MODELING AND MEASUREMENT OF OPTICAL POLARIMETRIC IMAGE PHENOMENOLOGY IN A COMPLEX URBAN ENVIRONMENT

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1. POLARIMETRIC IMAGE PHENOMENOLOGY

Urban environments typically include an assortment of man-made objects constructed of materials such as brick, tile, asphalt, glass, and painted metal that can each be modeled by a bidirectional reflectance distribution function (BRDF). Some of these materials (e.g., glass) are polarization selective when reflecting unpolarized solar energy from their surfaces, and therefore can be modeled through a Mueller matrix-based polarized BRDF (pBRDF). Stokes vector-based optical polarized imagery of a real-life scene can be mathematically produced using three to four images taken by a digital camera with a linear polarizer filter rotated at different angles [1]. Reproducible sensor-reaching radiance spectropolarimetric image cubes can also be generated through the use of a synthetic image generation (SIG) model [2]. A SIG can be configured for the same sun, scene, and sensor geometry as the real-life scene's conditions, so a measure of validation can be achieved for the synthetic polarized imagery. Additionally, SIG-rendered image cubes can be used to study spectropolarimetric phenomenology when performing remote sensing of objects in an urban environment for various sun-target-sensor geometries and atmospheric conditions. This paper investigates the polarization characteristics of urban scenes through synthetic images and empirical measurements.

2. SPECTROPOLARIMETRIC SCENE MODELING OF AN URBAN ENVIRONMENT

The Digital Imaging and Remote Sensing (DIRS) laboratory within the Center for Imaging Science at RIT is the home of the DIRS Image Generation (DIRSIG) model. DIRSIG is a first-principles, physics-based synthetic image simulation software package [3]. It has the ability to produce imagery in a variety of modalities, including multispectral, hyperspectral, polarimetric, and LIDAR in the visible through the thermal infrared regions of the electromagnetic spectrum. DIRSIG performs ray-tracing calculations of “light” emanating from realistic models of electromagnetic light sources (e.g., sun, moon), reflecting off of virtual object materials (e.g., trees, asphalt, sand, water, glass, paint), and arriving at a virtual imaging detector with a specific array size and optical field of view. Co-registered detector “channels” can be specified to output a variety of image cube types from monochromatic to hyperspectral, as well as Stokes vectors for each channel. DIRSIG has been used to create Megascene #1, a high-fidelity recreation of objects comprising a vast region of the Rochester, NY metro area [4]. The first of five “tiles” of Megascene #1 is just over 1 [km^2], and consists of modeled objects such as trees, houses, and vehicles, all atop a texture-mapped digital elevation model-based terrain.

Stokes vector radiance imagery of a single spectral band or multiple spectral bands can also be obtained from DIRSIG when using the polarized version of the Moderate Spectral Resolution Atmospheric Transmittance Algorithm (MODTRAN-4P) to simulate atmospheric scattering polarization effects. Mathematically, the Stokes vector imagery can be combined into a Degree of Linear Polarization (*DoLP*) image whose pixel values range between 0 (unpolarized) and 1 (completely polarized). Higher *DoLP* values are usually observed from shadows, vehicle paint, and glass, as shown below in Figure 1. Calibration panels simulating glass, paint, and Lambertian reflectors have been placed in the scene to confirm radiometric and polarimetric effects.

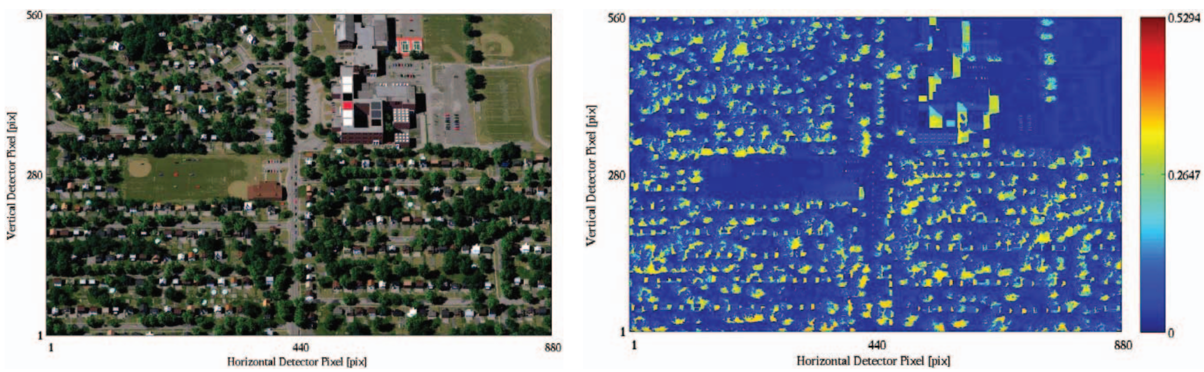

Figure 1. RGB and Corresponding *DoLP* Imagery for North-Pointing Sensor with no Aerosols

DIRSIG can ray-trace through a near-perfect atmosphere, or an atmosphere containing many urban aerosols, simply by loading different MODTRAN Tape5 input files. Although MODTRAN-4P only works with single scattering, its Urban Extinction model can simulate haze in the scene, increasing with solar declination and sensor slant range. Haze has an adverse effect on a pixel's *DoLP*, since aerosols can be slightly polarizing and thus increase the background *DoLP* from near-zero conditions. "Shiny" targets will produce a lower *DoLP* arriving at the sensor, since their rays will depolarize when combined with aerosol-scattered upwelled rays. The *DoLP* contrast between background and target pixels is significantly reduced, as shown below in Figure 2.

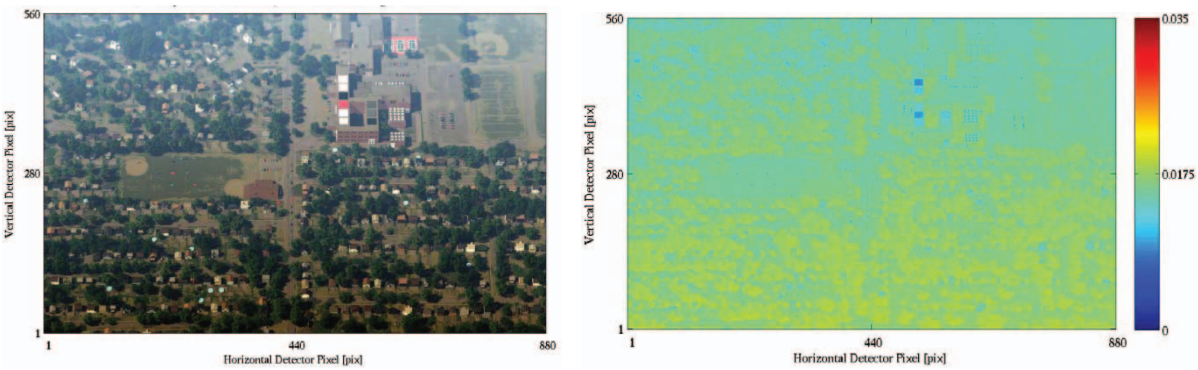

Figure 2. RGB and Corresponding *DoLP* Imagery for North-Pointing Sensor with Urban Aerosols

This work is being pursued in support of the design of an adaptive multimodal sensor that uses both micromirrors and micropolarizers to produce coregistered spectral and polarimetric imagery [5, 6].

3. MODEL AND MEASUREMENT VALIDATION AND PRELIMINARY RESULTS

Synthetic DIRSIG scene modeling is under way to match the real imagery of a pickup truck collected via RIT's WASP-Lite sensor [7, 8]. The measured intensity, *DoLP*, and Angle of Polarization (*AoP*) are shown in Figure 3.

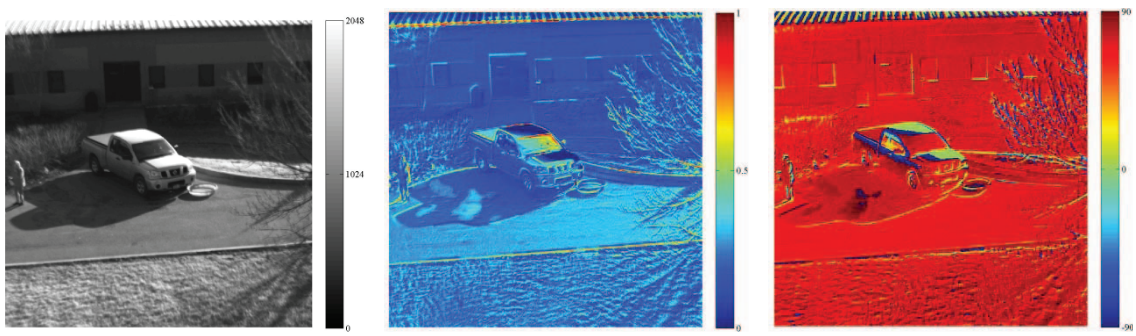

Figure 3. Measured Intensity, *DoLP*, and *AoP* Images of Real-Life Scene

Horizontal calibration panels placed within the synthetic scene can be imaged with a virtual single-pixel Stokes-vector detector at a variety of azimuth and declination angles. Figure 4 below demonstrates a full-circle *DoLP* and *AoP* measurement of a sheet of glass at 1° azimuthal increments for six sensor declinations with the sun declined 40° from zenith. This modeled pBRDF phenomenology should be similar to real-life measurements.

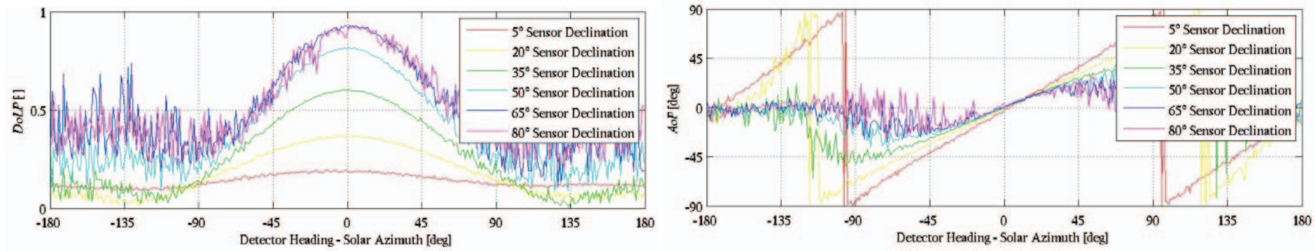

Figure 4. Synthesized *DoLP* and *AoP* vs. Relative Azimuth and Sensor Declination for a Glass Sheet

4. ACKNOWLEDGEMENTS

This material is based on research sponsored by the Air Force Office of Scientific Research (AFOSR) under agreement number FA9550-08-1-0028 (AFOSR-BAA-2007-08). The U.S. Government is authorized to reproduce and distribute reprints for Governmental purposes notwithstanding any copyright notation thereon.

5. REFERENCES

[1] J. R. Schott, *Fundamentals of Polarimetric Remote Sensing*, SPIE Press, Bellingham, WA, 2009.

[2] J. R. Schott, *Remote Sensing: The Imaging Chain Approach* (2 ed.), Oxford Univ. Press, New York, 2007.

[3] J. Schott, S. Brown, R. Raqueño, H. Gross, and G. Robinson, "An advanced synthetic image generation model and its application to multi/hyperspectral algorithm development," *Canadian Journal of Remote Sensing*, vol. 25 (2), pp. 99-111, 1999.

[4] E. J. Ientilucci and S. D. Brown, "Advances in wide area hyperspectral image simulation," *Proc. SPIE*, vol. 5075, pp. 110-121, 2003.

[5] J. P. Kerekes, M. D. Presnar, K. D. Fourspring, Z. Ninkov, D. R. Pogorzala, A. D. Raisanen, A. C. Rice, J. R. Vasquez, J. P. Patel, R. T. MacIntyre, and S. D. Brown, "Sensor modeling and demonstration of a multi-object spectrometer for performance-driven sensing," *Proc. SPIE*, vol. 7334, p. 73340J, 2009.

[6] M. D. Presnar, A. D. Raisanen, D. R. Pogorzala, J. P. Kerekes, and A. C. Rice, "Dynamic Scene Generation, Multimodal Sensor Design, and Target Tracking Demonstration for Hyperspectral/Polarimetric Performance Driven Sensing," *Proc. SPIE*, vol. 7672, to be published Apr. 2010.

[7] D. Pogorzala, S. Brown, D. Messinger, and C. Devaraj, "Recreation of a nominal polarimetric scene using synthetic modeling tools," *Proc. SPIE*, vol. 6565, p. 65650Z, 2007.

[8] Laboratory for Imaging Algorithms and Systems, http://lias.cis.rit.edu/projects/wasplite, 2009.