfully carried out. The results obtained a 1: 100 scale maps with GSD photo 0.395 m. Moreover, the total area produced is 54.323 m² and the volume of the mapped area is 32.213 m³. The 3D modeling on massive corals can form a model because the shape of the object is still relatively simple (shaped like a solid rock), but on a reef coral which is shaped like a tree branch, still exists a hole in modeling. This is due to the form of objects photographed is quite complicated, has many cavities so it requires an increase in the number of photos to produce a complete 3D model. The use of magenta or red color filters can be used to reduce the absorption of blue waves in the water medium to obtain accurate color from coral reefs.

ACKNOWLEDGMENT

The authors are grateful to the Board of Research and Community Service/Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) of Institut Teknologi Sepuluh November Surabaya for the research funding. This research is under research-based community service No: 1484/PKS/ITS/2018. We also gratitude the fellow members of NPC-LAB who help researchers in the data collection.

REFERENCES

- [1] Giyanto, et all. 2017. "Status Terumbu Karang Indonesia 2017". Jakarta: Puslit Oseanografi - LIPI.
- [2] Gleason, A.C.R., and Reid, R.P. 2007. "Automated Classification of Underwater Multispectral Imagery for Coral Reef Monitoring". OCEANS.
- [3] Hill, J., and Wilkinson, C. 2004. "In Method for Ecological Monitoring of Coral Reefs". 39. Los Angeles: Australian Institute of Marine Science.
- [4] Huffard, CL., Erdmann, MV., Gunawan, T. 2012. "Geographical Priority of Marine Biodiversity for Development of Water Conservation Area in Indonesia. Ministry of Maritime Affairs and Fisheries & Marine Protected Areas Governance Program". Jakarta-Indonesia. 105 pp.
- [5] ICRI. 2013. "Benefits of Coral Reefs - The International Coral Reef Initiative (ICRI)". <https://www.icriforum.org/about-coral-reefs/benefits-coral-reefs>.
- [6] Lam, K., et all. 2006. "A Comparison of Video and Point Intercept Transect Methods for Monitoring Subtropical Coral Communities". Journal of Experimental Marine Biology and Ecology: 115-128.
- [7] Leon, J.X., Roelfsem, C.M., Saunders, M.I., and Phinn, S.R. 2015. "Measuring Coral Reef Terrain Roughness Using 'Structure-from-Motion'". Geomorphology 242: 21-28.
- [8] Raoult, Vincent, et all. 2016. "GoProTM as an underwater photogrammetry tool for citizen science". Perr J: 1-18.
- [9] Schwalbe, E. 2005. "Geometric Modelling And Calibration Of Fisheye Lens Camera Systems". ISPRS, Dresden University of Technology, Paper Workshop Volume XXXVI-5/W8, Berlin, Germany.
- [10] Silvatti, Amanda Piaia., Fabio Augusto Salve Dias., Pietro Cerveri., and Ricardo M.L Barros.. 2012. "Comparison of Different camera calibration approaches for Underwater Applications." Journal of Biomechanics: 1112-1116.
- [11] Szeliski, R. 2010. Computer Vision: Algorithms and. Berlin: Springer. Wenhao, F. 2001. "Control Work in Close Range Photogrammetry". Geo-spatial Information Science: Vol 4 No.4 p 66-72.
- [12] Sukmara, A., Siahainia, A.J, dan Rotinsulu, C.2001. "Panduan pemantauan Terumbu Karang Berbasis-Masyarakat dengan Metode Manta Tow". Jakarta: Proyek Pesisir,Narragansett, Rhode Island.