Standard Operating Procedure for Flat Port Camera Calibration

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1 Goal

This document specifies the practical procedure to obtain good images for geometric camera calibration at GEOMAR[1]. Geometric camera calibration means that for each pixel in the image the associated 3D ray in space is known with respect to the camera. This is useful for measuring with cameras, i.e. to reason about sizes, distances, angles, volumes, surfaces in 2D and 3D and to track the motion of a camera through space, see e.g.[2].

2 Applicability and Overview

This document is the first SOP for calibration and refers to the **intrinsic, geometric calibration of a single camera with flat port interface** that is submerged underwater, in particular how to capture the calibration data. Photometric calibration (intensities, colors) of camera, light and water properties is out of scope of this document and also geometric calibration of dome ports, stereo systems, camera-laser calibration or so called handy-eye calibration of a camera and a platform (e.g. ROV) or other sensors, has to be specified in further documents. Still, the principles about image capture, image quality and so on, carry on to other calibration tasks as well. In a first step the classical intrinsic camera calibration is performed in air to obtain the exact focal length and other lens parameters. Ideally, in a second step the camera is submerged underwater to obtain the refractive calibration, i.e. parameters such as flat port interface normal, thickness and distance. All images must be captured with the same zoom[1] and focus[2] setting.

3 Prerequisites

Handheld DSLR or action cameras can be calibrated by a single person. For more bulky equipment two persons are required: One person takes images, the other person changes the pose of the camera or calibration target. Required material can be divided into three parts, for documentation

[1] For zoom cameras, we recommend to calibrate them for the fully zoomed-out setting and to use this setting whenever optical measurements are desired. Contact the authors if you want to use multiple zoom steps of a camera.

[2] If fixed focus is not easily possible, autofocus or changed focus is acceptable. However, note that focus also can sightly change the local magnification ratio and can thus degrade the calibration performance.

- information about camera make and model (alternatively chip size in mm and image resolution in pixel), lens make, model and focal length as well as distance of lens to port, port material (glas, saphire,...) and port thickness. Might require a vernier scale or tape measure.
- cell phone or other camera to document the system setup and the calibration setup

for air-calibration

- camera to be calibrated (with power and possibility to shoot photos)
- calibration target (chessboard[3]) of appropriate sizes: Ideally it covers a large part of the image at the desired working distance. We have targets up to A0 size.
- lights, flash or enough sunlight
- laptop or other way to look at the images in full resolution

and, additionally, for underwater-calibration:

- (waterproof!) calibration target, can be the same as for air calibration
- diver, ropes, mounts or other mechanisms to move and fix chessboard relative to camera

In case not enough light is available, longer exposure times will be required. This requires both the camera and the calibration target to be absolutely stable to avoid motion blurred images (mounts, tripods, etc.). Motion blur happens when the camera is moved/rotated half a pixel during exposure time (this is typically less than $0.01°$ and happens quickly when hand-held). In case target or camera cannot be stabilized, rather than exposure time the ISO/ASA setting should be increased leading to more image noise.

Finally, it might be useful to bring a Siemens star like pattern (see figure 1) for judging the effective resolution at a certain distance and for focussing the camera. Waterproof calibration patterns are available at GEOMAR as well as pdfs if you want to print yourself.

4 Procedure

The calibration procedure contains a step for calibration in air and a step for calibration in water. In both cases the calibration target is presented to the camera and captured in various different poses (10-20). The calibration in air can be done behind the flat port, however if possible calibration should be done without the port, as the air-glass-air transition also changes the optical path. If calibration in water is infeasible, instead high resolution photos of the setup should be taken with an external camera and the setup (distance of camera lens to glass port, glass port thickness) should be measured as precisely as possible using tape measures etc. The refraction-related parameters will then be optimized from the actual data (self calibration), if possible. Reassembling camera, lens, mount, zoom or focus will change the optical parameters. It is important to do the calibration only after the final setup has been made and to keep this setup for data capture.

4.1 Camera, sensor and mode considerations

Video vs. Photo. Videos can be considered sequences of photos. In principle, and for photogrammetry, videos and photo sequences are equivalent and differences are only in required storage/bandwidth, compression, format or whether or not rolling shutter effects may be present.

[3]From practical experience, chessboards are easy to make and to handle, both during image capture, but also later for processing. Under controlled conditions and with good preparation, results might be further improved in case a more complex 3D calibration target is used, but the procedures are out of scope of this document, which addresses also the non-expert.

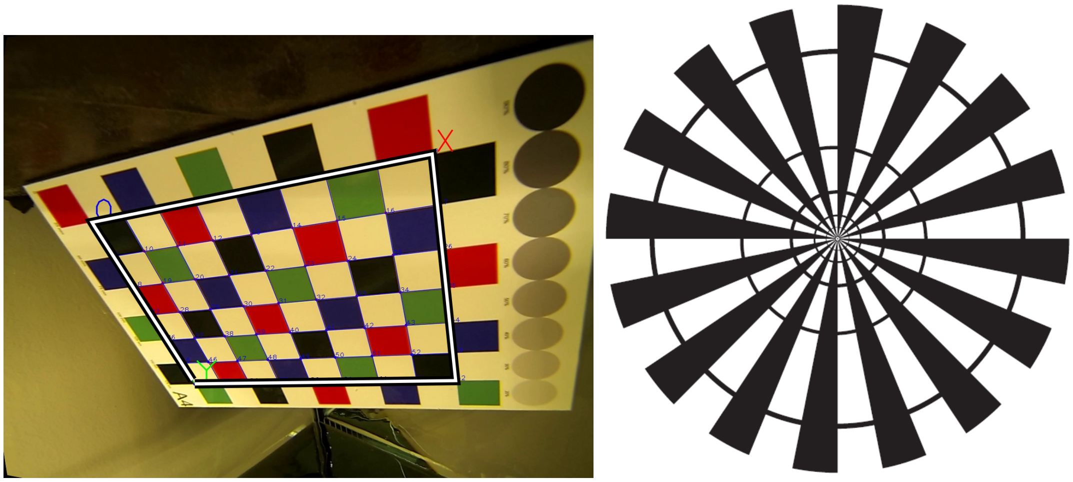


Figure 1: Left: Inner corners used for calibration. The region indicated by the rectangle must be visible in all calibration images. Right:Star pattern for focussing and determing sharpness of an image.

Compression. For the best possible reconstructions, raw or uncompressed formats allow the best results, however they also mean substantial overhead in storage and processing. Very often, jpeg compression of photos yields good quality images and reasonable sizes (loss of detail happens however in dark areas, e.g. at the boundary of the light cone, those cannot be recovered after compression). A good compromise is often to set the format to jpeg, but with as little compression as possible and highest details. Similar considerations apply to video compression (mpeg etc.).

Interlacing. If your camera is planned for use with automated techniques, avoid "interlaced" settings. This is a "compression" technique of analogue television of the last century that has been made obsolete by video compression. Interlacing means that in the first image of a video (a field) only the odd scanlines are captured. In the next image, only the even scanlines are recorded and so forth. In scenarios with motion this leads to comb artefacts. Set the camera to "progressive" if possible.

Rolling Shutter. Modern, and particularly, cheap, cameras employ CMOS sensors with a so-called rolling shutter. This means that an image is not "shot" in an instant but that scanlines in an image are recorded sequentially. If the camera or the object is moving, this leads to shear, wobble or jitter and complicates measurements substantially.

4.2 Preparation and setup of imaging parameters

Check that the internal time/date of the camera is set properly and that it records images in desired resolution and format. Fix the zoom. Find out what is approximately the field of view of the camera (read manual or take a test image). This helps to determine a good working distance. Clean the lens. Position the chessboard in front of the camera such that it covers most of the image. The camera must see all inner corners of the chessboard at all times, compare figure 1 in each image. Focus the camera and select the aperture such that the depth of field spans at least over the whole chessboard roughly plus/minus the longest dimension of the chessboard. If unsure, prefer a higher F-number to avoid out-of-focus images. Make sure there is enough light such that the images are not noisy. If too little light, increase the exposure time. Remember to mechanically stabilize the system and to avoid motion blur in case long exposure times are selected. Take a picture with your cell phone to document the setup. This might also be useful for a later paper to document the system.

4.3 Capture of Photos in Air

Capture 20 sharp photos in different poses in air. It does not matter whether you move the camera or the calibration target as only the relative pose is relevant. The calibration software will try to automatically detect all corners in all images, therefore avoid shadows or reflections from the light source and dont cover the chessboard with your fingers. Given the detected corners, the calibration software will then estimate an individual chessboard pose per image and concurrently optimize a common focal length and distortion parameters for all images. Varying the poses avoids ambiguities between the parameters (e.g. for almost frontal photos, focal length and distance to the chessboard are highly correlated). Therefore, cover all possible perspectives (frontal, oblique, diagonal, rolled, from close, from far), see figure 2.

In order to calibrate not only the image center, include images where the inner chessboard corners come close to the image boundary, idealy to the image corners. Images where the chessboard is bigger are preferrable over those where it covers only a smaller region, however both types should be included. Images, where the chessboard fields are extremely small (below 5 pixels) are of very little use.

Caveats

- Avoid looking into the sun or photographing into the sun direction.
- Avoid reflections from flash, sun or bright lights on the chessboard.
- Avoid casting shadows onto the chessboard. It is ok if the chessboard is completely in the shadow or completely not in the shadow for some images, but shadow boundaries on the chessboard can confuse the corner detection algorithm.
- Avoid motion blur.
- Dont cover the chessboard with your hands.
- Dont zoom. Dont change camera to port setup.
- Dont put other chessboards in the background that could confuse the detector.
- Dont bend the target, it should be a perfect plane. If you printed the target yourself, make sure the squares are square and that you know the size of the squares. Write down these numbers.

4.4 Capture of Photos in Water

Keep in mind that the field of fiew is significantly reduced underwater, so you have to go approximately 30% further away than in air. After the camera and the port is submerged, clean the port and remove bubbles stucking to it. Essentially, repeat the calibration procedure from air. Avoid ropes or other instruments to occude parts of the chessboard. Avoid flickering caustics from sunlight on the chessboard.

4.5 Quality Control

After images have been captured, view all images. For each image, check:

- Are all inner corners visible ?
- Are there shadows, reflections or other chessboards/patterns that might disturb detection ?
- Is the image sharp (not too noisy, defocused or motion blurred), see figure 4 ?

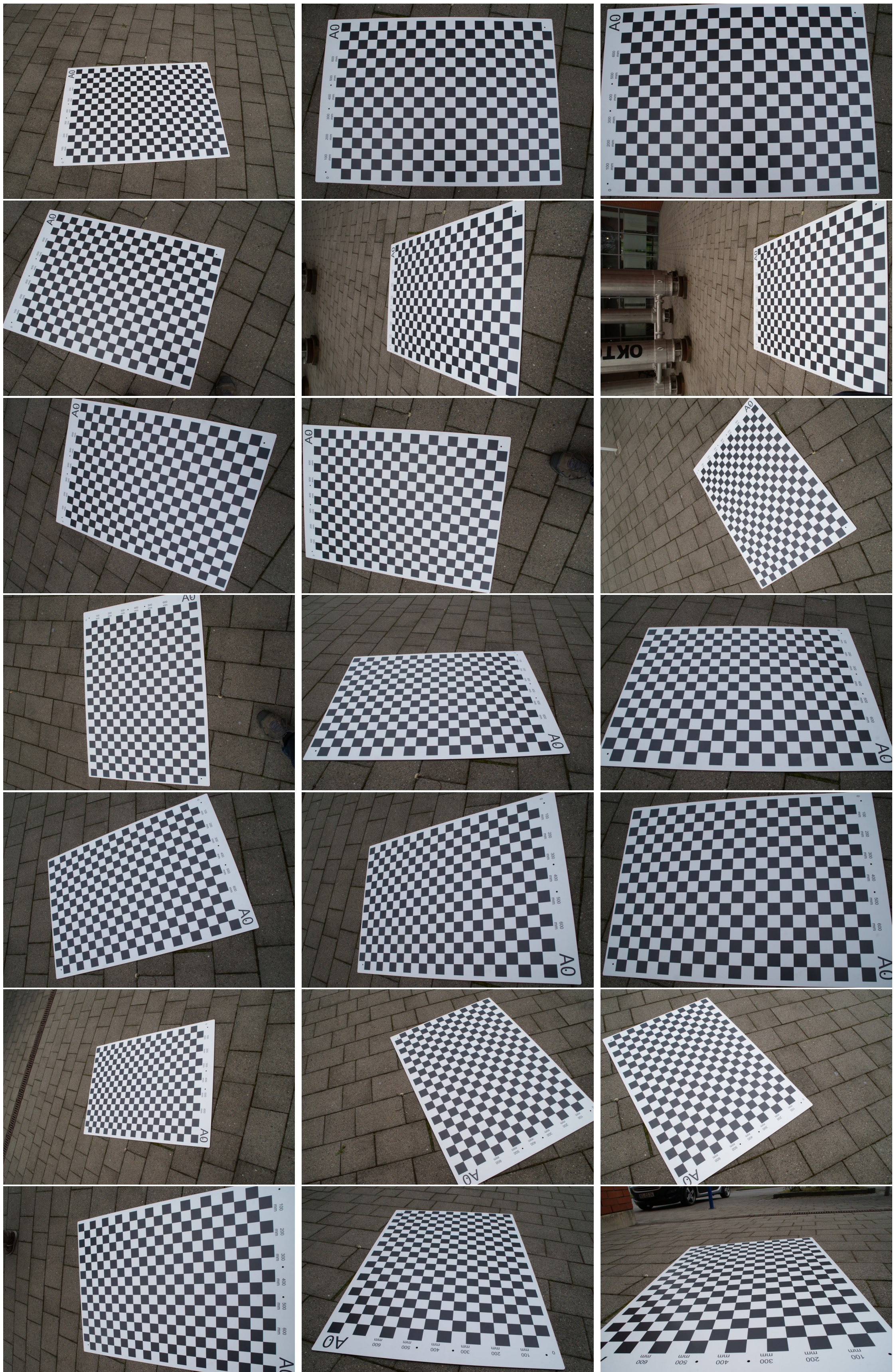
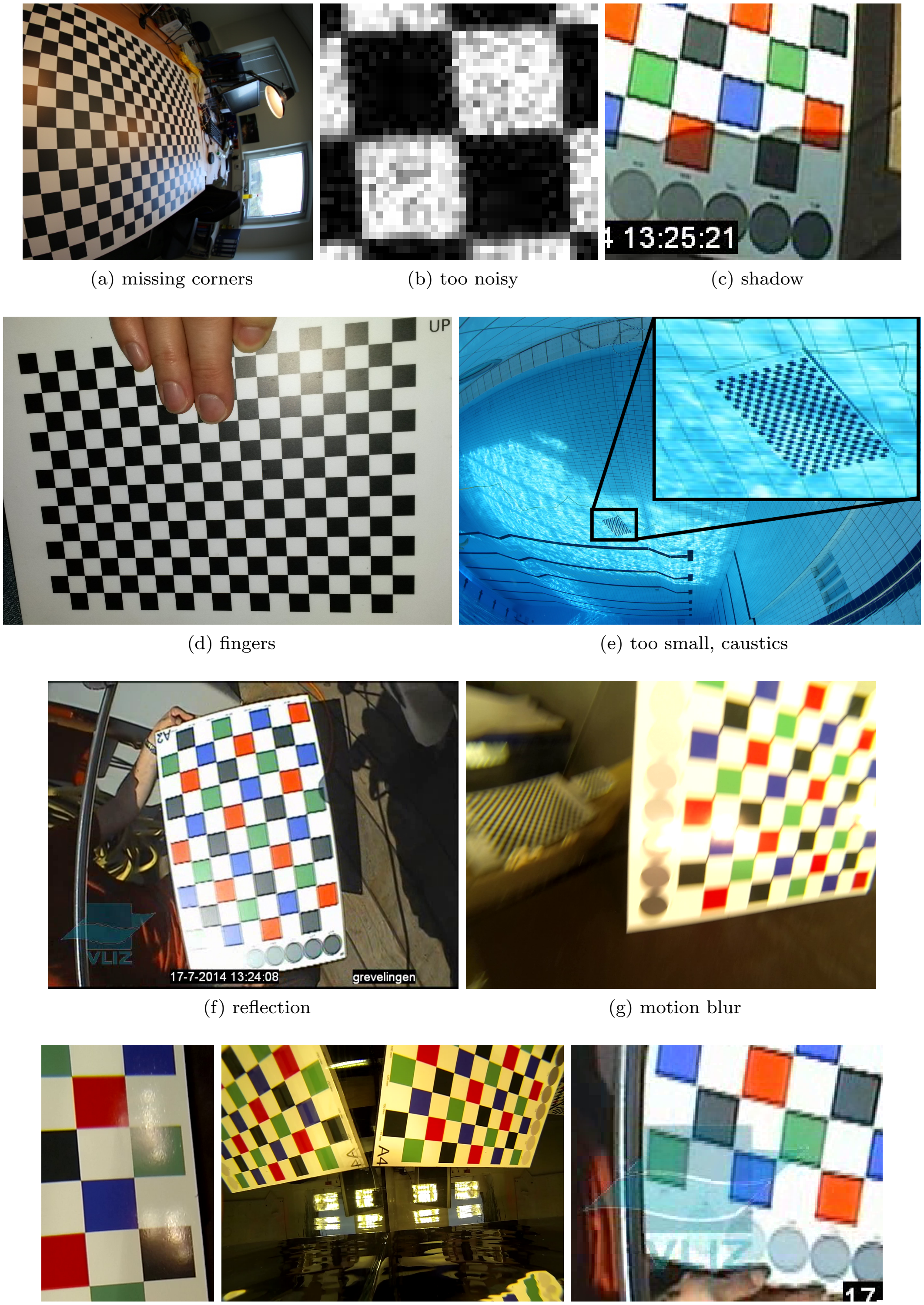


Figure 2: Chessboard presented in various different poses. All inner corners must be visible in all images.



(a) missing corners (b) too noisy (c) shadow

(d) fingers (e) too small, caustics

(f) reflection (g) motion blur

(h) reflections (i) reflected chessboard (j) logo

Figure 3: Bad images.

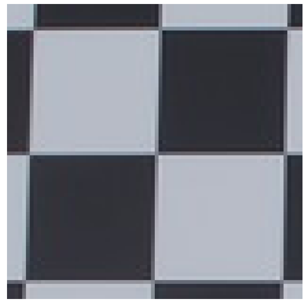


Figure 4: Acceptable sharpness and jpeg artefacts.

Erase all images, where not all of the above things hold.[4] For the whole set (e.g. all pictures in air) check:

- Did you cover a good variety of poses (at least 10 different, like frontal, oblique, rolled)
- Have you taken pictures where the chessboard came close to the image boundaries ?

If something is missing, take more pictures (too many is safer than not having enough).

5 Result and Documentation

Create a folder with a name like cameracalibration-20150321. Create a readme.txt file inside. The file should contain the camera, lens and port data mentioned above as well as any extra settings you have made, like zoom step, exposure time, aperture and so on. Additionally, write who performed the calibration, name of the cruise, station or place. Put the cell phone documentation photos of your calibration setup in that folder. In case the camera is mounted on some platform or vehicle, document the mounting position and orientation. Ideally perform a hand-eye calibration (but out of scope of this document). Create a subfolder “air” and another subfolder “water” where you put the respective photos. The images can be used for camera calibration according to [1] or similar approaches (contact the authors at GEOMAR if unsure).

6 Additional Information

This document, as well as calibration patterns and further information and material can be obtained from

http://www.geomar.de/en/cameracalibration

References

[1] A. Jordt-Sedlazeck and R. Koch: Refractive Calibration of Underwater Cameras. In Computer Vision – ECCV 2012, pp. 846-859, Springer, 2012, doi 10.1007/978-3-642-33715-4_61

[2] A., Jordt, K. Köser and R. Koch: Refractive 3D Reconstruction on Underwater Images, Methods in Oceanography, Volumes 15–16, 2016, pp. 90-113, doi 10.1016/j.mio.2016.03.001

[4] In case it is not possible to produce sharp images at full resolution, it is possible to downsample images afterwards. However, calibration quality from low-resolution photos might be degraded.

Checklist

Preparation

- prepare cables, lights, notebook, mounts/ropes for underwater
- choose appropriate chessboard, distance
- set camera time/record mode/format/resolution/zoom
- write down setup/hardware parameters such as camera/lens make, model, port distance, material, thickness and take photos of setup

Image Capture

- set ISO/focus/exposure time to avoid motion blur
- keep all inner corners visible at all times
- cover all possible orientations (+/- 30° from frontal) and vary the distance from full image coverage to 1/3 image coverage
- take close pictures (big chessboard) where inner corners are at the image boundary or even image corner

Quality Control

- all inner corners visible and nothing else on chessboard (reflections, shadows, occlusion, overlay, finger, rope, out of image) ?
- sharp image (noise, defocus, motion blur) ?
- covered also oblique perspectives, image boundary and have more than 10 high quality images (the more the better) ?
- store photos and documentation in a safe place