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Preliminary Result of Drone UAV Derived Multispectral Bathymetry in Coral Reef Ecosystem: A Case Study of Pemuteran Beach

Masita Dwi Mandini Manessa [a,*], Dadang Handoko [b], Fajar Dwi Pamungkas [a], Riza Putera Syamsuddin [a], Dwi Sutarko [b], Agus Sukma Yogiswara [c], Mutia Kamalia Mukhtar [a], Supriatna Supriatna [a]

[a] *Geography Departement, University of Indonesia, Depok, 10430, Indonesia*
[b] *School High Tech Navy, Jakarta, 14430, Indonesia*
[c] *Center for Remote Sensing and Ocean Science, Udayana University, Denpasar, 80361, Indonesia*
*Corresponding author: *manessa@ui.ac.id*

***Abstract*— UAV-derived multispectral bathymetry is an alternative to creating a shallow water bathymetry map without a massive field survey. Multispectral UAV technology can be used for detailed scale identification scopes because it has better spatial resolution and relatively affordable cost. The UAV used in this study record the coastal area using four multispectral sensors, blue, green, red, and near-infrared bands. The UAV images are processed into point cloud information under the use of the Structure from Motion (SfM)-based algorithm with a spatial resolution of 0.075 m. Then the point cloud information is used to predict the water depth using the random forest algorithm. This research was conducted at Pemuteran Beach, Bali, Indonesia. We compared the performance of only spectral, cloud point, and the combination of cloud point – spectral information to predict the water depth. As a result, the cloud point – spectral based shows significant accuracy improvement compared with the spectral only approach that reaches ~1.5, ~2.5 m, and ~0.3m for R^2, RMSE, and MAPE, respectively. So, the use of the SfM UAV technique can improve the common spectral-based SDB method.**

***Keywords*— UAV; multispectral; bathymetry; coral reef; random forest.**

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I. Introduction

The implementation of photogrammetric technology for monitoring coral reef ecosystems is nothing new. In 1978, helium balloons were used for the first time to record aerial photographs of coral reef ecosystems [1]. Then this photogrammetric technique experiment was continued by Fryer in 1983, aiming to study a photogrammetric system suitable for detailed shallow water mapping at a scale from 1:50 to 1:500 using a simple camera [2]. Stereo mapping is a 3D (three-dimensional) mapping technique of the earth's surface based on the concept of two overlapping images recorded at different angles. Figure 1 shows the basic concept of stereo mapping, which Baker developed in the 1980s for terrestrial mapping morphology.

3D mapping of coral reef ecosystems is very useful to visualize detailed bathymetric information of coral reef objects. UAVs have become a widely used remote sensing platform [3]. UAV photogrammetric method had several advantages, especially the quality of spatial resolution information from UAVs is incredibly good, so that detailed information up to species aspects of existing organisms can be recorded. With the stereo mapping concept of photogrammetry, Structure from Motion (SfM) algorithm, and MVS, detailed morphological information can be identified. Moreover, the drone UAV-based SfM is challenging due to the effect of atmospheric and sea surface scattering that also been recorded from the drone UAV.

Several scientific studies have assessed the accuracy of UAV-based multispectral images for extraction of the water depth information in coral reef environments using three different approaches. The first is a spectral-based approach that uses the multispectral or hyperspectral sensor [4], [5]. The second is the photogrammetry approach, which uses photogrammetry to get the water depth information [6]–[14]. The third is the combination of spectral and photogrammetry approaches [15].

In this study, two different approaches to extracting the deep shallow water area are compared a machine learning-based approach with different inputs, namely, multispectral random forest models [16], [17] and the combination of point cloud - multispectral random forest models [18]. Pemuteran water in the North part of Bali is chosen as the study site because the clear case one water on coral reef environment is very suitable for multispectral derived bathymetry study.

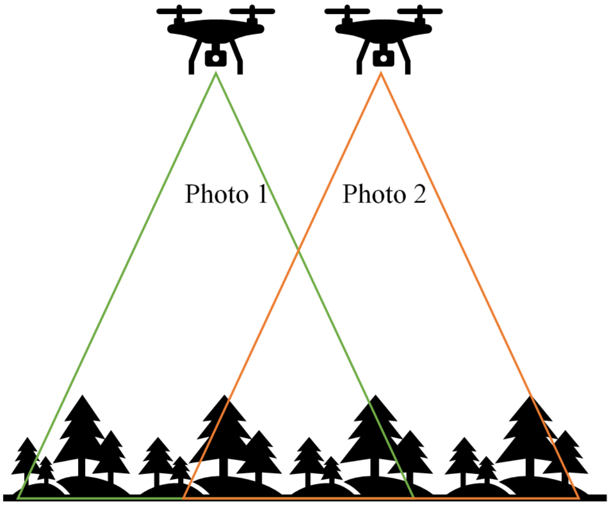

Fig. 1 The concept of overlapping recording in the 3D stereo mapping method.

II. Materials and Methods

A. Study Area Description

The study area is in Pemuteran, Buleleng Regency, Bali Province, Indonesia, coordinating 8^0 09' 48.04" South and 114^0 37'50.82" East. Pemuteran is a tourist area with various types of coral reefs and decorative fish. It is a 0.55 km^2 reach of the shallow water of Pemuteran Waters (Fig. 2). The shallow sea waters are dominated by coral islands, and reef flats and decorated with reef slopes. The Pemuteran Water consists of a coral reef ecosystem mixed with sand, coral reef, and dead coral reef. The waters of the Pemuteran are part of the waters of the North Bali Sea, as conditions are strongly influenced by the oceanographic conditions of the Bali Sea. The field campaign was performed on 18 and 21 May 2021 including an in situ bathymetric surveys, the deployment of a pressure transducer for tide correction, UAV flights, and ground control points (GCPs) acquisition.

B. Materials

1) UAV Imagery: The UAV instrument used in this study is Phantom4-RTK Multispectral from DJI with the multispectral camera [19]. In addition, the aerial imageries with 3840 × 2160 pixels (about 0.079 m/pixel) in the spatial resolution were acquired using the multispectral camera mounted on a UAV simultaneously for 2 s with 30 frames per second. The UAV was operated on 910 scan mode and 150 meters above the ground to cover the whole range of the experimental channel in the image frame.

2) In Situ Bathymetric Survey: For the in-situ bathymetry measures, a single beam 300 kHz Echotrac CV100 echo-sounder, with a sample rate of 1 Hz and a theoretical vertical resolution of 0.05 m, was mounted on a RIB (Rigid Inflatable Boat), together with RTK-GPS positioning (DGNSS Trimble BX992). The bathymetric survey covered an area shown in Figure 2.

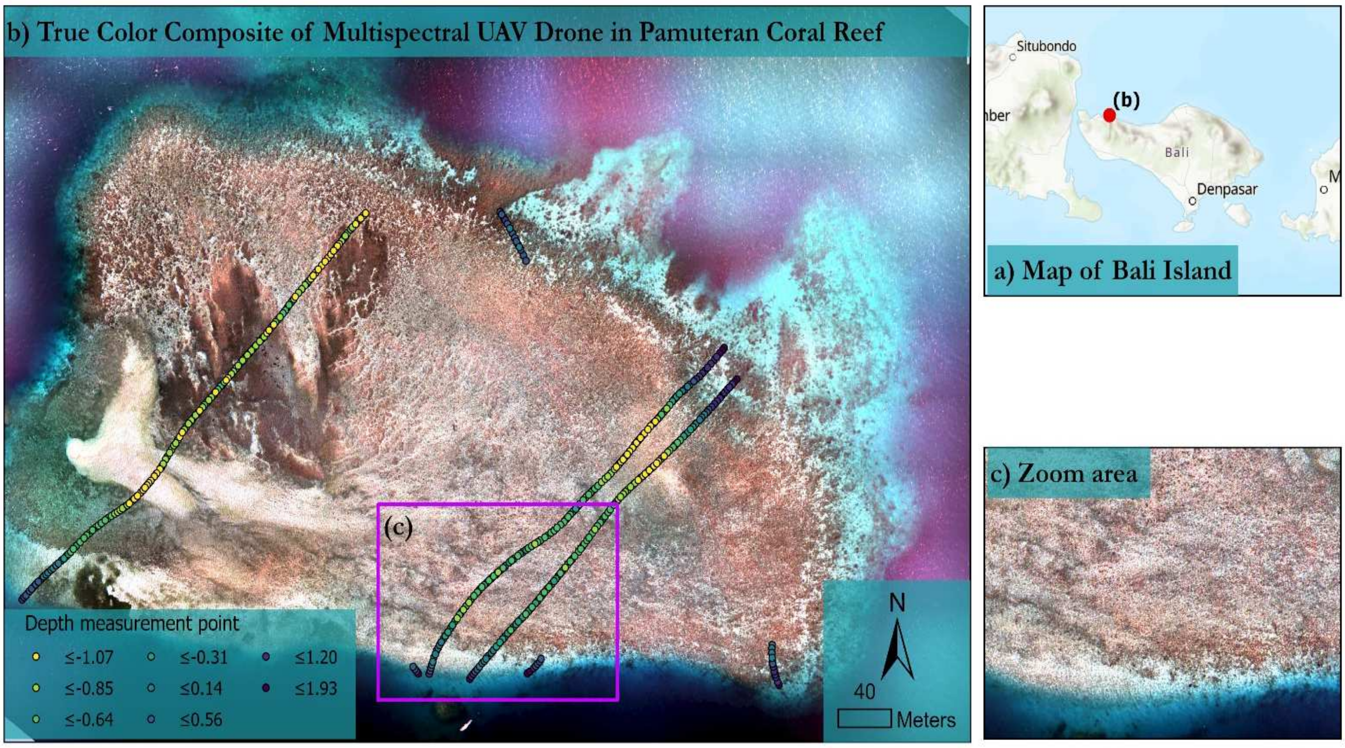

Fig. 2 Study Site: a) Map of Bali; b) True Color Composite of Multispectral UAV Drone in Pemuteran Coral Reef; c) Zoom area

C. Methods

1) SfM: The images captured by the UAV platform were processed into bathymetry information using the multi-view 3D reconstruction software Agisoft PhotoScan 1.7.3 [20]. The software utilizes a structure from motion (SfM) algorithm [21]. SfM technology has become the standard for aerial triangulation of UAV images [22]. SfM photogrammetry provides hyper-scale three-dimensional landform models using overlapping images from different perspectives with standard cameras and geo-referencing information [23]. SfM is processed using Agisoft Meta shape. First, UAV's raw data imagery was aligned using tools to align photos. It was aligned based on the location image taken. The overlap percentage is 80%, and the side lap percentage is 60%. After the image was aligned, the next step was to build a dense point cloud. A dense point cloud is built based on overlapping camera positions. Every point has unique information about the ground object. It can be classified as terrain, building, trees, or another object that was captured by a UAV. The following process is to build the mesh. It is based on point cloud information. In this process, construct a polygonal model using height field surface type. It is suitable for planar surfaces such as terrains or relief. After building the mesh, the following process is to build a digital elevation model (DEM). DEM was built based on the point cloud. Point cloud allows creating DEM based on surface (digital surface model or DSM). Then the point cloud data is corrected for the water refraction effect using the snell algorithm.

2) Multispectral Random Forest Transform Models: Multispectral Random Forest Transform Models is a modification of Lyzenga method [24] that determines the nonlinear relation between depth and linearized reflectance using Random Forest (RF) algorithm [16], [17]. RF for nonlinear regression is formed by growing trees dependent on a random vector such that the tree predictor takes on numerical values as opposed to class labels [25]. Then, the depth estimation formula can be written as:

$$\hat{h} = \sum_{j}^{i} \left(\frac{1}{m} \sum_{j=1}^{m} W_j(X_i, X_i') \right) + \varepsilon \tag{1}$$

$$X_i = log\left(\rho_{c_i} - \bar{\rho}_{c_{\infty,i}}\right) \tag{2}$$

where $W_j(X_i, X')$ is the non-negative weight of its training point relative to the new point x' in the same tree, m is a number of the tree, ρ_i is observed spectral reflectance and $\rho_{\infty i}$ represents the water depth-averaged reflectance at band i. The implementation of the random forest algorithm is performed under R software and the random forest package [26].

3) Accuracy Test: The UAV-derived depths (three approaches) were compared against the bathymetric survey depth. The differences between prediction and measurement were then analyzed statistically and plotted. The accuracy tests are done using the following statistical equation:

$$R^2 = 1 - \sum_i \left(h_i - \hat{h}_i\right)^2 \Big/ \sum_i \left(h_i - \bar{h}\right)^2 \tag{3}$$

$$RMSE = \left(\sum_{i=1}^{n} \left(h_i - \hat{h}_i\right)^2 / n \right)^{0.5} \tag{4}$$

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{h_i - \hat{h}_i}{h_i} \right| \tag{5}$$

where h is measurement depth, $\hat{h}$ is estimated depth, $\bar{h}$ is the mean of the depth measurement value, and n is the amount of data.

III. Results and Discussion

Figure 3 shows the plot between measurement depth and estimate depth for each tested approach. The spectral RF graph indicates that the model predicts the depth value lower than the actual data. While the point cloud RF and spectral-point cloud RF show a better fitting curve. The spectral-point cloud RF became the best performance compared with the other two methods.

Figure 4 shows the accuracy metric for each tested approach based on 10-fold cross-validation. In the case of the spectral RF approach, a high variance on the accuracy metric shows that the models are not stable, and the selection of data for the learning process significantly affected the model. The usage of point cloud data to the model significantly improves accuracy, reaching ~1.5, ~2.5 m, and ~0.3 m for R^2, RMSE, and MAPE, respectively.

Figure 5 shows the depth map created from each tested approach. The area above 1.5 m below sea level is excluded in the analysis because the point cloud data cloud cannot generate from a dark reflectance. The depth distribution map from the spectral-point cloud RF models shows a smooth detail of spatial depth variation. The morphology of the reef area can identify as a flat reef, and a fringing reef indicates by slight, rapid depth drops.

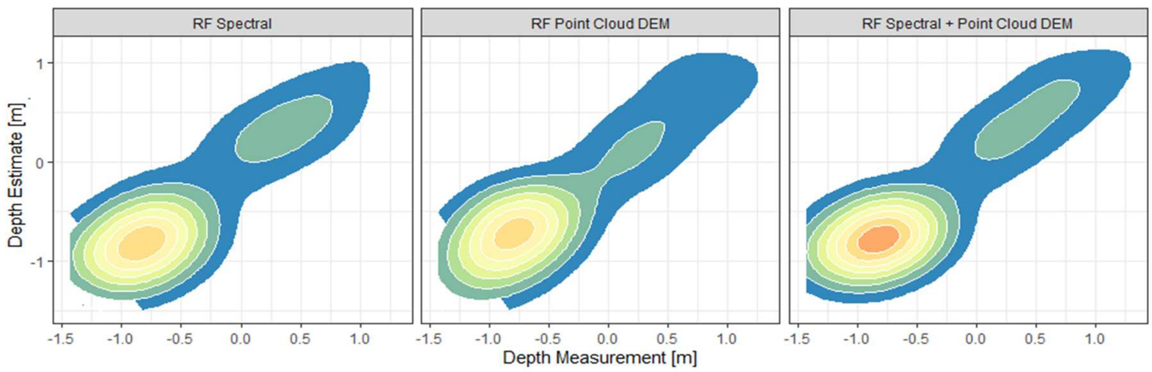

Fig. 3 Scatter density between predicted depth and measurement depth

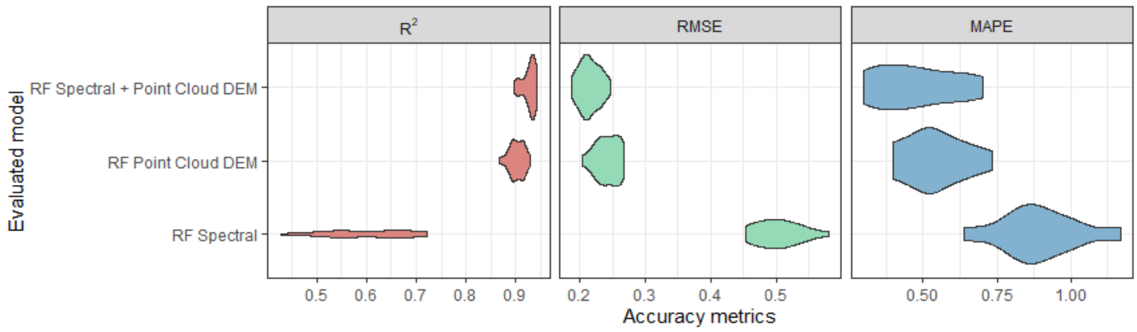

Fig. 4 Accuracy metric for each evaluated method

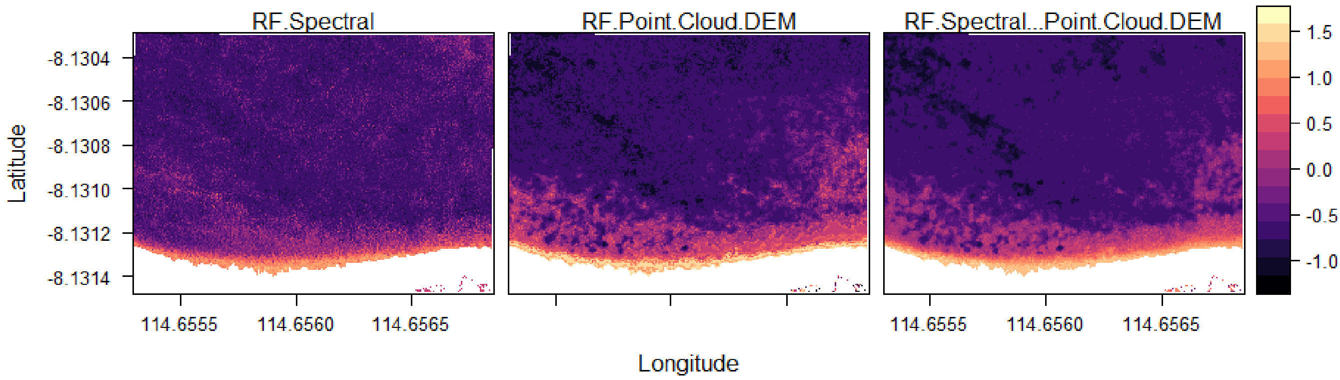

Fig. 5 Depth distribution map over-tested methodology

The algorithm that is commonly used in extracting 3D or morphological information is Structure from Motion (SfM). Due to the stereo mapping technique on coral reef ecosystems using data taken from aerial vehicles, it is not easy and has a high failure rate which can be caused by three factors, namely inconsistent spatial resolution, effects of shadows and sun angles, and wind and water movement effects [14], as issues also found in our study site. However, the accuracy from the spectral–point cloud still shows better accuracy than the common spectral-based SDB method.

Even the performance of the proposed approach shows a promising result. One downside regarding our methodology is the availability of actual bathymetric maps based on the bathymetric survey because of the limited number of measurements. Then the accuracy assessment is only based on several samples of measurement, not the spatial distribution that could be provided in this study.

IV. Conclusion

Based on this study, the information derived from the SfM UAV technique was found to be useful in improving the common spectral-based SDB method. Photogrammetry and UAV techniques are a trend in mapping coral reef ecosystems, and this is because satellite-based data has spatial and temporal limitations. The ability of UAVs to record detailed spatial and temporal information that can be adjusted has resulted in many studies starting to use them. UAV recording data generally uses multispectral sensors, so apart from being used for stereo mapping applications, it can also be used for object classification analysis as is done on satellite-based multispectral image data. Multispectral UAV technology can be used for detailed scale identification scopes with better spatial resolution and relatively affordable cost, as tested in this study. However, for studies on a regional scale or time series, the use of satellite data cannot be replaced.

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