Underwater Image Systems Simulation

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Abstract: We use modern computer graphics tools such as ray-tracing, digital camera simulation tools, and a physically accurate model of seawater constituents to simulate how light is captured by the imaging sensor in a digital camera placed in underwater ocean environments. Our water model includes parameters for the type and amount of phytoplankton, the concentration of chlorophyll, the amount of dissolved organic matter (CDOM) and the concentration of detritus (non-algal particles, NAP). We show that by adjusting the model parameters, we can predict real sensor data captured by a digital camera at a fixed distance and depth from a reference target with known spectral reflectance. We also provide an open-source implementation of all our tools and simulations.

1. Introduction

In this paper, we describe an underwater camera simulation environment that combines ray-tracing techniques with physically accurate sensor simulations to predict the images captured by different cameras under different underwater viewing conditions. We also describe a simple image formation model that establishes a link between underwater scene appearance and biological and physics-motivated parameters, such as chlorophyll concentration, or particulate matter sizes. Our simulation environment advances previous related models [1,2] by 1) using spectral data rather than camera RGB data in our analyses and 2) providing open source code for the implementations of our simulations. We hope that our work will foster collaboration and advance the design of imaging systems for underwater applications, including consumer photography and scientific measurement.

2. Image Formation Model

Our underwater image formation model is based on prior work by McGlamery [3] and Jaffe [4] who described light absorption and scattering in units of medium beam absorption and scattering coefficients. McGlamery [3] modeled a volume of water by decomposing it into small, non-overlapping "elemental volumes" or cells and then analyzed the effects that each cell has on light propagation through the medium. Specifically, he described how the intensity of a beam interacting with a cell is attenuated by light absorption and how scattering can change the direction in which a beam propagates. Jaffe [4] later used this basic image formation model to evaluate the effects that different spatial arrangements of external light sources have upon the image that is captured by a CCD (monochrome) sensor. To reduce the computational cost of analyzing systems with large numbers of such cells, the effects water column has on images is often modeled as a blur kernel applied to water-free image [1,3]. Rather than image filtering we are using computer graphics techniques, specifically physics-based ray tracing, to model non-overlapping cell formulation and cell-light ray interactions. These techniques can reproduce scene appearance by mimicking physical light interactions between objects and media present in the scene [5].

In addition to using ray-tracing methods, we also use models of light scattering and absorption by seawater and its' constituents [6]. More specifically, we analyze how fundamental seawater constituents, such as phytoplankton, color dissolved organic matter (CDOM) and non-algal particles (NAP), affect spectral absorption and scattering coefficients [7-10]. This makes it possible to control the appearance of underwater camera images by varying physically meaningful quantities, such as chlorophyll concentration, in ways that agree with both biological observations and real camera data.

We use a full camera simulation pipeline to model how digital cameras convert incident light rays into raw sensor data (ISET, [11]). These simulations specifically include the effects of camera sensor spectral sensitivity and photodetector noise components.

3. Camera Images

To validate our approach, we conducted a simple experiment in which we captured images of a known target (Macbeth ColorChecker) in different water conditions. The chart and the camera (Canon G7X in a WP-DC54 waterproof housing) were attached to a PVC pipe truss which fixed the distance between the camera and the target to about 1.5 meters. The truss was lowered on a rope to different depths of up to 20 meters in different locations in the West Indies.

We adjusted our underwater image formation model parameters in order to match the appearance of simulated and real images. Figure 1 shows a comparison between the simulated and real appearance of a Macbeth chart at a

depth of about 5 meters. The parameters for concentrations of seawater constituents are within the bounds of published data. Our final paper will compare simulations with measurements for different types of water and at different depths.

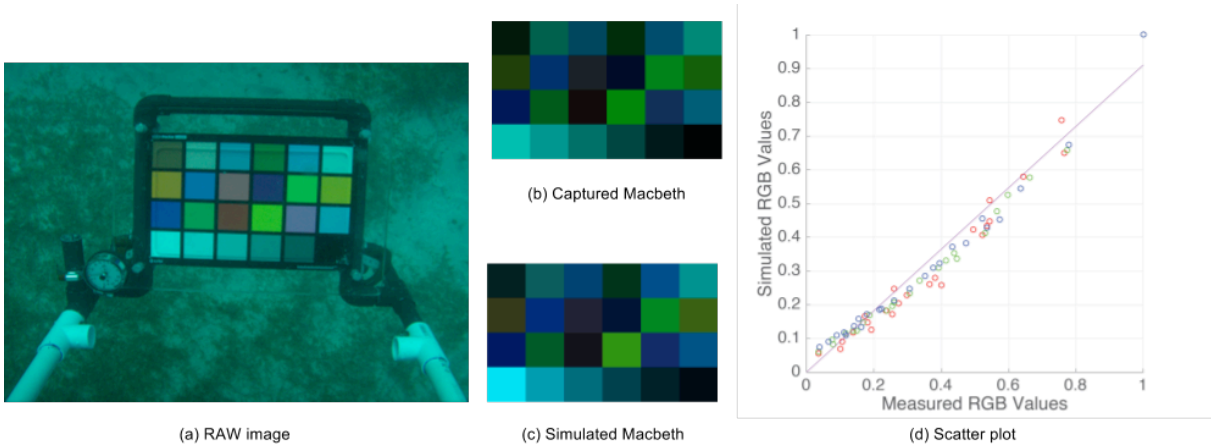

Fig. 1. A comparison between images of a Macbeth chart captured at a depth of about 5m. (a) RAW sensor image, (b) captured Macbeth patch intensities extracted from (a), (c) simulated Macbeth patch intensities, (d) scatter plot of pixel intensities (b) vs. (c).

4. References

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