IEEE Workshop on Volumetric Scattering in Vision and Graphics

PI: Srinivasa G. Narasimhan (Carnegie Mellon University)

Technical Report

1 Motivation for Workshop

Computer vision and graphics are multi-disciplinary fields of research with a wide spectrum of applications that impact our daily lives. Today, cameras and displays are ubiquitous and the amount of imagery generated is overwhelming. That said, most of computer generated imagery in video games, movies and scientific simulations are of scenes on clear days or nights. Volumetric scattering effects such as the beautiful fog rolling down the hills, the bluish haze of mountains, the eerie night mist, the brilliance of underwater effects, or the light streaming through clouds provide pure artistic and entertainment value. They are used in movies and paintings to portray different moods, and are captured in photographs to provide realism. Besides digital entertainment, scattering effects are also simulated for training human operators in safety, medical and hazardous situations — pilots landing through fog, soldiers conducting reconnaissance in dusty desert terrain, divers exploring ocean depths, and doctors looking for cancerous tissue. In the absence of scattering effects, current renderings appear unnatural and cartoonish.

Analogously, most computer vision systems have not enjoyed success when deployed in uncontrolled outdoor environments. Today, modern vehicles have (semi-)automatic intelligent transportation systems that assist drivers in navigation. However, they fail to work in common bad weather conditions such as fog, snow and rain, indeed when they are most required. Similarly, field robots fail to navigate in hazardous environments such as smoke and dust, underwater exploration tasks are hindered by murky water, aerial and satellite imaging tasks are made difficult due to the presence of the atmosphere, and finally, medical image analysis is made hard due to the complex scattering properties of tissues. Unfortunately, however, most vision techniques are designed to only perform in clear air. Even with perfect performance, scattering effects are the one fundamental hurdle that can stop vision from having successful impact in these domains.

1.1 Related Research

For the past few years, there has been growing acknowledgment of the importance of volumetric scattering effects in graphics and vision. In computer graphics, the emphasis is on accurate simulation of scattering effects through participating media. A brute force approach to simulating scattering effects would require tracing millions of rays through hundreds of scattering events [3, 4, 16, 17, 18, 22, 24, 43, 47, 48, 7]. However, recent novel methods based on analytic derivations, approximations and empirical models [51, 18, 15, 20, 45, 13, 52, 9], and hardware accelerations [6, 12, 46], have the potential of decreasing the computational complexity by many orders of magnitude [52].

The emphasis in vision and image processing has been to enhance or restore visibility in the presence of bad weather (fog, mist, rain) [37, 27, 21, 67, 10, 11, 29, 33] or murky water [28, 23, 36]. Physically based models and algorithms that exploit optical cues such as polarization [49, 50] and spectral [30] properties of scattering have been developed. As a by-product, the analysis of scattering effects has also yielded information about the scene (3D structure) [31, 32] and the medium (optical properties) [34, 26] that is useful for computer vision. It should be noted that recent research into both computer graphics and vision benefits from studies into human perception and tolerance in the presence of such effects [61, 65, 2].

Given the broad impact and the recent surge of research, we believed that the time was ripe for a first workshop dedicated to volumetric scattering. We conducted such a workshop in conjunction with a major computer vision event - IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2007.

2 Workshop Objectives and Broader Significance

The following three broad objectives were envisioned for this workshop.

- **Increasing awareness of imaging in scattering media:** In recent years, computer vision has seen great advances in the areas of object detection, recognition, segmentation and tracking, 3D reconstruction, autonomous navigation, image retrieval, and industrial inspection. These advances have been made possible due to successes in core areas of scene sensing and interpretation. However, almost all of this research is still based upon one fundamental assumption — that light reflected by a surface reaches the sensor unaltered. For the large part of the past 35-40 years, image formation has been defined as "a geometric mapping from 3D to 2D", which inherently leads to loss of information. We strongly argue that light transport must not be viewed as "noise" that a traditional vision algorithm needs to overcome, but rather as a new form of "encoding" of light and hence, the images themselves. Our objective in this workshop is to increase awareness about this research area.

- **Computer vision as an enabling technology for imaging sciences:** The past decade has seen computer vision research double in size in terms of both the number of papers in journals and conferences and applications. The field has converged in new ways with other fields like machine learning, graphics and medical imaging. As a result, there is a fast growing demand for vision techniques in various scientific fields [69] ranging from oceanography (underwater imaging) [55, 59, 60, 64, 68, 14, 23, 35, 8], to astronomy (telescope and satellite imaging)[1, 5, 53], to remote sensing (aerial imaging) [58, 21, 67, 70], and to even biology and medicine (microscopy, endoscopy, tomography) [44]. In all these areas, however, there is no escape from light scattering. We believe this workshop can inspire research in this area increasing the impact of vision in many application domains.

- **Promoting interdisciplinary research and collaborations:** We also believe that the workshop will spur new interdisciplinary collaborations among researchers in diverse fields. The invited talks in this workshop helped focus on both the remarkable similarities in light transport research problems faced in a range of disciplines, as well as their distinctive aspects.

3 Workshop Organization and Format

The organizing committee included Profs. Shree Nayar (Columbia University), Srinivasa Narasimhan (Carnegie Mellon), and Yoav Schechner (Technion, Israel). The workshop was held for a full day (June

18, 2007). This is the first workshop on this topic. Thus, the workshop featured lectures solely by invited speakers, each being a prominent figure in an aspect of the workshop's theme. The entire workshop comprised of 10 speakers:

- Berthold K. P. Horn (MIT)
- David Lynch (Aerospace Corp, Thule Scientific)
- Paul Debevec (IST, USC)
- Shree Nayar (Columbia)
- Yoav Schechner (Technion)
- Jules Jaffe (UCSD)
- Henrik Wann Jensen (UCSD)
- Dvir Yelin (Mass General Hospital and Harvard)
- Shahriar Negahdaripour (Miami)
- Srinivasa Narasimhan (CMU)

The budget from ONR was utilized for arranging the talks from speakers (travel, stay, food, conference registration and other related expenses).

A website was designed and maintained that gives the biographies about the speakers and the talks they gave.

`http://vasc.ri.cmu.edu/Scattering07/`

References

[1] V. A. Ambartsumian. *Theoretical Astrophysics*. Pergamon Press, London, 1958.

[2] S. Anstis. Moving objects appear to slow down in low contrasts. *Neural Networks Special Issue*, 16, 2003.

[3] S. Antyufeev. *Monte Carlo Method for Solving Inverse Problems of Radiative Transfer*. Inverse and Ill-Posed Problems Series, VSP Publishers, 2000.

[4] P. Blasi, B. Le Saec, and C. Schlick. A rendering algorithm for discrete volume density objects. *Computer Graphics Forum*, 12(3):201–210, 1993.

[5] S. Chandrasekhar. *Introduction to the study of stellar structure*. Dover Publications, Inc., 1957.

[6] Y. Dobashi, T. Yamamoto, and T. Nishita. Interactive rendering of atmospheric scattering effects using graphics hardware. In *Graphics Hardware Workshop 02*, pages 99–109, 2002.

[7] R. Fedkiw, J. Stam, and H. W. Jensen. Visual simulation of smoke. *In Proc SIGGRAPH*, 2001.

[8] G.R. Fournier, D. Bonnier, J.L. Forand, and P.W Pace. Range-gated underwater laser imaging system. *Optical Engineering*, 32 (9), 1993.

[9] K. Garg and S.K. Nayar. Photorealistic rendering of rain streaks. *ACM Trans. on Graphics (SIGGRAPH)*, 2006.

[10] K. Garg and S.K. Nayar. Detection and removal of rain from videos. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2004.

[11] K. Garg and S.K. Nayar. When does a camera see rain? *Proceedings of the International Conference on Computer Vision*, 2005.

[12] M. Harris and A. Lastra. Real-time cloud rendering. In *Eurographics 2001*, pages 76–84, 2001.

[13] C. Hansen J. Kniss, S. Premoze and D. Ebert. Interactive translucent volume rendering and procedural modeling. In *IEEE Visualization*, 2002.

[14] J. S. Jaffe, J. McLean, M. P. Strand, and K. D. Moore. Underwater optical imaging: Status and prospects. *Technical Report, Marine Physical Lab, Scripps Institution of Oceanography, La Jolla, California*, 2002.

[15] H. Jensen, S. Marschner, M. Levoy, and P. Hanrahan. A practical model for subsurface light transport. In *SIGGRAPH 01*, pages 511–518, 2001.

[16] H. W. Jensen, F. Durand, M. M. Stark, S. Premoze, J. Dorsey, and P. Shirley. A physically-based night sky model. *In Proc. SIGGRAPH*, 2001.

[17] H. Wann Jensen. *Realistic Image Synthesis Using Photon Mapping.* AK Peters, 2001.

[18] J. Kajiya and B. Herzen. Ray tracing volume densities. In *SIGGRAPH 84*, pages 165–174, 1984.

[19] A. Khamene and S. Negahdaripour. Building 3-d elevation maps of sea-floor scenes from underwater stereo image. *In Proc. Oceans*, 1999.

[20] J. J. Koenderink and A.J. van Doorn. Shading in the case of translucent objects. In *Human Vision and Electronic Imaging VI, B.E. Rogowitz, T.N. Pappas (eds.), SPIE*, pages 312–320, 2001.

[21] N.S. Kopeika. *A System Engineering Approach to Imaging.* SPIE Press, 1998.

[22] E. Languenou, K. Bouatouch, and M. Chelle. Global illumination in presence of participation media with general properties. In *Eurographics Rendering Workshop*, pages 69–85, 1994.

[23] M. Levoy, B. Chen, V. Vaish, M. Horowitz, I. McDowall, and M. Bolas. Synthetic aperture confocal imaging. In *SIGGRAPH*, 2004.

[24] N. Max. Efficient light propagation for multiple anisotropic volume scattering. In *Eurographics Rendering Workshop*, pages 87–104, 1994.

[25] K.D. Moore and J.S Jaffe. Time-evolution of high-resolution topographic measurements of the sea floor using a 3-d laser line scan mapping system. *IEEE Journal of Oceanic Engineering*, 27 (3), July 2002.

[26] S. G. Narasimhan, M. Gupta, C. Donner, R. Ramamoorthi, S. K. Nayar, and H. W. Jensen. Acquiring scattering properties of participating media by dilution. In *ACM Trans. on Graphics (SIGGRAPH)*, 2006.

[27] S. G. Narasimhan and S. K. Nayar. Removing weather effects from monochrome images. *In Proc. CVPR*, 2001.

[28] S. G. Narasimhan, S. K. Nayar, B. Sun, and S. J. Koppal. Structured light in scattering media. In *Proc. ICCV*, 2005.

[29] S. G. Narasimhan, C. Wang, and S. K. Nayar. All the images of an outdoor scene. *In Proc. ECCV*, 2002.

[30] S.G. Narasimhan and S.K. Nayar. Chromatic framework for vision in bad weather. *In Proc. CVPR*, 2000.

[31] S.G. Narasimhan and S.K. Nayar. Vision and the atmosphere. *IJCV*, 48(3):233–254, August 2002.

[32] S.G. Narasimhan and S.K. Nayar. Contrast restoration of weather degraded images. *IEEE Trans. on PAMI*, 25(6), June 2003.

[33] S.G. Narasimhan and S.K. Nayar. Interactively deweathering an image using physical models. *In Proc. ICCV Workshop on Color and Photometric Methods in Computer Vision*, 2003.

[34] S.G. Narasimhan and S.K. Nayar. Shedding light on the weather. *In Proc. IEEE CVPR*, June 2003.

[35] P. Naulleau and D. Dilworth. Motion-resolved imaging of moving objects embedded within scattering media by the use of time-gated speckle analysis. *Applied Optics*, 35 (26):5251–5257, 1996.

[36] S.K. Nayar, G. Krishnan, M.D. Grossberg, and R. Rasker. Fast separation of global illumination effects using high frequency illumination. *ACM Trans. on Graphics (SIGGRAPH)*, 2006.

[37] S.K. Nayar and S.G. Narasimhan. Vision in bad weather. *In Proc. ICCV*, 1999.

[38] S. Negahdaripour. Motion-based compression of underwater video imagery for the operations of unmanned submersible vehicles. *Computer Vision and Image Understanding: Special Issue on Underwater Computer Vision and Pattern Recognition*, 79, 2000.

[39] S. Negahdaripour, X. Xu, A. Khamene, and Z. Awan. 3d motion and depth estimation from sea-floor images for mosaic-based positioning, station keeping and navigation of rovs/auvs and high resolution sea-floor mapping. *In Proc. IEEE/OES Workshop on AUV Navigation, MIT Draper Lab., Cambridge, MA*, August 1998.

[40] S. Negahdaripour, X. Xun, and L. Jin. Direct estimation of motion from sea floor images for automatic station-keeping of submersible platforms. *IEEE Journal of Oceanic Engineering*, July 1999.

[41] S. Negahdaripour and C.H. Yuh. On shape and range recovery from image shading for underwater applications. *Robotic vehicles: Design and Control, J. Yuh (Ed.), TSI Press*, 1995.

[42] S. Negahdaripour, S. Zhang, X. Xu, and A. Khamene. On shape and motion recovery from underwater imagery for 3d mapping and motion-based video compression. *In Proc. Oceans*, September 1998.

[43] S. Pattanaik and S. Mudur. Computation of global illumination in a participating medium by monte carlo simulation. *Journal of Visualization and Computer Animation*, 4(3):133–152, 1993.

[44] S. Prahl. *Light Transport in Tissue*. PhD Thesis, University of Texas at Austin, 1998.

[45] S. Premoze. Analytic light transport approximations for volumetric materials. In *In Proc. Tenth Pacific Conference on Computer Graphics and Applications*, 2002.

[46] K. Riley, D. Ebert, M. Kraus, J. Tessendorf, and C. Hansen. Efficient rendering of atmospheric phenomena. In *EGSR 2004*, 2004.

[47] H. Rushmeier and K. Torrance. The zonal method for calculating light intensities in the presence of a participating medium. In *SIGGRAPH 87*, pages 293–302, 1987.

[48] P. Shirley S. Premoze, M. Ashikhmin. Path integral approach to light transport in volumetric materials. In *Proceedings of Eurographics Symposium on Rendering*, 2003.

[49] Y.Y. Schechner, S.G. Narasimhan, and S.K. Nayar. Instant dehazing of images using polarization. *In Proc. CVPR*, 2001.

[50] Y.Y. Schechner, S.G. Narasimhan, and S.K. Nayar. Polarization based vision through haze. *Applied Optics, Special Issue : Light and Color in the Open Air*, 42(3), January 2003.

[51] J. Stam. Multiple scattering as a diffusion process. In *Eurographics Rendering Workshop*, pages 41–50, 1995.

[52] B. Sun, R. Ramamoorthi, S. Narasimhan, and S. Nayar. A practical analytic single scattering model for real time rendering. *ACM Transactions on Graphics (SIGGRAPH 2005)*, 2005.

[53] R. K. Tyson. *Principles of Adaptive Optics*. Academic Press, New York, 1991.

[54] X. Xu and S. Negahdaripour. Automatic optical station keeping and navigation of an rov; sea trial experiment. *In Proc. Oceans*, 1999.

[55] J. Åhlén and D. Sundgren, "Bottom reflectance influence on a color correction algorithm for underwater images," Scandinavian Conf. Image Analysis, pp. 922-926 (2003).

[56] P. Barham, L. Andreone, X. H. Zhang and M. Vaché, "The development of a driver vision support system using far infrared technology: progress to date on the DARWIN Project," Proc. IEEE Intel. Vehicle Sympos. pp. 545-549 (2000).

[57] F. Cozman and E. Krotkov, "Depth from scattering," Proc. IEEE Conference on Computer Vision and Pattern Recognition, pp. 801-806 (1997).

[58] Y. Du, B. Guindon, and J. Cilhar, "Haze detection and removal in high resolution satelite image with wavelet analysis," IEEE Trans. Geoscience and Remote Sensing **40**, pp. 210-217 (2002).

[59] G. L. Foresti, "Visual inspection of sea bottom structures by an autonomous underwater vehicle," IEEE Trans. Syst. Man and Cyber, Part B **31**, pp. 691-705 (2001).

[60] R. Garcia, J. Batlle, X. Cufi and J. Amat "Positioning an underwater vehicle through image mosaicing," Proc. IEEE Int. Conf. on Robotics and Automation, pp. 2779-2784 (2001).

[61] R. C. Henry, S. Mahadev, S. Urquijo, and D. Chitwood "Color perception through atmospheric haze," J. Opt. Soc. Am. A **17**, 831-835 (2000).

[62] D. M. Kocak and F. M. Caimi, "The current art of underwater imaging with a glimpse of the past," MTS Journal **39**, pp. 526 (2005).

[63] B. Korn, H. U. Doehler and P. Hecker, "Weather independent flight guidance: Analysis of MMW radar images for approach and landing," Proc. IEEE Int. Conf. Patt. Recog. Vol. I, pp. 350-353 (2000).

[64] J. S. Jaffe, "Computer modeling and the design of optimal underwater imaging systems," IEEE Journal of Oceanic Engineering **15**, pp. 101-111 (1990).

[65] M. G. J. Minnaert *Light and color in the outdoors* (1974). Translated by L. Seymour (Springer-Verlag, New York, 1993).

[66] L. J. Mullen and V. M. Contarino, "Hybrid lidar-radar: Seeing through the scatter," IEEE Microwave Mag. **43**/3, pp. 42-48 (2000).

[67] J. P. Oakley, and B. L. Satherley "Improving image quality in poor visibility conditions using a physical model for contrast degradation," *IEEE Trans. Imag. Proc.* **7**, 167-179 (1998).

[68] A. Ortiz, M. Simo and G. Oliver, "A vision system for an underwater cable tracker," Machine Vision and Applications **13**, pp. 129-140 (2002).

[69] J. S. Tyo, M. P. Rowe, E. N. Pugh Jr., and N. Engheta "Target detection in optically scattering media by polarization-difference imaging," App. Opt. **35**, 1855-1870 (1996).

[70] Y. Zhang and B. Guindon, “Quantitative assessment of a haze supression methodology for satelite imagery: Effect on land cover classification peformance,” IEEE Trans. Geoscience and Remote Sensing **41** pp. 1082-1089 (2003).