

Calibration of Housing Parameters for Underwater Stereo-Camera Rigs

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Underwater imaging is becoming more and more popular as technology becomes available to explore the ocean floor at great water depths. Images captured below water are often utilized in algorithms exploring the implicitly contained geometry of the images. However, the necessary underwater housing changes those geometric properties due to refraction. Therefore, a proper camera model needs to be used for successful application of Structure-from-Motion (SfM) algorithms for reconstruction [1]. In a lot of applications, the perspective pinhole camera model is used by allowing focal length and radial distortion to absorb the model error [3].

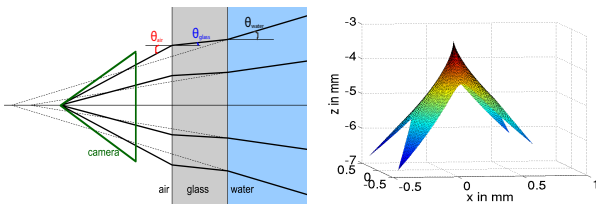


Figure 1: Left: camera with flat port. Note, that rays coming from the water do not meet in common center of projection. Right: rays are tangents to caustic instead of center of projection. Asymmetric nature is due to interface normal inclination with respect to image sensor.

However, as can be seen in figure 1 on the left, the single view point (SVP) assumption is invalid. Instead of having a center of projection, the rays coming from the water are tangents to a caustic, an exemplary one can be seen in fig. 1 on the right.

Refractive Camera Model and Error Functions This non-SVP nature of cameras in underwater housings induced by refraction causes a model error when computing 3D reconstructions using the perspective camera model. In order to eliminate this model error, refraction should be modeled explicitly (similar to [2]). However, in order to achieve that, the housing parameters need to be known. When working in underwater environments, using a calibration pattern for calibrating housing parameters is at best cumbersome, if not infeasible. This work therefore aims at developing a calibration routine for stereo images that calibrates the housing parameters without using a calibration target, by gaining the required correspondences from the images captured underwater. This is achieved by explicitly modeling the refraction of the camera at the glass interface, including equations for determining the points on the caustic. Note, that the projection from image coordinates to a ray in water can be modeled directly, however, the other direction, the projection of a 3D point into a 2D image point involves an optimization step for each projection.

Once correspondences between images have been established, and the initial camera poses and 3D points have been computed, the housing parameters can be computed using optimization algorithms. In the perspective case, the reprojection error is usually used for optimization, meaning, the error in the images is minimized. We considered 3 different errors for optimizing the housing parameters:

Reprojection Error in the image. 3D points need to be projected onto 2D points in the image using the current extrinsics, intrinsics, and housing parameters (time consuming in case of refractive camera model due to extra optimization step for each projection).

3D Error is determined between 3D points (sensitive to noise in correspondences).

Outer Interface Plane Error is measured on the outer interface (we build upon [4]). If the caustic points are known, a virtual camera can be defined for each 2D point in the image for which the 3D point can be projected perspectively (fig. 2).

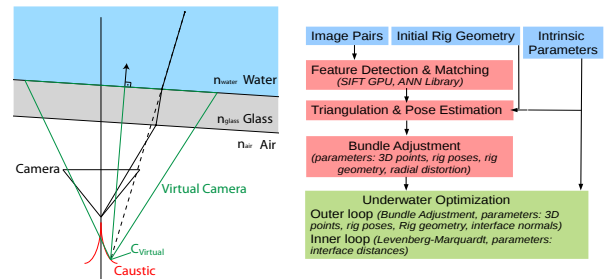


Figure 2: Left: virtual projection, right: system overview.

Algorithm and Results We experimented with two options. First, only the interface normal parameters were optimized, assuming the intrinsics and stereo rig extrinsics to be known. In a second option, we assumed a classic perspective SfM result [1], meaning perspectively computed camera poses, 3D points, and 2D correspondences. After that, the interface normal parameters and the interface distances of both stereo cameras were estimated using the algorithm summarized in fig. 2 on the right.

Experiments were conducted on both, synthetic and real data and showed that the method works for both, normal estimation and interface distance. Results for normal estimation on synthetic images can be seen in fig. 3 on the left. Normal estimation on real images showed that it is possible to robustly estimate the normal of the interface, which can be parametrized by two angles θ and φ . Since no ground truth is known in this case, the means and variances of different calibration trials need to be compared:

	φ_{left}	θ_{left}	φ_{right}	θ_{right}
$\bar{\varphi}$	6.887°	0.703°	168.430°	0.760°
var	2.38°	0.009611°	11.823°	0.219°

Results for estimating the interface distances can be seen in fig. 3 on the right.

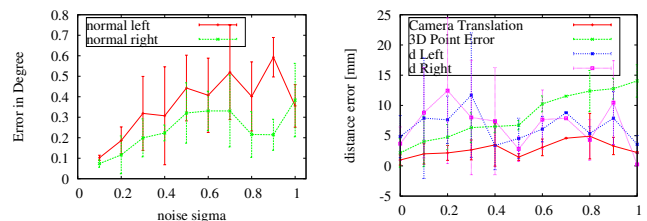


Figure 3: Left: results for normal estimation on synthetic data. Right: results for interface distance estimation.

- [1] R. Hartley and A. Zisserman. *Multiple View Geometry in Computer Vision (Second Edition)*. Cambridge University Press, second edition, 2004.
- [2] C. Kunz and H. Singh. Hemispherical refraction and camera calibration in underwater vision. In *OCEANS 2008*, pages 1–7, 15-18 2008.
- [3] Jean-Marc Lavest, Gérard Rives, and Jean-Thierry Lapresté. Underwater camera calibration. In *ECCV '00: Proceedings of the 6th European Conference on Computer Vision-Part II*, pages 654–668, 2000.
- [4] Gili Telem and Sagi Filin. Photogrammetric modeling of underwater environments. *ISPRS Journal of Photogrammetry and Remote Sensing*, 65(5):433 – 444, 2010. ISSN 0924-2716.