Thesis Statements

1. Underwater imaging devices are characterized by a transition of the entering light through different media, such as the very common water-glass-air transition in a Flat Refractive System (FRS), and therefore get affected by the physical phenomenon of the refraction of light. Refraction poses a problem to every discipline aiming at the recovery of metric 3D structure from underwater image data. In contrast to lens distortion, distortion due to refraction is distance-dependent and therefore not an image space distortion.

2. The common strategies to handle refractive effects are their disregard, their absorption or their explicit modeling. The first two essentially consider refractive effects to be image space distortions and are based on image formation following the pinhole camera model, which is invalid for underwater image formation due to refraction. Consequently, the disregard needs to be avoided and the absorption should be avoided, since the required setups represent a severe restriction and the elimination of refractive effects is incomplete. With both of these strategies, an accurate 3D reconstruction is not possible. The only way to handle refractive effects physically correct is their explicit modeling, which in turn requires the calibration of the modeled refractive parameters.

3. An underwater image formation model that represents the parametrization of a stereo camera in front of a single flat refractive interface is the model for a Shared Flat Refractive System (SFRS). There are multiple practical configurations of imaging setups that can be represented by it and although being more specialized than single camera systems, it can be designated as a representative of a common viewing condition. The model for a SFRS comprises a master and a slave camera and shows beneficial properties that make it worth to adjust the basic design of the imaging system accordingly. An exemplary benefit is the reduction of the refractive parameters, since these have to be estimated just with respect to the master camera.

4. The refractive parameters modeled by the SFRS have to be determined by refractive calibration. These are the refractive indices of the participating media, and the so-called system axis and air layer thickness, which essentially represent the orientation and the distance of the master camera to the flat refractive interface, respectively. However, since the refractive indices are in general measurable, commonly known (air and water) or known from manufacturer data (underwater housing), they can be excluded from algorithmic determination. The system axis can be determined independently of the air layer thickness.

5. The refractive calibration of a SFRS can be realized by two different strategies, which can be distinguished by an implicit (simultaneous strategy) and an explicit system axis determination (consecutive strategy). The consecutive strategy can be realized by determining the system axis with the aid of calibration objects with feature points arranged in straight lines and a following determination of the air layer thickness for that system axis. In contrast, the simultaneous strategy can be realized without any calibration objects.
6. A Virtual Object Point (VOP) model is a beneficial extension for underwater image formation models. The VOP model can be readily integrated into the underwater image formation models of monocular and binocular vision. The combined models amount to an efficient tool for the extension of the concepts of stereo 3D reconstruction in air for underwater environments with an explicit consideration of refractive effects.

6.1. The simultaneous and the consecutive strategy for the refractive calibration of a SFRS both benefit from the integrated VOP model. Based on the VOP model, an optimization problem can be defined for the determination of the air layer thickness of a SFRS. This optimization problem can be solved efficiently by linear optimization and can be realized within both calibration strategies.

6.2. Reoccurring operations within the concepts of stereo 3D reconstruction are refractive projections for coordinate transformations between 3D and 2D spaces. Within a refractive system, these are the computationally intensive refractive forward projections and refractive back-projections. The integration of the VOP model serves the development of alternative strategies and the reduction of the computational expense. Together with these refractive projections, the VOP model furthermore benefits the computation of adapted and novel cost functions and the definition of optimization problems for the determination of the system axis of a SFRS in an iterative fashion.

6.3. Refractive calibration is the first necessary step of underwater stereo 3D reconstruction. For the actual recovery of 3D coordinates with an underwater stereo camera, corresponding pixels in the left and the right view of the stereo camera need to be computed by stereo matching. Due the invalidity of the pinhole camera model for underwater image formation, epipolar geometry gets invalid as well. An alternative is the computation of correspondence curves based on refractive projections. Finally, the actual recovery of 3D coordinates can be realized with the aid of refractive projections as well.

7. A valid approach for benchmark data generation for the evaluation of the developed approaches with real test data can be realized with the aid of a calibration object that is fixed to the stereo camera in a solid construction. With such a construction, it is possible to compute a benchmark 3D point cloud with respect to the stereo camera in air. This benchmark 3D point cloud can in turn be utilized for the implicit evaluation of the refractive parameters by explicit evaluation of a recovered 3D point cloud. It represents a simple and efficient means for the evaluation of underwater stereo 3D reconstruction.