Prospects for Improved Performance

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1. Coherent Imaging

Among the various techniques for imaging through a scattering medium, coherent techniques have been shown to offer advantages, especially in biomedical imaging where optical coherence tomography (OCT) has become a standard method for viewing various classes of objects. The central idea with OCT is that signal enhancement will result from processing a complex waveform that is propagated into the medium and then detected using heterodyne techniques.

In one of the earliest examples of coherent imaging through a scattering environment, Stetson [4] imaged a pitcher in a small tank filled with water with suspended particles. Although no pictures were shown or analyzed quantitatively, the author claimed that via simple viewing, the use of coherent methods yielded better images than those that did not. In other work, to measure the spatial distances over which light can propagate and still remain coherent, Stachnik [3] summarily stated that coherent behavior is observable in coastal Atlantic waters at a range of 7.84 m (4 attenuation lengths) and that the interference patterns that form have good linearity, but can vary significantly in contrast.

2. Biomedical Perspective

The use of optical biomedical imaging is an area that has seen tremendous growth in recent decades. Comparing the difficulty of imaging through living tissue with that of the ocean leads to the conclusion that the underwater imagers are quite fortunate, although that is not necessarily their perspective. A review paper [2] presents a wealth of information in addition to offering a somewhat different perspective on much the same physics. A document that considers the various mathematical formulations for diffusion imaging is [1]. Diffuse imaging plays an important role in the biomedical case because the absorption can range between 0.03 and 0.007 1/cm and the mean free path for scattering can be on the order of 100 m, leading to a ratio of scattering to absorption of at least 2000.

Input Power(Watts)	Total No.Atten.Lengths
10^{-6}	11.7
10^{-3}	15.1
1	18.6

Table 1. RESULT OF COMPUTING THE NUMBER OF POTENTIALLY ACHIEVABLE ATTENUATION LENGTHS FOR THE ROUND-TRIP IMAGING FROM (5)

3. Advanced Methodologies

In this section, a number of more advanced technologies are considered to aid in underwater imaging. Topics range from the ultimate limitations imposed by the physics to the use of more advanced hardware and software for processing. A natural question that should be asked by those seeking to image underwater is: What is the ultimate limit to the process? As considered, the answer to this question can be found in considering the contrast transmittance, as given in several examples. To date, the standard assumption has been that several hundred photons are needed per pixel to form an acceptable image.One can compute, via simple analysis, a limit to visibility for a scanned system that images one pixel at a time. So, given approximately 200 photons of shot noise, the ultimate limit would imply an SNR. Since 1 W of 532-nm green light corresponds to 2.6747×10^{18} photons, the equation that governs the SNR for a single pixel, assuming that only ballistic photons are used in the image process, is

$$200 = I \times 2.67 \times 10^1 8 \times e^{-2al} \longrightarrow 37 + ln(I) = 2 \times al \quad (1)$$

The results contained in Table1 indicate that systems, considering only absorption-based imaging and assuming 100% collection of the reflected photons, should be able to image at close to 12 attenuation lengths. However, since the VSF for underwater targets is quite forward pointed, it is not unreasonable to assume that some fraction of those photons, especially after reflection from the target, will be useful. Since no underwater imaging system has achieved the performance as listed in this table, it appears as if there is some room for improvement.

References

[1] S. Arridge and J. Schotland. Optical tomography: forward and inverse problems. *Inverse Problems*, 2012. 1

[2] C. Dunsby. Techniques for depth-resolved imaging through turbid media including coherence-gated imaging. *Journal of Physics D Applied Physics*, 2003. 1

[3] Stachnik and J. William. The measurement of optical coherence loss in atlantic waters. In *Society of Photo-optical Instrumentation Engineers Conference Series*, 1978. 1

[4] Stetson and A. Karl. Holographic fog penetration. *Journal of the Optical Society of America*, 1967. 1