Quantitatively accurate 3D underwater scene reconstruction from imagery: challenges and solutions

Dr. Yuri Rzhanov

Center for Coastal and Ocean Mapping, University of New Hampshire, USA

3D reconstruction of objects, topography, and urban scenes from in-air imagery is a well-researched subject. There exist a variety of techniques allowing for conversion of unordered set of photographic images into a solid textured surface. Some repositories, such as Middlebury, maintain datasets with ground truth and estimates of reconstruction errors for considered techniques. In the recent decades, underwater imagery – of corals, fish species, geological formations, etc. – has become the part of routinely collected data. However, use of these data for accurate reconstruction is still a challenge. Most researchers collect imagery only for observation and annotation purposes. Thus they often use cameras of opportunity, without any prior calibration. Camera positioning, which is also crucial for successful 3D reconstruction, is known underwater with much larger uncertainty than in air, due to unavailability of GPS. Almost all cameras available on the market are designed for work in air, which means that underwater they have to be in a waterproof housing. This makes the problem of reconstruction even more complex as it requires to take into consideration the effects of refraction – bending of light rays on the interfaces between media with different speed of light. And last but not least – refractive effects also cause chromatic aberration, leading to color changes in addition to that due to wavelength-dependent absorption of light in water.

All the above mentioned effects make 3D reconstruction underwater extremely challenging. Use of techniques designed for in-air imagery usually results in a nice looking 3D model, which, in fact, may have wrong dimensions, proportions, and color. Attempts to feed these models to recognition and classification algorithms are bound to fail or to provide incorrect results. To overcome these problems we have developed an extensive simulation framework, accounting for effects of light propagation through water and refractive interfaces. Extensive numerical simulations allowed for determination of optimal conditions for underwater image acquisition, including camera(s) calibration. A rig with five cameras was built and calibrated intrinsically (individual camera properties) and extrinsically (positioning of cameras with respect to each other). A novel technique for determination of parameters responsible for refractive effects has been proposed and verified in numerical and real experiments. We have constructed several targets imitating various types of seafloor and acquired ground truth 3D models using Kinect2 sensor in air. All models' reconstructions – from images acquired in air and in water - were compared to these ground truth models, and reconstruction errors were estimated.

The data obtained from numerical simulations and real experiments allowed for formulation of requirements for hardware, water properties, and acquisition conditions that guarantee that the reconstruction error does not exceed some specified value.