Pre- and Self-calibration of underwater cameras for photogrammetric documentation of archaeological sites

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PRE- AND SELF-CALIBRATION OF UNDERWATER CAMERAS FOR PHOTOGRAMMETRIC DOCUMENTATION OF ARCHAEOLOGICAL SITES

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Abstract:

Underwater photogrammetry has become one of the most affordable and adopted methods for the documentation and the 3D reconstruction of submerged archaeological assets. In digital photogrammetry, images are captured to exploit (using computer vision-based procedures) their intrinsic metric contents. To preserve the metric consistency and to obtain reliable 3D metric products, this process must be followed according to photogrammetric principles that are even more important in underwater photogrammetry. The wide diffusion of low-cost and non-metric sensors requires that some attention be given to proper geometric calibration of the employed cameras. Via calibration, it is possible to opportunely describe geometric distortions that are observable on final images due to lens shapes and construction characteristics of the cameras and the optics used in the survey operations. This research addresses the importance of pre-calibration in underwater cameras, and for this purpose, three calibration datasets are acquired and compared: the first (A) where the camera is pre-calibrated without any addition (flat or dome ports); the second (B) in which the camera is used in combination with a dome port; and the third (C) where the camera setup has been employed in an underwater environment. For both scenarios (dry and wet), self-calibration and pre-calibration procedures are compared. Moreover, is possible to notice how the use of the right camera and lens combinations, specifically designed for underwater survey purposes, are functional to lower the distortion of the images and consequently improve the accuracy of the final 3D products. Different tests have been performed, and preliminary results are presented and discussed in this work-in-progress paper.

Keywords: underwater photogrammetry, digital archaeology, cultural heritage, 3D reconstruction, camera calibration, radial distortion

1. Introduction

Calibration of digital cameras for photogrammetric purposes is a well-known practice (Remondino & Fraser, 2006) and is an essential preliminary step for a correct 3D object reconstruction. Via camera calibration, it is possible to obtain intrinsic camera parameters (f, c_x, c_y, k_1, k_2, k_3, b_1, b_2, p_1, p_2) that allow for describing the interior orientation and the lens distortion. Knowing these parameters is essential as they can be used for generating undistorted images to be used for metric purposes.

There are, however, different methods and strategies for calibrating digital cameras. The most commonly available photogrammetric suites that use computer vision algorithms allows performing the so-called *self-calibration* of the camera (Fraser, 1997). In this standard approach, it is possible to reach accuracy improvements up to a factor of 3 (Gruen & Beyer, 2001) compared to a situation where no camera calibration is performed. This approach proved to be effective even in the case of non-metric and non-conventional Low-Cost photogrammetric sensors (Perfetti, Polari, & Fassi, 2018).

In situations where the conditions do not significantly change between the calibration and the survey phases, it is possible to pursue a *pre-calibration* strategy. In pre-calibration, the camera is calibrated in a controlled environment (using a calibration polygon) or with ad-hoc procedures (employing calibration panels with checkerboard or dot patterns) in order to obtain a set of intrinsic parameters to be used as an initial guess during the self-calibration phase performed before or during the BBA (Bundle Block Adjustment) in a typical photogrammetric workflow.

While the first option is the most common in data acquisition situations, especially in archaeology (Rodríguez-Martín & Rodríguez-González, 2020), it is still possible to observe a consistent gain in the accuracy of the survey whenever a robust self-calibration

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procedure is conducted; when correctly performed this will pay back in lower reprojection errors. This aspect is essential mostly when a photogrammetric survey is conducted in underwater environments (Fryer & Fraser, 1986), as additional distortions are introduced due to the different refractive indexes of the two mediums (the water and the air), and due to the geometric characteristics of the flat or dome port that could be used (Menna, Nocerino, & Remondino, 2017).

This research aims to investigate the pros and cons of pre- and self-calibration approaches when underwater cameras are used in combination with dome ports, both in subaerial and in submerged situations. At first, the materials and methods adopted in this research are introduced. Then results with a comparison of different camera configurations are presented, and the observable gain in accuracy is discussed. In the end, conclusions and future perspectives of this work-in-progress paper are outlined.

2. Materials and methods

The material used in this paper is related to three datasets of images acquired using a Nikon Z7 mirrorless camera (sensor diagonal 43,13 mm; Pixel size 4,34 μm), equipped with a 14 mm Rokinon Cine DS lens. The camera was used in combination with a zen 230 mm glass dome port, to enhance the quality of images along the edges. This setup has been previously used in combination with other two identical cameras mounted on the *SeaArray*; a diver operated photogrammetric system designed by Marine Imaging Technologies (Calantropio et al., 2020; Wright, Conlin, & Shope, 2020).

The three datasets are comprised of images acquired to produce a geometric calibration of the sensors using a calibration checkerboard (Fig. 1) of 120x65 cm (with each square 5 cm in size). The acquisitions have been divided into three datasets:

- (A) Camera: Nikon Z7 with 14 mm Rokinon Cine DS lens: 42 images;
- (B) Camera + Dome port: As (A) with a zen 230 mm glass dome port: 41 images;
- (C) Camera + Dome Port Underwater: Same setup of (B) but employed in underwater condition: 83 images.

Figure 1: The calibration panel employed in the acquisition of the dataset (A) and (B) on the left; and the dataset (C) on the right.

3. Results and discussions

After the data acquisition, camera calibration was performed for the three datasets using the Single Camera Calibrator App of the Camera Calibration Toolbox for Matlab (Fetić, Jurić, & Osmanković, 2012). The results of this self-calibration procedure, based on (Heikkila & Silven, 1997), explicitly aimed at obtaining the values of the polynomial radial distortion coefficients, that are summarized in the following Table 1.

Table 1: Values of polynomial radial distortion coefficients and focal length (in pixels) for each of the three camera configurations employed.

Camera Configuration	*K_1 (pix)*	*K_2 (pix)*	*K_3 (pix)*	*f (pix)*
(A) Camera	-0.1257	0.0586	-0.0096	3328.63
(B) Camera + dome port	-0.1234	0.0731	-0.0093	3365.25
(C) Camera + dome port Underwater	-0.1081	0.0650	-0.0128	3678.33

In order to make a more straightforward comparison of the obtained parameters, the curves of the radial distortions have been graphed for the three datasets in the same diagram using MS Excel, as presented in Figure 2. The curves of radial distortion are described as a function of the radial distance from the centre of the sensor (Brown, 1971; Krauss, 1997), as presented in Eq. (1):

$$\delta r = k1\ \rho 3 + k2\ \rho 5 + k3\ \rho 7 \tag{1}$$

where:

- ρ = distance from the centre of the sensor
- k1*,* k2*,* k3 = polynomial coefficients of the radial distortions

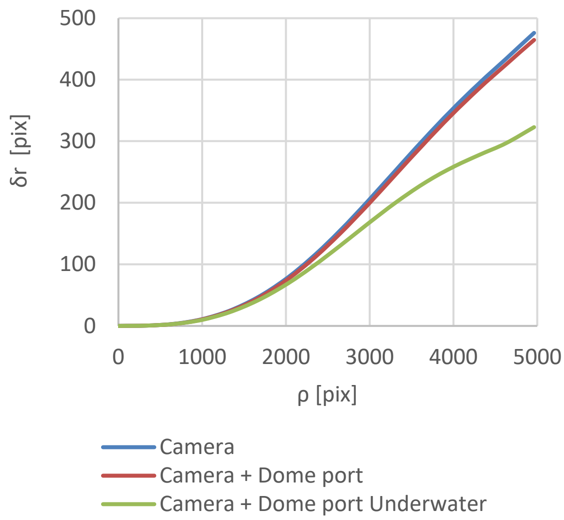

Figure 2: Radial distortion curves for the three camera configurations: in blue, the configuration (A), in red (B) and in green (C).

To also investigate how a pre-calibration approach can positively affect the quality of the survey, pre-calibration has been performed for the dataset (B) and (C). In doing so, the calibration certificate obtained from the self-calibration of (A) has been used as an initial guess for the pre-calibration of (B). Following the same principle, the calibration certificate obtained from the self-calibration of (B) has been used as an initial guess for the pre-calibration of (C). The comparison of the reprojection error when self-calibration or pre-calibration are performed, are shown in the following Figure 3.

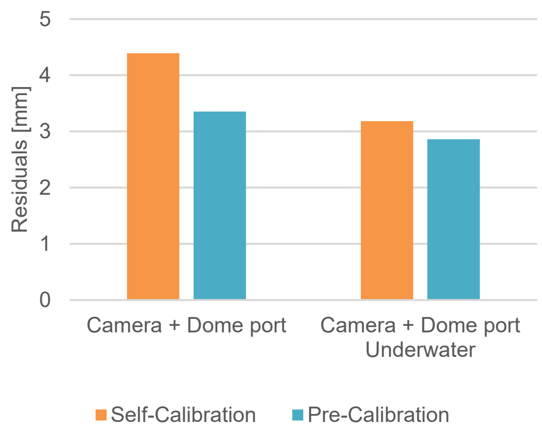

Figure 3: Comparison of the reprojection errors based on the values of the residuals, expressed in millimetres, for the datasets (B) and (C) both when self-calibration and pre-calibration are performed.

In this case, it is possible to observe how the use of a pre-calibration approach can further improve the quality of the survey, reducing the residual reprojection error of the self-calibration in a consistent way.

4. Conclusions

This paper focuses on the importance of the geometric calibration of a camera in underwater photogrammetric surveys for archaeological purposes. It is also presented how the adoption of pre-calibration strategies could increase survey accuracy, reducing the reprojection errors. It is also essential to underscore how calibration itself is undoubtedly an important step, but the proper use of specific cameras must accompany it. Underwater cameras and dome ports, specifically made for marine environments, are essential for lowering errors related to the presence of two mediums. Future research will be aimed at deepening these aspects.

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