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Improving Underwater Imaging with Ocean Optics Research

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Introduction: Underwater vision is vital to many Navy applications involving mine detection, diver visibility, and search and rescue. The ability to see better and farther has always been a central goal of underwater imaging projects. Unlike in the atmosphere, where visibility can be on the order of miles, the visual range in the underwater environment is rather limited, at best on the order of tens of meters, even in the clearest waters. This is the result of combined attenuation effects from both absorption, where photons disappear into water molecules, phytoplankton cells, and detritus, and scattering, where photons bounce away from the original path into different traveling directions. It is mostly the effects of scattering by water and particulates that make the water look dirty or less transparent, resulting in a blurred image recorded by cameras. Although traditional image enhancement techniques can be applied to imagery obtained from underwater environments, their effectiveness is considerably limited because they do not take into account any knowledge of the optical properties of the medium or the processes that lead to the degraded images. Our efforts aim to find ways to incorporate the knowledge of ocean optics to automatically enhance and restore such blurred images from underwater imaging systems, and in turn, to be able to estimate environmental optical properties via through-the-sensor techniques.

Reducing Image Blur using Knowledge of Ocean Optics: The most significant contributor to image blur is multiple scattering, where the path of a photon changes several times before reaching the camera. Associated with multiple scattering, the non-scattered direct beam that contributes to the sharp part of the image is correspondingly reduced, and the combined result is less contrast, which further lowers the quality of the image. The reduction in signal can be so great that the electronic noise of the system becomes a factor, further complicating the issue.

To reduce blur and improve imagery effectively, it is critical to incorporate knowledge of the optical properties of the water to better model the degradation process. The amount of blurring in an image can be described by how much blur a point-source will introduce over the imaging range. This property is the point-spread function (PSF) and its Fourier transformed form is the modulation transfer function (MTF), which describes how fast the details of an image degrade in a given environment. Little attention has been paid to associating these powerful imaging descriptors to the controlling processes, namely, multiple scattering. We have developed a scattering-imaging model to link commonly measured optical properties of the water to the image degradation process. The effectiveness of this scattering-imaging model was successfully validated by comparing the visibility of the Secchi disk under this current model, to the visibility predicted by the classical radiative transfer model, shown in Fig. 1.[1] This scattering-imaging model enables us to automate the image restoration process using the framework discussed below.

NRL Image Restoration via Denoised Deconvolution (NIRDD): We have established a framework to automatically restore underwater imagery to the best level possible, working with both simulated and field measured data. Under this framework, the standard image restoration approach is extended by incorporating water optical properties into the system response function. The implementation of this automated restoration framework is termed NRL Image Restoration via Denoised Deconvolution (NIRDD),[2] shown in Fig. 2.

The key to automated processing is the ability to objectively determine underwater image quality, as small, incremental improvements in restored images cannot be measured by visual inspection due to time constraints and subjectivity. Therefore, a special, objective image quality metric (IQM) was developed for underwater imaging. This metric is based on weighted grayscale angle (WGSA), a sharpness metric constrained by a normalized high-frequency wavelet power spectrum. Due to the intensity variations involved in underwater sensing, denoising is carefully carried out by wavelet decompositions. This is necessary since in the underwater environment the effects of high-order scattering can be easily classified as either signal or noise.

The restoration framework first determines the quality of the subject image by IQM and arrives at a single value (WGSA), which serves as a reference to future improvements. The optimization process starts with a set of estimated optical properties of the water, which are converted to the PSF using our model. The modeled PSF is further used to deconvolve the subject image to a restored version and its quality is then assessed by the same IQM. The resulting WGSA is compared to the reference to determine if further optimization is needed. The final results yield the best restored images, as well as the best estimation of environmental optical properties such as absorption, scattering, and attenuation coefficients that are important in ocean optics, including remote sensing applications. The images used in the framework testing were from a 2006 NATO trial experiment in Panama City, Florida. In-water optical properties during the experiment were measured. These included the absorption and attenua-

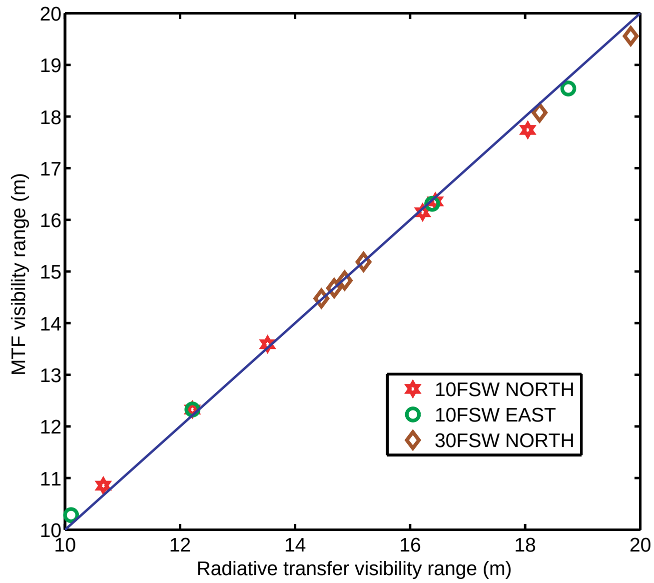

FIGURE 1
Comparison of visibility ranges based on the classical radiative transfer method and the scattering property–derived imaging method (using the MTF). Data are from the GLOW experiment (Gauging Littoral Optics for the Warfighter, September 17–22, 2001, Pensacola, FL). Visibility measurements were taken at 10 ft (10 FSW) and 30 ft (30 FSW) water depths each day, facing different track directions as indicated. Solid blue line depicts 1:1 ratio.

tion coefficients, particle size distributions, and volume scattering functions. Using NIRDD, image restoration was achieved. In addition, the in-water optical properties were estimated as part of the final output via through-the-sensor techniques; results were in line with field measurements.

Summary: Using a systematic approach, we demonstrate the ability to apply ocean optics research results to achieve better underwater images. The framework is applicable to a wide array of imaging systems and platforms, complementing and enhancing hardware-based approaches in reducing effects of multiple scattering. Since it is based on a physical model, it has the benefit of scaling with new camera systems, such as high definition (HD) systems. It is also expandable to include more complex imaging situations, such as those created by motion- and turbulence-induced phenomena, and under active illumination conditions. Applied inversely, our model also provides the means to generate accurate virtual environments for underwater scene simulations.

[Sponsored by NRL and ONR]

References

[1] W. Hou, Z. Lee, and A. Weidemann, "Why Does the Secchi Disk Disappear? An Imaging Perspective," *Opt. Express* **15**, 2791-2802 (2007).

[2] W. Hou, D. Gray, A. Weidemann, G.R. Fournier, and J.L. Forand, "Automated Underwater Image Restoration and Retrieval of Related Optical Properties," *IEEE International Geoscience and Remote Sensing Symposium, IGARSS, Barcelona, Spain, 2007*, pp. 1889-1892 (2007).

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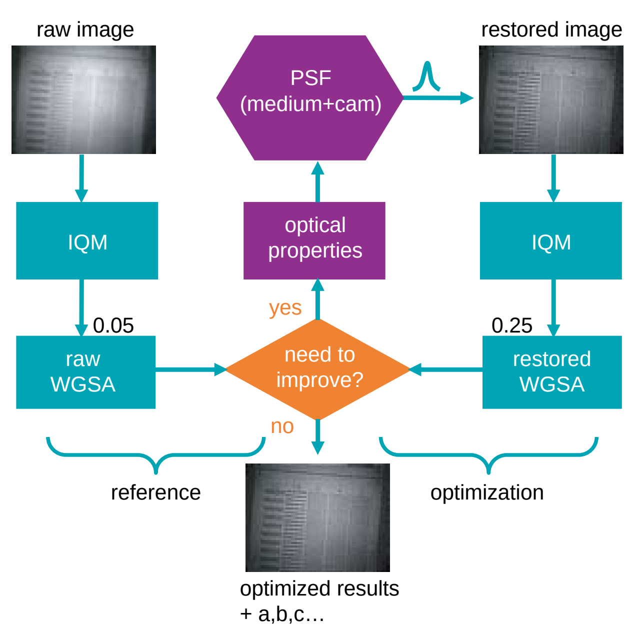

FIGURE 2
Flow chart of NIRDD (NRL Image Restoration via Denoised Deconvolution). Images used are from a 2006 NATO field exercise in Panama City, FL. 0.05 and 0.25 are corresponding WGSA values of the images before and after restoration was applied. The total PSF consists of the effects of both the medium and the camera system ("cam"). When no further improvements can be made, the optimization loop exits with restored images and derived optical properties (a: absorption; b: scattering; c: attenuation).