Effect of angle increments and morphological complexity on the application of photogrammetry on the shells of *Turbo crassus, Angaria delphinus,* and *Thais aculeata*

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Abstract

Photogrammetry is the act of generating a three-dimensional model using photographs taken from various angles around an object. It can be applied in various fields such as designing in architecture and documentation in historical researches and calculating volume and irregularity in biological researches. This study aimed to determine the extent of agreement between photogrammetric measurements and the direct measurements. Specifically, effects of the morphological complexity of the specimens and the angle increments utilized in the acquisition of photographs were explored. To do so, three sea snail shells with varying morphological complexities were chosen as specimens. Photographs of the shells were taken with the following angle increments: 5°, 8°, and 12° and were run through Autodesk Recap Photo. Body length and width were measured directly and photogrammetrically. These were statistically analyzed using Bland-Altman Plots and Two One-sided Test (TOST) for Equivalence. It was found that the three-dimensional models produced are accurate representations of the objects. Furthermore, results showed that accuracy of the model increases as angle increment increases and that as complexity of the shell increases, so does the accuracy of body length measurements.

Keywords: *angle increments, morphological complexity, photogrammetry*

Introduction. Photogrammetry is the method of producing three-dimensional models using a series of overlapping photographs taken from different locations around the object [1]. It has been utilized in various fields of research, particularly in archeology and in biology. The use of photogrammetry in archaeological research mainly involves the recording and modelling of the topography of an area and the detection and mapping of archaeological sites and features [2]. It has also been applied in biological studies involving the quantification of various body measurements of organisms including corals, sponges, caddisflies, dolphins, and sea lions [3,4,5,6,7]. From these studies, it has been shown that three-dimensional photogrammetry is able to generate accurate models of numerous subjects.

Many factors affect the accuracy of the three-dimensional model generated from photogrammetry. To maximize the quality of the model produced, expensive equipment has often been utilized; however, recent research has shown that smartphone cameras and open-source photogrammetric software can be utilized in three-dimensional reconstruction studies without sacrificing the quality of the three-dimensional models produced [1,2,8].

Shape and structure of the object are also factors that can affect the accuracy of the three-dimensional model produced by photogrammetry [3,9]. In the study, three-dimensional models of the shells of *T. crassus*, *A. delphinus*, and *T. aculeata* with varying morphological complexity were generated. The extent of the agreement between measurements obtained through photogrammetry and direct measurements was determined to validate the use of photogrammetry as done by another study [10]. Additionally, research has shown that angle increments can affect the accuracy of the model; however, a standard for angle increments has not been made yet [9]. Thus, the proposed study also explored the effect of angle increments on the accuracy of the model produced.

In particular, effects of the morphological complexity of the specimens and the angle increments utilized in the acquisition of photographs were explored.

This study aimed to determine if measurements of specimens with varying morphological complexity computed from photogrammetry are comparable to measurements obtained directly on the specimens. It specifically aims:

(i) To explore different angle increments (5° ,8°, 12°) when taking photos of the specimens

(ii) To apply photogrammetry in making digital three-dimensional models of specimens with a.) simple, b.) moderate, and c.) complex morphologies

(iii) To measure body length and body width of the specimens

(iv) To determine the extent of the agreement between measurements obtained through photogrammetry and directly

Methods. In this study, shells of varying morphological complexities were collected from

Ajuy, Iloilo and were subjected to identification by the National Stock Assessment Program of the Bureau of Fisheries and Aquatic Resources (BFAR - NSAP). The shell specimens were placed on a rotating platform and photographs were taken at three angle increments, specifically, 5°, 8°, and 12°. The photographs were then imported into the Autodesk Recap Photo software and the three-dimensional models of the specimens were generated. Body length and body width of the shells were measured directly using a vernier caliper tape measure while the same measurements of the three-dimensional models were measured photogrammetrically using the measurement tool in Autodesk Recap Photo. These measurements were then statistically analyzed using hypothesis test for equivalence and Bland-Altman plots.

Materials and Equipment. A local resident of Ajuy was hired to gather shells that fit the descriptions used in this study. The shells were gathered from Nasidman island and Calabasa island, Ajuy. The shells' sizes range from 2 cm up to 5 cm. Permission to use the shells as specimens was requested from the mayor of Ajuy prior to the gathering of the shells. The shells were verified by the National Stock Assessment Program of the Bureau of Fisheries and Aquatic Resources to be the shells of *T. crassus*, *A. delphinus*, and *T. aculeata*. Each species was selected to represent one of the three morphological categories, namely, simple, moderate, and complex.

The 16-megapixel rear-facing camera of a Samsung Galaxy S6 edge was used to acquire the photographs. The choice of camera was based upon functionality and availability. A standard camera tripod with phone attachment was used.

The platform was designed to have two circular layers with varying diameters. The first layer had a white surface on where the specimens were placed. The second layer had a longer diameter and had angle indicators. The platform was commissioned.

Classification of Specimens. The definition used for classifying simple, moderate, and complex morphologies was adopted from the study conducted by Abdo et al. [3]. The specimen with the least rough exterior and with no major protrusions relative to the other specimens was classified as simple. Thus, the *T. crassus* shell was utilized to represent the simple morphology. The specimen with a rough exterior and with a modest amount of protrusions relative to the other specimens was classified as moderate. Thus, the *A. delphinus* shell was utilized to represent the moderate morphology. The specimen with the roughest exterior and with both protrusions and concavities relative to the other specimens was classified as complex. Thus, the *T. aculeata* shell was utilized to represent the complex morphology.

Acquisition of Photographs. Specimens were washed with distilled water and left for two hours to air dry. Afterwards, specimens were placed onto a rotatable white platform with angle indicators. The 16 megapixel rear-facing camera of a Samsung Galaxy S6 edge was used to acquire the photographs. The phone was placed in a tripod with tilt angle indicators to facilitate the tilting.

Photographs of the specimens were taken at varying rotation angle increments (5°,8°, 12°) with 0° as the starting point. This was repeated at two tilt angles with reference to the ground (0° and 45°). For the tilt angle 90°, only one image was taken since the image is the top view of the specimen. For photographs taken at angle increments of 5°, 145 photographs were utilized to create a three-dimensional model. For photographs taken at angle increments of 8°, 91 photographs were utilized to create a three-dimensional model. For photographs taken at angle increments of 12°, 61 photographs were utilized to create a three-dimensional model. This was done thrice for each specimen and, thus, 27 three-dimensional models were generated overall.

Generation of Three-dimensional Models. Autodesk Recap Photo was utilized in this study. The application allowed a maximum of 300 photographs per upload and, thus, was able to accommodate all of the setups. The photographs taken were imported into the software and were run through it to create a three-dimensional object.

Acquisition of Body Dimensions of Specimens. Two linear body dimensions were measured, namely body length and body width. Body length was measured as the distance from the apex of the shell to the base of its aperture and the body width was measured at the diameter of the greatest whorl. The specimen was measured to the nearest 0.1mm using a vernier caliper. This was done thrice and their mean values were calculated. The same body dimensions were measured using the three-dimensional model produced photogrammetrically. To do so, the measurement tool in Autodesk Recap Photo was utilized.

Data Analysis. As done in the study conducted by Lee. et al. [10], a Bland-Altman plot was used to compare the photogrammetric measurements with the measurements obtained directly from the specimen. In this graphical method, the differences between two measurements are plotted against the averages of the two measurements in a scatter diagram. Horizontal lines are drawn at the mean difference, and at the limits of agreement. The limits of agreement are defined as the mean difference ± 1.96 SD of differences. This will provide visual and qualitative assessment of the agreement between the two assays. The assays were considered to be in agreement if all of the pairwise difference between them are within the limits of agreement.

Two One-sided Tests (TOST) for Equivalence was also used to evaluate the agreement between the two measurements. To test equivalence, the null hypothesis was that the difference between the means was outside the equivalence interval. The alternative hypothesis, on the other hand, was that the difference between the means was inside the equivalence interval. This statistical analysis was done using the XLSTAT, statistical software for Microsoft Excel. The application offers two equivalent methods to test equivalence using the TOST test. In the first method, the 90% confidence interval around the mean is utilized. By comparing the confidence interval with the equivalence interval, equivalence or non-equivalence can be concluded.

The other method utilizes two one-sided tests, one on the right and one on the left. The right one-sided t-test is applied on the lower boundary of the equivalence interval while the left-sided t-test is applied on the upper boundary of the equivalence interval. P-values are then obtained for both tests and the greatest of the two is taken as the p-value of the test. Both methods were done in this study.

Safety Procedure. The shells were thrown into a trash bin after the conduct of this experiment.

Results and Discussion. Previous studies have found that the shape and structure of the object can affect the accuracy of a three-dimensional model [9]. The importance of object shape as a source for additional error introduced when modelling irregularly shaped objects has also been recognized in another study [7]. In this study, the specimens were irregularly shaped and were of varying morphological complexities.

Table 1. Results for Two One-sided Test for Equivalence using P-values.

Measurement	Angle Inc.	P-Value		
		Simple	Moderate	Complex
Body Length	5°	0.0003	0.0002	<0.0001
	8°	0.0002	<0.0001	<0.0001
	12°	<0.0001	<0.0001	<0.0001
Body Width	5°	0.0041	0.0006	0.0032
	8°	0.0002	0.0002	<0.0001
	12°	<0.0001	0.0002	<0.0001

Results of the hypothesis test for equivalence using P-values for body length measurements showed that accuracy was greatest on the shell with complex morphology (Table 1). On simpler subjects, accuracy decreased. This result can be related to the lack of surface features on the simple model. Variables such as presence and dimensions of reference features or edges on the area of interest can influence reconstruction accuracy [9]. Furthermore, a previous study reported that a lack of features limits the creation of a sufficient point cloud for accurate three-dimensional reconstruction by the software, resulting in an underestimation [3]. Body width measurements, on the other hand, showed no consistent trend. This could be due to an error in the measuring of the shells. In measuring the body length directly and digitally, it was easy to locate the apex of the shell and the base of its aperture since the two are distinct ends. On the other hand, measuring the diameter of the greatest whorl was different.

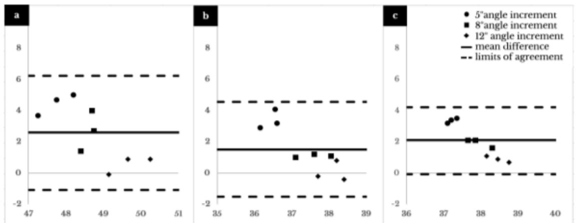

Figure 1. Comparison of direct and photogrammetric body length measurements of shells with (a) simple, (b) moderate, (c) and complex morphologies.

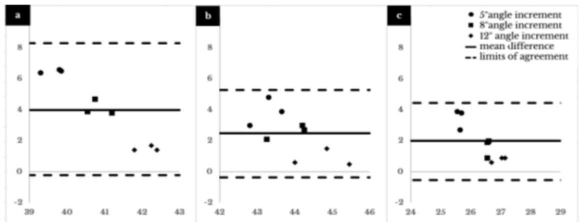

Figure 2. Comparison of direct and photogrammetric body width measurements of shells with (a) simple, (b) moderate, (c) and complex morphologies.

This underestimation can be seen in the Bland-Altman plots presented in Figures 1-2 wherein the mean differences were above zero. Despite that, all photogrammetric measurements showed excellent agreement with the direct measurements. This is because the differences between the two types of measurements were all within the bounds set by the limits of agreement. These results were also reflected on the Two One-sided Tests for equivalence results. In all cases, the 90% confidence interval of the mean fell within the set equivalence interval; thus, it can be said that the measurements are equivalent.

Results of the two statistical analyses also showed that as angle increment increased, the difference between the measurements decreases; thus, it can be said that using a minimum of 12° angle increment in taking pictures of a specimen is sufficient enough to generate an accurate three-dimensional model using photogrammetry. However, because of the fact that photogrammetry relies on the overlapping of the images, further research is necessary to determine the maximum angle increment that is able to generate an accurate three-dimensional model.

Error Analysis. Measurement errors may arise from taking down the data from the vernier caliper and from choosing the points on the three-dimensional model used to measure photogrammetrically. To prevent this, both researchers cross examined the data recorded by the other at all times.

Conclusion. In conclusion, the models generated through photogrammetry were found to be accurate representations of the actual specimens and a minimum of 12° angle increments is sufficient enough to generate an accurate three-dimensional model.

Recommendations. The researchers recommend that camera calibration be done prior to the collection of photographs. The researchers also recommend the investigation of the effects of angle increments above the 12°.

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