R·I·T

Rochester Institute of Technology
Chester F. Carlson Center for Imaging Science
Digital Imaging and Remote Sensing Laboratory

Annual Report for the Fiscal Year 2007-2008

of the

Frederick & Anna B. Wiedman Professor

on the

Activities of the Digital Imaging and Remote Sensing Laboratory

Prepared by the DIRS Laboratory

Submitted by Professor John R. Schott

John R. Schott, Ph.D.
Frederick & Anna B. Wiedman Professor
Head, Digital Imaging and Remote Sensing Laboratory
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology
54 Lomb Memorial Drive Rochester, NY 14623

Contents

List of Figures

1 Introduction

Welcome to this year's annual report of the DIRS Lab's activities. It is a particular pleasure for me to review this year's accomplishments of the DIRS group as I was on sabbatical leave this year and not as intimately involved as usual. The year saw much of the growth into a wider range of research programs that I had forecast in the last annual report. This continuing growth into new technical areas and support for a broader range of sponsors has been enabled by a paralleled growth in our senior faculty/staff. This year we were pleased to have Dr. Emmett Ientilucci promoted from research staff to research faculty. This brings us to six faculty (four tenure track and two research) and eight staff. With all the faculty and senior staff developing new research areas and working with graduate students, the DIRS group is able to support the much broader range of topics reported here and presented at our annual research symposium in May.

I want to particularly acknowledge Dr. David Messinger who took charge of the Lab during my sabbatical. The fine job Dave did this year is only partially reflected in the research accomplishments reported here. These accomplishments do indeed attest to the effective way Dave managed the group this year. However, they don't reflect the strong sense of camaraderie and professionalism that Dave has maintained and encouraged within the group. It was truly a joy to stop in once a week this past year and see the supportive/collaborative attitude between the staff and students and among the staff. I want to particularly thank Dave for his efforts and acknowledge his accomplishments this year.

On a more personal note, let me say a few words about my sabbatical year. I spent much of my time doing what I always do in terms of working with students and staff on various research projects. However, with the time freed up from administrative and teaching responsibilities, I had time for a number of other activities. These included teaching three short courses at government and contractor facilities and participating on a number of program review and technical advisory boards. On top of all this was my largest single project which was to research and assemble an introductory text book on Polarimetric Remote Sensing which is scheduled to be published by SPIE this spring. Since I can't do much (some would say anything) by myself, I had a lot of help on this project from DIRS staff, several of whom are contributing authors for chapters in the book. This was a large undertaking that I hadn't planned for at the start of the sabbatical and I am grateful to the staff and students who have helped bring it together in so short a time.

In closing, I want to acknowledge once again the generosity of Frederick Wiedman Jr. whose gifts to the Institute in honor of his parents Frederick and Anna B. Wiedman endowed the chaired professorship I hold. The income from this endowment enables us to occasionally fund a small amount of exploratory research until we can identify external support for these studies. The AANEE study described in Section 4.2 exemplifies this process where the Wiedman endowment is helping to support one of the students who is working to explore this new direction for the DIRS group. This year, the Wiedman endowment also supported much of the behind the scenes work on the Polarimetric Remote Sensing book. At many points during the year I stop to acknowledge the help that Mr. Wiedman's generosity has enabled.

As ever, my thanks to our sponsors for your confidence in us and also to the DIRS faculty, staff and students for making this another very successful year.

John R. Schott, Frederick and Anna B. Wiedman Professor
Head, Digital Imaging and Remote Sensing Laboratory
Chester F. Carlson Center for Imaging Science
Rochester Institute of Technology

2 DIRS Laboratory Overview

The Digital Imaging and Remote Sensing (DIRS) Laboratory is a research group within the Chester F. Carlson Center for Imaging Science. Our work focuses on the development of hardware and software tools to facilitate the extraction of information from remotely sensed data of the earth and the education of students who will continue this work for government agencies and private industry.

The DIRS group is made up of faculty and research staff working with over 30 students ranging from the Baccalaureate through Doctoral level. Most students are degree candidates in Imaging Science, but students from other departments, such as Engineering and Physics, are often part of the student population supporting our research initiatives. This year also saw the inclusion of several high school interns who were provided the opportunity to participate in research projects and learn more about imaging science.

2.1 Laboratory Organization

The DIRS laboratory is managed using a matrix approach where faculty and senior staff manage programs to generate research results, student theses, and meet sponsor requirements. The research staff, organized into three overlapping groups managed by leaders, supports the needs of the research programs.

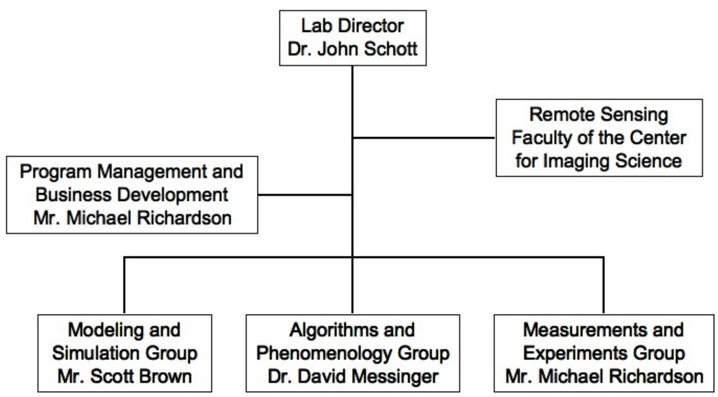


Figure 2.1-1: DIRS Group Organization

The Laboratory of Imaging Algorithms and Systems (LIAS) is a parallel laboratory within the Center for Imaging Science which also conducts remote sensing research typically with a more user-oriented engineering scope. DIRS and LIAS have several joint endeavors. The DIRS component of these activities is included below.

2.2 Laboratory Personnel

2.2.1 Faculty

The past year saw the DIRS faculty ranks grow yet again with the appointment of Dr. Emmett Ientilucci to the position of Assistant Research Professor in the Center for Imaging Science. The DIRS Laboratory now counts 6 faculty members as affiliated with the remote sensing research program.

Dr. John Schott, Professor and DIRS Laboratory Head
Research Interests: Hyperspectral data analysis and algorithm development; multi and hyperspectral instrument development; synthetic scene simulation and modeling
Contact Information: `schott@cis.rit.edu`; 585-475-5508

Dr. Anthony Vodacek, Associate Professor
Research Interests: Environmental applications of remote sensing; forest fire detection and monitoring; active and passive sensing of water quality
Contact Information: `vodacek@cis.rit.edu`; 585-475-7816

Dr. Carl Salvaggio, Associate Professor
Research Interests: Novel techniques and devices for optical property measurement; applied image processing and algorithm development; image simulation and modeling
Contact Information: `salvaggio@cis.rit.edu`; 585-475-6380

Dr. John Kerekes, Associate Professor
Research Interests: Image processing and algorithm development; image chain modeling and parametric analysis
Contact Information: `kerekes@cis.rit.edu`; 585-475-6996

Dr. David Messinger, Assistant Research Professor, DIRS Laboratory Interim Director, AY 2007-08
Research Interests: Multi- and hyperspectral algorithm development; advanced mathematical approaches to spectral image processing
Contact Information: `messinger@cis.rit.edu`; 585-475-4538

Dr. Emmett Ientilucci, Assistant Research Professor,
Research Interests: Multi- and hyperspectral algorithm development; physics-based signature detection in hyperspectral imagery; low SNR imaging systems
Contact Information: `emmett@cis.rit.edu`; 585-475-7778

2.2.2 Staff

Modeling and Simulation Group:
Mr. Scott Brown, Group Lead: `brown@cis.rit.edu`; 585-475-7194
Mr. Niek Sanders: `sanders@cis.rit.edu`
Dr. Michael Gartley: `gartley@cis.rit.edu`; 585-475-5612
Dr. Adam Goodenough: `goodenough@cis.rit.edu`
Mr. David Pogorzala: `pogorzala@cis.rit.edu`; 585-475-5388

Algorithms and Phenomenology Group:
Dr. David Messinger, Group Lead: `messinger@cis.rit.edu`; 585-475-4538
Dr. Emmett Ientilucci: `ientilucci@cis.rit.edu`; 585-475-7778
Dr. Rolando Raqueño: `rolando@cis.rit.edu`; 585-475-6907

Measurements and Experiments Group:
Mr. Michael Richardson, Group Lead: `richardson@cis.rit.edu`; 585-475-5294
Ms. Nina Raqueño: `nina@cis.rit.edu`; 585-475-7676

Administrative Support:
Ms. Cindy Schultz: `schultz@cis.rit.edu`; 585-475-5508

Figure 2.2-2: DIRS faculty members. Left to right: Dr. Carl Salvaggio, Dr. John Kerekes, Dr. John Schott, Dr. Emmett Ientilucci, Dr. Anthony Vodacek, Dr. David Messinger.

2.2.3 Student Researchers

The students listed below (42 in total) conducted research in the DIRS laboratory between July 1, 2007 and June 30, 2008. With only a few exceptions, they were enrolled in the Center for Imaging Science BS, MS, and Ph.D. programs.

Andy Adams	James Albano	Cliff Anderson	May Arsenovic
Brent Bartlett	Juliet Bernstein	Joey Bishoff	Marvin Boonmee
Jason Casey	Jake Clements	Brian Daniel	Chabitha Devaraj
Colin Doody	Tim Doster	Manny Ferdinandus	Michael Foster
Kenny Fourspring	Aaron Gerace	Adam Goodenough	Matt Heimbueger
Shawn Higbee	David Kelbe	Scott Klempner	Christina Kucerak
Justin Kwong	Stephen Lach	Ryan Mercovich	Matt Montanaro
Sharah Naas	David Nilosek	Frank Padula	Sarah Paul
Ariel Schlamm	David Snyder	Eugenie Song	Jacqueline Speir
Alvin Spivey	Marcus Stefanou	Matt Turk	Karl Walli
Jason Ward	Michael Zelinski	Yushan Zhu	

Figure 2.2-3: DIRS technical and administrative staff. Left to right: Dr. Rolando Raqueño, Michael Richardson, Cindy Schultz, Scott Brown, Nina Raqueño, David Pogorzala, Dr. Michael Gartley. Not shown: Niek Sanders & Dr. Adam Goodenough.

Figure 2.2-4: DIRS BS, MS and Ph.D. students taken in summer 2008.

Figure 2.2-5: DIRS US Air Force MS and Ph.D. students taken in summer of 2008.

2.3 Theses Defended in Past Year

- Dominico Luisi, MS, “Conceptual design and Specification of a MICROSATELLITE Forest fire Detection System”, John Schott, advisor
- Manuel Ferdinandus, MS, “Selection of Optimal Background Estimation Methods for Unstructured Detectors”, John Schott, advisor
- Jason Casey, MS, “A Comparative Analysis of Hyperspectral Target Detection Algorithms in the Presence of Misregistered Data”, John Kerekes, advisor
- Shari McNamara, MS, “Using Multispectral Sensor WASP-Lite to Analyze Harmful Algal Blooms”, Anthony Vodacek, advisor
- Marvin Boonmee, Ph.D., “Land Surface Temperature and Emissivity Retrieval from Thermal Hyperspectral Imagery”, John Schott, advisor
- Adam Goodenough, Ph.D., “In-water Spectral Radiative Transfer Modeling using Photon Mapping”, John Schott, advisor
- Brent Bartlett, Ph.D., “Improvement of Retrieved Reflectance in the Presence of Clouds”, John Schott, advisor
- Zhen Wang, Ph.D., “Modeling Wildland Fire Radiance in Synthetic Remote Sensing Scenes”, Anthony Vodacek, advisor
- Michael Foster, Ph.D., (USAF), “Using LIDAR to Geometrically Constrain Signature Spaces for Target Detection in Hyperspectral Imagery”, John Schott, advisor
- Andrew Adams, Ph.D., (USAF), “Multispectral Persistent Surveillance”, John Schott, advisor
- Stephen Lach, Ph.D., (USAF), “Semi-Automated DIRSIG Scene Modeling from 3D LIDAR and Passive Imagery”, John Kerekes, advisor
- Jason Ward, Ph.D., (USAF), “Realistic Texture in Simulated Thermal Imagery”, John Schott, advisor

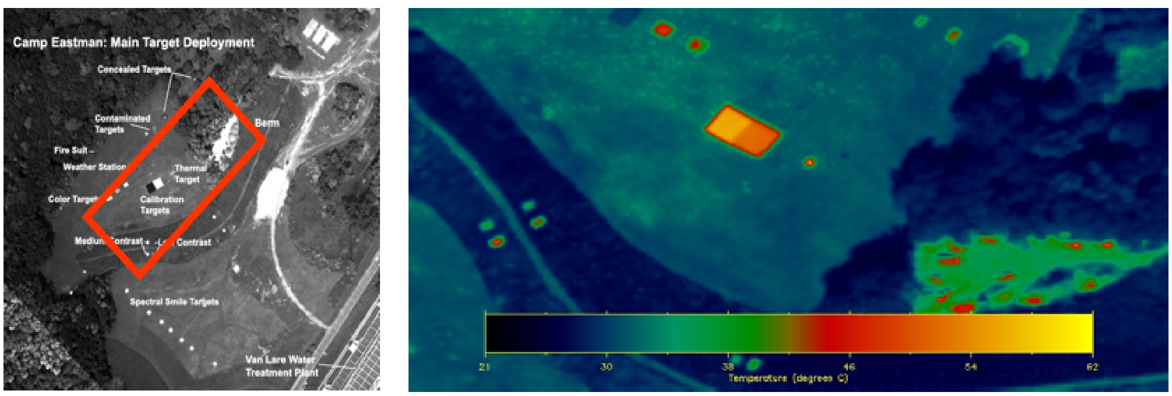
3 Research Project Summaries

3.1 ONR MURI - Physics-based Exploitation Algorithms for Hyperspectral Imagery

Sponsor: Office of Naval Research (ONR)

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Dr. David Messinger, Dr. Emmett Ientilucci, Dr. Rolando Raqueño, Dr. Adam Goodenough, Dr. Marvin Boonmee, Don Taylor, Jason Hamel

Project Description:
This 5 year research project was focused on the development of physics-based algorithms for use in extracting information from hyperspectral imagery. Applications spanning the reflective (visible / near infrared / short wave infrared) and thermal (long wave) infrared were developed leveraging knowledge of, and the ability to model, the physical phenomena associated with target and background signatures. Three specific applications were considered in the last year of the project: quantitative in-water constituent estimation, rare small target detection, and atmospheric compensation and temperature / emissivity separation in thermal imagery (see Figure 3.1-6).



(a) (b)

Figure 3.1-6: (a) RIT WASP high resolution image of the MegaCollect target area showing target layout. (b) Results of OLSTER processing (surface temperature map) on thermal hyperspectral image of same area.

Project Status:
This project was completed in the fall of 2008. As a result of this program 3 students successfully defended Ph.D. theses and 4 students (2 are ABD) successfully completed the CIS MS program.

3.2 ARO MURI - Spectral Signatures of Land Targets

Sponsor: Army Research Office (ARO)

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Dr. David Messinger, David Pogorzala

Project Description:

The focus of this modeling and simulation effort was to create several realistic scenes of land targets using the DIRSIG simulation tool. Previous year's efforts resulted in the creation and dissemination of a desert scene containing simulation surface and buried land mines and the development of an initial concealed target scene. The final efforts under this project were to create a much higher fidelity model of a concealed target scene. As shown below (Figure 3.2-7), a scene was created with several targets embedded in a forested area. Targets included several types of military vehicles. Confusers such as small metallic buildings and fences were also included in the scene to provide a challenging test of detection algorithms.

Project Status:
This project was completed in the fall of 2008.

Figure 3.2-7: Low spatial resolution rendering of the concealed target scene.

3.3 NGA University Research Initiative - Semi-Automated Imagery Analysis & Scene Modeling

Sponsor: National Geospatial-Intelligence Agency (NGA)

Principal Investigator(s): Dr. Harvey Rhody, Dr. John Kerekes, Dr. Eli Saber, Mr. Scott Brown
Research Team: Xiaofeng Fan, Prudhvi Gurram, Stephen Lach

Project Description:
The purpose of this project is to develop automated or semi-automated techniques to register multi-modal images, construct realistic 3-D scene models, infer material characteristics, and integrate these models into the DIRSIG physics-based image simulation tool. This research will enable analysts to rapidly synthesize a geometric and material representation of a target area.

The Digital Imaging and Remote Sensing Image Generation (DIRSIG) model is a first principles based synthetic image generation model developed by the Digital Imaging and Remote Sensing Laboratory at Rochester Institute of Technology. The model can produce multi- or hyper-spectral imagery from the visible through the thermal infrared region of the electromagnetic spectrum. The model can be used to test image system designs, to create test imagery for evaluating image exploitation algorithms and for creating data for training image analysts. This tool is widely used in the community. DIRSIG scene models are currently built with a highly manual process that can require man-months to man-years to accomplish. This limits the ability of the system to model scenes that are of current and immediate interest. If modeling could be built on a semi-automated basis using current imagery then it would be possible to represent scenes with fidelity and with a fast turn-around.

This research is directed toward the development of algorithms to extract and fuse information about scene structure from imagery using multiple modalities. The end product is a representation that can be used in Computer Aided Design (CAD) tools to build structures and cover them with appropriate materials. Objects of interest include man-made (roads, bridges, buildings) and natural objects (trees, grass, rivers, lakes, turf). These descriptions can be directly ingested into DIRSIG and, after possible additional editing, used to model scenes with a physically realistic rendition.

Project Status:
This three-year project is scheduled to end in July 2008. The tools and techniques developed in this project are supporting further work in 3D modeling, image registration, and advanced image analyst exploitation.

3.4 Landsat 5/7 Thermal Calibration

Sponsor: NASA

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Nina Raqueño, Frank Padula, Cliff Anderson

Project Description:
This project has three major tasks. The first is to continue to provide vicarious calibration of the thermal bands on the Landsat 5 and 7 satellites, the second is to attempt to evaluate the historical calibration state of the Landsat 5 thermal band and the third is to attempt to develop improved methods to characterize the historical calibration of the reflective bands of the Landsat instruments.

A major emphasis this year was placed on the Landsat 5 Band 6 historical calibration. A method was devised to use buoy data from a number of NOAA buoys in the Great Lakes and along the east coast of the United States (see Figure 3.4-8). The subsurface temperatures are used to estimate surface temperatures using a thermal model that accounts for variations in the diurnal temperature cycle with depth and cool skin effects. This yields a surface radiance that is propagated to sensor reaching radiance using the MODTRAN radiative transfer code and local estimates of atmospheric conditions. The sensor reaching radiance is then compared to the radiance observed by the satellite to evaluate the instruments calibration. Figure 3.4-9 shows the comparison of model predicted vs. observed radiances for data from 1984 to the present including multiple samples from each year. The results indicate the satellite has maintained calibration through this entire period to within 1K. It also indicates that there are consistent miscalibrations that can be corrected for and should allow the calibration error to be reduced to less than 0.5K for the entire mission life.

Project Status:
This is a three year effort with an ongoing component aimed at current calibration of Landsat 5 and 7 thermal bands. Next years effort will see a major thrust aimed at improvement of the long term radiometric calibration of the reflective bands of Landsat 5.

Figure 3.4-8: Picture of a NOAA buoy of the type deployed in the Great Lakes that records hourly air and water temperatures.

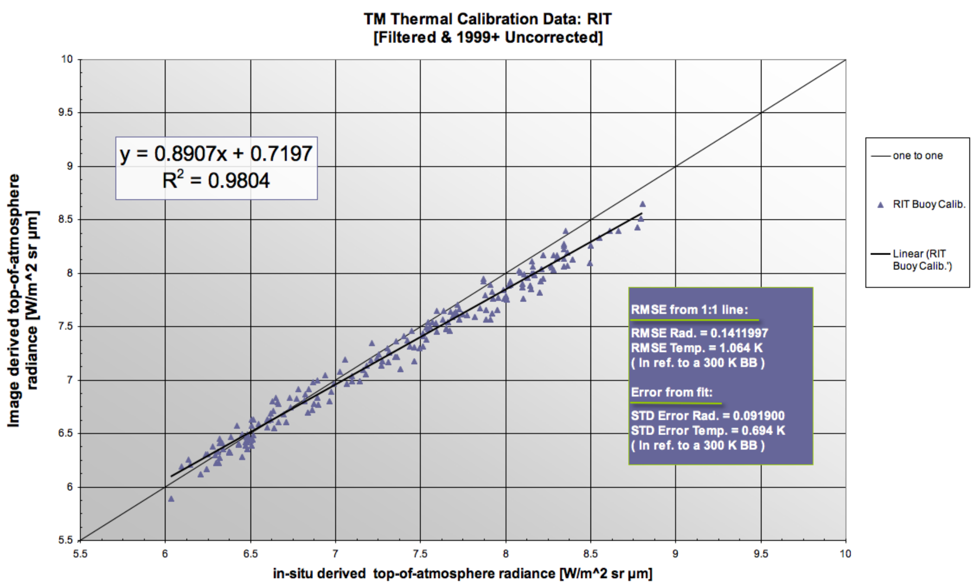


Figure 3.4-9: Comparison of model predicted (InSitu) and observed radiance (image derived) for data from 1984-2007 showing slight miscalibrations of the instrument.

3.5 Landsat Data Continuity Mission

Sponsor: US Geological Survey (USGS)

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Aaron Gerace

Project Description:
This project represents RITs contribution to the LDCM program. As part of the project, Dr. Schott partici-

pates on the Landsat Science Team and provides technical input on science issues related to current Landsat data and the evolving LDCM mission.

In addition, RIT is evaluating the potential utility of the next Landsat instrument to support studies of coastal and fresh waters. During the first phase of the effort we modeled the ability of three sensors to retrieve in water concentrations of the three dominant coloring agents in coastal waters (i.e. chlorophyll (CHL), colored dissolved organic material (CDOM) and suspended materials (SM). This study was conducted using in water radiative transfer models to predict the spectral reflectance of the water. These reflectances were then converted to observed reflectances that would be sampled by one of the three sensors. These are the existing Landsat 7 ETM+ sensor, the proposed Landsat 8 OLI sensor and NASAs airborne test bed AVIRIS, which is an imaging spectrometer (i.e. the best case example). These observed reflectances are degraded to include expected sensor noise and quantization errors. The resulting simulated reflectances are then analyzed using a model matching algorithm (developed at RIT under earlier NASA sponsorship) to retrieve in water concentration values. This approach assumes perfect atmospheric compensation and is designed to test the best performance we might expect for each sensor. The results from the first years study are shown in Figure 3.5-10 in terms of error in retrieved concentration and what percent of the range in concentration the error represents (errors of less than 10% of the range are used as an acceptable goal). The results are shown for a noise free scenario, then with instrument noise and then with instrument noise and quantization noise. These results show that the LDCM OLI instrument has the potential to enable Landsat to become a useful tool for water resource studies. With its 30 meter resolution this could revolutionize the use of remote sensing for monitoring coastal and fresh water ecosystems. In order to realize this potential,

	CHL(μg/L)	SM(mg/L)	CDOM(1/m)
AVIRIS	.5	.1	.1
ETM+	.5	.6	.2
LDCM	.5	.5	.1
ETM+ Quantized	5.7 8.4%	2.8 11.7%	1.7 12.1%
LDCM Quantized	1.2 1.8%	.6 2.5%	.2 1.4%
ETM+ Noise & Quantized	7.4 10.9%	4.8 20.0%	3.2 22.9%
LDCM Noise & Quantized	3.7 5.4%	1.2 5.0%	.9 6.4%

Figure 3.5-10: Illustration of the in water constituents concentration retrieved for various sensor configurations. The values in parenthesis are the errors expressed as % of the range.

we must be able to effectively invert the satellite observed radiance to surface reflectance. Ongoing work at RIT is investigating ways to use the new blue band of the LDCM-OLI instrument to help in this process. Figure 3.5-11 shows the observed radiance spectra of a range of water samples resampled to the OLI spectra. Note how the data converge at the largest and shortest wavelengths. This means that if we observe a water body and the apparent reflectance is varying in these two extreme bands, the effect is dominated by atmospheric rather than in water phenomena. We are currently attempting to develop LDCM-OLI specific atmospheric compensation techniques that take advantage of this phenomenology.

Project Status:
This is an ongoing effort that is in its second year with instrument launch planned for 2011.

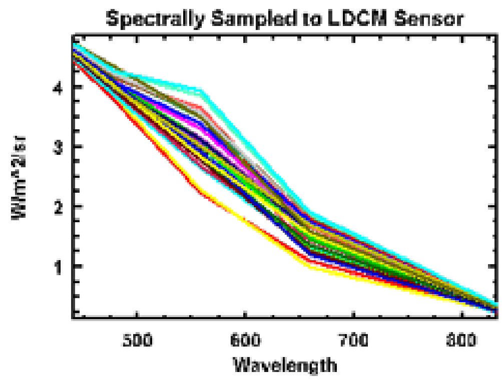


Figure 3.5-11: Plot of observed radiance for a range of water bodies with different constituents resampled to Landsat OLI bands.

3.6 GeoSage Support

Sponsor: ITT AES / National Geospatial-Intelligence Agency (NGA)

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Mr. Michael Richardson

Project Description:
GeoSage is an ITT managed support contract to NGA (Innovision Directorate) that provides technical assistance in areas related to remote sensing and imaging science. RIT provides technical consulting support, technical training, and coordinates the monthly Brown Bag presentations. The focus of the last year has been on training and speakers to support the Brown Bag presentations. On April 3, 2008, Dr. Schott delivered a day long training session on the fundamentals of Polarimetric Imaging to a group of engineers and scientists at NGA. The course emphasized the physical principles that describe the polarimetric behavior of materials, the propagation of EM energy, and the sensing of that energy for remote observation of the earth from overhead. Other speakers from RIT included: Scott Brown, October 4, 2007 on the use of DIRSIG as an image simulation tool to support sensor modeling and algorithm testing and Drs. Basener and Messinger on the operation and use of the TAD algorithm including its use in a NURI project entitled "Dynamic Analysis of Spectral Imagery for Improved Exploitation".

Project Status:
This project is ongoing.

3.7 IC Postdoctoral Research Fellowship - Physics-Based Target Detection in Hyperspectral Imagery

Sponsor: National Geospatial-Intelligence Agency (NGA)

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Dr. Emmett Ientilucci

Project Description:
The overall goal of this effort is to develop improved physics-based modeling approaches to target detection. More specifically, alternative methods for describing background / foreground spaces, improved

physics-based computing infrastructure, visualization and incorporation of algorithms into a user friendly software environment.

Project Status:
A new approach has been developed, tested, and implemented, which minimizes the overall number of MODTRAN runs necessary in generating signature spaces. This includes the use of polynomials that model signature spaces. A minimum set of MODTRAN runs is performed and used as training to the model. The model is then used to estimate the user desired signature space in its entirety. This polynomial signature space has been compared to a similar spaces derived using many runs of MODTRAN. Residuals were less than one percent. Furthermore, signature and MODTRAN derived spaces were compared in a target detection scheme and were shown to produce similar results (see Figure 3.7-12).

In addition, a full study was performed which looked at the impact calibration errors have on target detection when using the physics based approach to detection. Errors such as spectral gain, bias, and shift, in a variety of combinations, were addressed. Results, in the form of ROC curves, showed that only spectral shift significantly impacted performance, for the given detector in question.

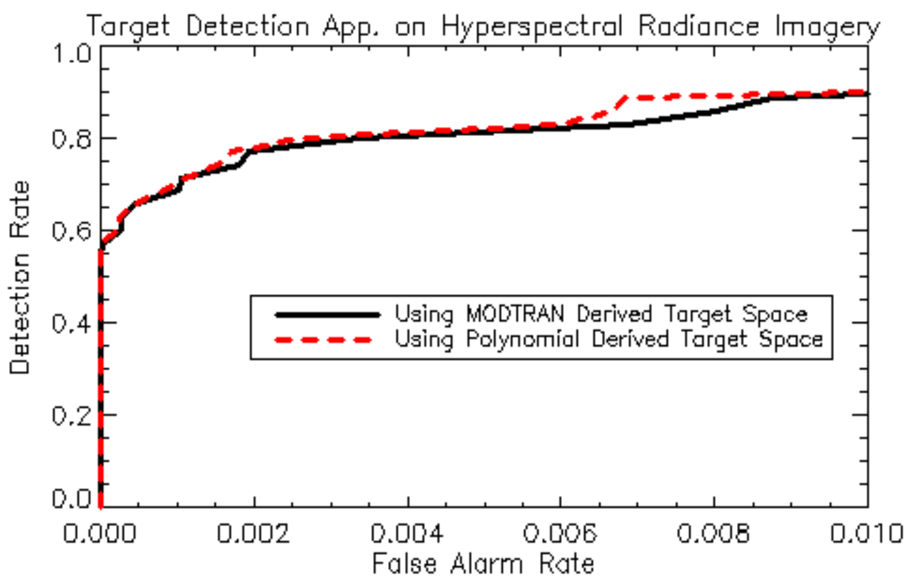


Figure 3.7-12: Comparison of ROC curves based on using a MODTRAN derived target spaces versus a polynomial modeled target space.

3.8 IC Postdoctoral Research Fellowship - Effects of Humidity on Atmospheric Transmission

Sponsor: Intelligence Community

Principal Investigator(s): Dr. Carl Salvaggio
Research Team: Dr. Carl Salvaggio, Dr. Rolando Raqueño, Dr. Robert Kremens, Robert Gelein (University of Rochester Medical Center), David Chalupa (University of Rochester Medical Center)

Project Description:
The overall objective of this research is to understand an unusual phenomenon that has been observed with

high altitude (6000-16000 meters) oblique-viewing airborne spectral imaging systems in the LWIR. It is a condition where a seemingly clear atmosphere with little extinction in the VNIR-SWIR region is coupled with a dramatic decrease of the transmission in the LWIR. These situations are especially problematic because decisions to collect thermal data based on visible observations have resulted in thermal imagery of poor quality with little or no exploitation value. The goal is to identify the conditions under which this phenomenon is likely to occur in order to task collections appropriately. Observations of this phenomenon have been correlated to the onset of high humidity conditions indicating that the phenomenon probably occurs during a transitional phase in the atmospheric aerosol constituency. The characteristics of these particles are such that their sizes are small enough that they do not scatter visible light to produce the familiar hazy conditions often associated with high humidity. The increased humidity conditions likely induces a water vapor to liquid vapor phase change on these aerosols as nucleation sites. The hypothesis behind this LWIR attenuation suggests that the atmospheric attenuation is caused by high concentrations of liquid water coated aerosol particles with diameters in the order of 0.1-0.2 microns. While these particles impart an attenuation due to absorption in the thermal region, their particle size has very little impact in the reflective regime.

We conducted an experiment to test this hypothesis. The method takes a simple, but novel approach of using a camera suite to image the effluent from a Harvard Ultrafine Concentrated Ambient Particle System (HUCAPS). Used primarily for toxicology studies of environmental aerosols, the HUCAPS has the ability to control and vary properties of humidity, temperature, particle size distribution, and number density of ambient aerosol particles concentrated by this system. This give a unique opportunity to image a controlled and well characterized plume of very fine aerosol particles and determine if any significant optical effects are observed in the LWIR region.

Project Status:

The results of this experiment suggest that it is unlikely that a high concentration of small hygroscopic aerosol particles will impart a detectable absorption effect in the LWIR region, while imparting negligible scattering effects in the visible region. The current physical experimental setup does not conclusively address this because of the short imaging path lengths in the chamber. Because the HUCAPS system and the human subject chamber was not designed for optical measurements of the incoming aerosol particle stream, the physical configuration needs to be modified to streamline future experiment. An improved chamber design would be a long temperature controlled cylindrical tube with a camera at one end imaging a blackbody target at the other end through the intervening aerosol particles introduced at one end and evacuated at the other end. This configuration may also be more amenable to LWIR spectroscopic analysis because of the extended path length allowing quantitative measurements of the aerosol stream.

Simulation of high altitude conditions suggest that the anomalous transmission effects may be due to a rapid growth of particles from nascent cloud condensation nuclei causing detectable sizes in both the visible and thermal regions as captured by the cameras. These transient effects observed in the chamber are possible in airborne remote sensing scales where unstable atmospheric conditions can cause the mode of the particle sizes to oscillate in and out of the detectable size regime. Future work in modeling analysis using Mie codes, coupled with the MODTRAN model, can be used to verify these findings and quantify the extent of particle growth that made the plume optically detectable. This can then be compared with aerosol growth model predictions simulating the rapid cooling and heating conditions of these high humidity aerosol plumes in the chamber. Extension to other numerical models that govern the physical formation of natural aerosols can also be studied. Attempts can then be made to confirm the likelihood of these aerosol characteristics based on environmental factors at a much larger scale for observation in airborne remote sensing.

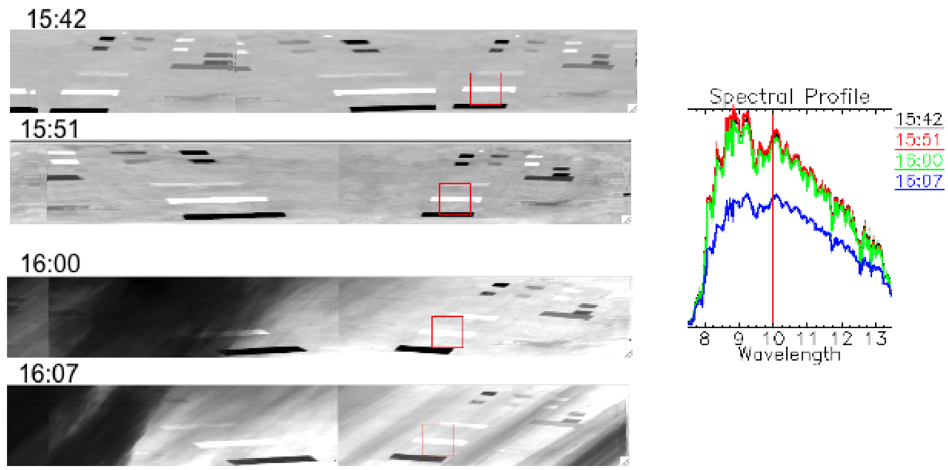


Figure 3.8-13: Thermal infrared spectral imagery sequence of control panels showing transmission degradation as a function of time as atmospheric feature enters the sensor field of view.

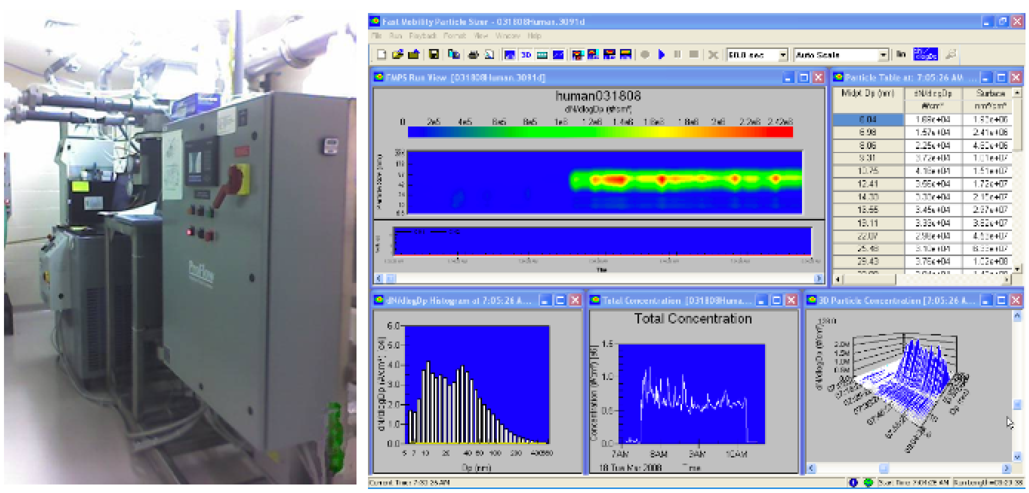


Figure 3.8-14: HUCAPS aerosol instrument at University of Rochester Medical Center used for LWIR/Visible imaging experiment.

3.9 IC Postdoctoral Research Fellowship - Microscale Surface and Contaminate Modeling for Radiometric Exploitation

Sponsor: Intelligence Community

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Dr. Michael Gartley, Scott Brown

Project Description:
This task is aimed at developing, verifying, and applying a micro-scale surface reflectance model. The focus of the model will be to predict the changes in surface optical properties in response to changes in sur-

face condition and/or contamination with particulate and liquid contaminates. The resulting bi-directional reflectance and directional emissivity characterizations can be used in traditional, surface oriented radiometry codes and signature-based algorithms.

Project Status:
A modified version of DIRSIG (microDIRSIG) has been developed to perform virtual spectral-polarimetric BRDF measurements of complex surface geometries. The model predictions have been verified against experimental measurements, Mie scattering code, and analytical polarimetric BRDF models (Figure 3.9-15) for randomly rough surfaces.

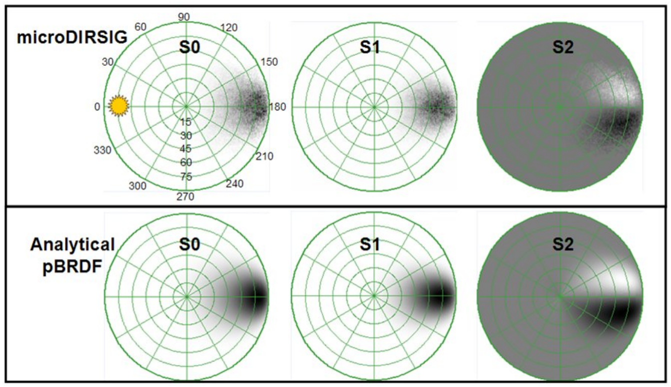


Figure 3.9-15: Comparison of hemispherical polarized BRDF between microDIRSIG and an analytical model for a randomly rough Gaussian surface.

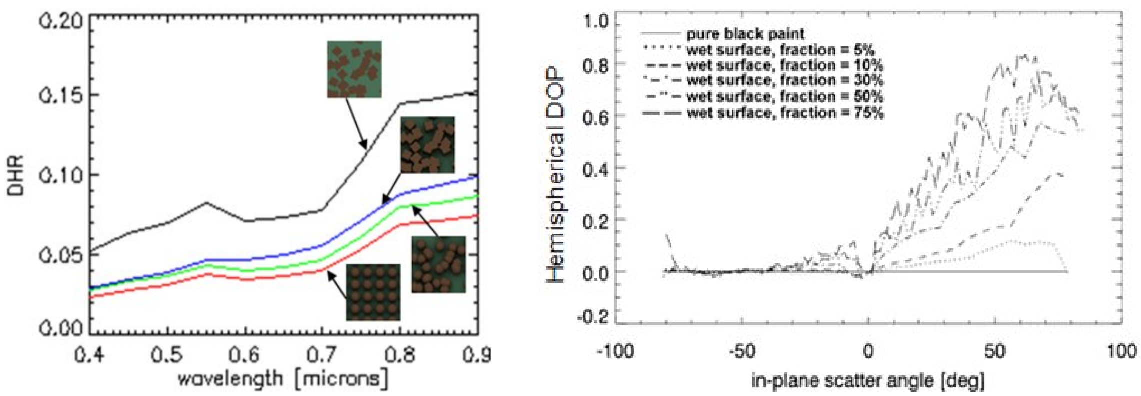
The model has been utilized to predict the reflectance properties of a painted surface contaminated with soil particles. We have found the geometry and spatial distribution pattern of the soil particles have a significant impact on spectral reflectance properties (Figure 3.9-16(a)) and behave non-linearly with increasing soil concentration. In addition, the same model was utilized to predict how the soil particles might lower the observed polarization signature as a function of both particle geometry and concentration. Another case example examined how the presence of surface water contamination might alter the magnitude and polarimetric state of light reflected from a painted surface (Figure 3.9-16(b)). These predictions indicate that target surfaces that are undetectable by polarimetric imaging methods when in the clean state may develop a significant polarization signature in the presence of surface water (such as after a rain or from early morning dew).

3.10 Revolutionary Automatic Target Recognition and Sensor Research (RASER)

Sponsor: Air Force Research Laboratory (AFRL) Sensors Directorate

Principal Investigator(s): Dr. John Kerekes
Research Team: Dr. John Kerekes, Jason Casey, David Snyder

Project Description:
The main research topic of this project, HSI vehicle tracking, was pursued through empirical data collection, empirical data analysis, and sensor system modeling analysis. Four vehicle tracking experiments (three on the RIT campus and one in Cooke City, Montana) were conducted, resulting in significant amounts of airborne hyperspectral imagery and ground truth data used for analysis. Three of these experimental data sets have been compiled and documented adequately for further analysis by the community. Analyses of



(a) (b)

Figure 3.9-16: (a) Directional hemispherical reflectance as a function of soil particle geometry and spatial distribution for a 50% covered surface. (b) Hemispherical degree of polarization for varying levels of surface water contamination on a Lambertian black surface.

two of these data sets confirmed that it is possible to track a vehicle of interest from one hyperspectral image to another, although the success of this task is highly dependent upon the spectral contrast of the vehicle with the urban background and other confuser vehicles.

Several other conclusions resulted from this work. In the case of the availability of lidar imagery over the area of interest, it was demonstrated that false detections in the hyperspectral imagery can be mitigated through analysis of the lidar data and a derived static object map. A simulation study of the effects of spectral misregistration of the hyperspectral imagery found that even for objects similar in size to a pixel, up to 0.5 pixel misregistration can be tolerated, and that stochastic detection algorithms generally were more robust than geometric algorithms. A short investigation into candidate UAV-based HSI sensor systems found commercial off the shelf (COTS) technology was available for HSI sensors that could be flown in a modest (∼12 foot wingspan) size UAV. For the identified systems, reasonable radiometric performance could be expected and successful detection possible at false alarm rates of 0.00001 or lower.

While this study has demonstrated hyperspectral image tracking of vehicles is possible, it has also identified situations where it is not possible. These include vehicles with paints that have no spectral features of distinction (dark paints or whites) or whose paint is very similar to other confusing vehicles in the area. These situations are the primary reasons why HSI tracking may not be successful.

Project Status:
This project was completed at the end of 2007. Several publications, reports, and data sets were produced and are available upon request.

3.11 Performance Driven Multi-modal Sensors

Sponsor: Air Force Office of Scientific Research (AFOSR

Principal Investigator(s): Dr. John Kerekes, Dr. Zoran Ninkov, Dr. Alan Raisanen
Research Team: Michael Pressnar

Project Description:
The objective of this project is to perform basic research in the development and use of integrated micro-

electromechanical systems (MEMS) devices coupled with optics and solid state focal plane array technology for adaptive exploitation-driven multi-modality sensing suitable for ISR applications. In particular, we are investigating adaptive sensor designs that enable co-registered electro-optical imagery, video, polarization and spectral sensing in a robust compact unit. These designs are being explored together with research into real-time exploitation algorithms that can adaptively control the sensing modality and field-of-view to enable object tracking and monitoring specific to the situation. These device and algorithm research efforts are being conducted together with scene phenomenology modeling and simulation tools to perform comprehensive system-level performance analyses and demonstrations of the potential for the concepts to lead to transformational intelligence, surveillance, and reconnaissance (ISR) capabilities.

Our approach for this effort is to explore feasible optical device constructs which through further research and development could lead to integrated imagery (both intensity and polarization), video and spectroscopic sensing together with the algorithms and scene phenomenology for adaptive sensing and tracking of objects of interest in a cluttered environment. This approach combines three interrelated research veins. 1) Sensor and Device Research. This research thrust is exploring conceptual designs and component modeling for integrated multi-modality optical sensors based on MEMS, digital micromirror, integrated Fabry-Perot, and high resolution lithography technologies. 2) Exploitation Driven Adaptive Sensing. This effort is working on the basic science of algorithms necessary to exploit, track and adaptively control the sensing parameters based on the scene phenomenology, observational geometry, and target information. 3) System Performance Modeling and Analysis. This third research vein provides the framework for end-to-end system modeling of the device concepts and processing algorithms and enables system level trade-off studies and performance predictions.

Project Status:
This project was initiated in the spring of 2007 and will continue until 2010. Early efforts are focusing on proof-of-concept initial sensor designs, tracking algorithms and laying out the scenes of interest for full three-dimensional simulation.

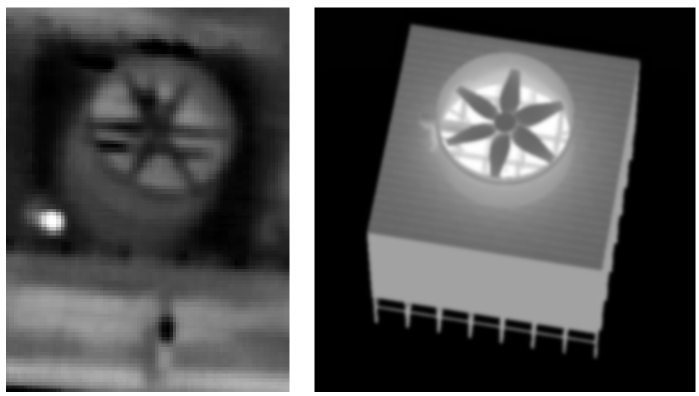
3.12 Accurate Temperature Retrieval of the Exhausted Air Temperature from Mechanical Draft Cooling Towers for Use with Power Plant Process Models

Sponsor: Savannah River National Laboratory (SRNL), Department of Energy (DOE)

Principal Investigator(s): Dr. Carl Salvaggio
Research Team: Dr. Carl Salvaggio, Dr. David Messinger, Scott Brown, Matt Montanaro, Dr. Adam Goodenough, Dr. Alfred Garrett (SRNL)

Project Description:
For the past two years, the Digital Imaging and Remote Sensing (DIRS) laboratory has been actively involved in determining methods and modeling techniques for the prediction of the exhausted air temperature from mechanical draft cooling towers (MDCT) using remote sensing approaches. The exhausted air temperature from these structures is a critical input to power plant process models developed the Savannah River National Laboratory (SRNL). DIRS is part of a team addressing the overall problem of power plant operating level prediction. DIRS is addressing the radiometric transfer parts of the problem in hopes of returning an exhaust air temperature with an accuracy of 1 °C. Thermodynamics, hydrodynamics, and fluid flow engineers at SNRL are addressing other portions of this overall problem including the prediction of the air vectors and their temperature throughout these complex towers as well as the power plant operating level prediction based upon the observed drop in cooling water temperature across the condenser.

In this past year, a greater understanding of the physical phenomenology has been obtained that governs the radiative transfer and numerous enhancements have been made to the radiometric model and optical properties models in the DIRSIG code (see Fig. 3.12-17 for latest modeling results). Exhaustive error budgets have been made of the major contributing factors to the imagery derived temperature of the exhausted air from an MDCT. The path from the sensor to the observables deep inside a tower is a complex one to be sure. In addition to the atmosphere that exists between the sensor and the target in every remote sensing application, this application involves the modeling of a localized atmosphere above the tower opening that consists of a variably-disapating water vapor plume at elevated temperature. In addition, the complex physical structure that makes up the interior of an MDCT poses a time consuming modeling task for DIRSIG. Studies of the effect of simplifying assumptions of the blackbody behavior of this target have been carried out. These studies have shown that multiply-bounced photons quickly begin to act as photons emitted from a blackbody and therefore justify some simplifying assumptions that will allow DIRSIG to execute much more rapidly when the parametric temperature error model begins this coming year.



(a) (b)

Figure 3.12-17: (a) Actual longwave infrared image collected by the Savannah River National Laboratory at the Savannah River Site H-Area complex along with (b) a DIRSIG simulated version of a single cell of this tower.

Key findings during this year included the identification of the primary error contributing source as the intervening atmosphere between the top of the water vapor plume and the sensor. Unexpected as this was, it points out that even though the plume is nearly saturated and at elevated temperature, it is a small contributor to the overall radiance field along the target sensor path. For a 20 meter thick plume, Fig. 3.12-18, the contribution to the overall temperature error predicted with the sensed image is less than $0.5\,°\mathrm{C}$.

Project Status:
This project is in the middle of the second of three years. It is scheduled to be completed during the fall of 2009.

3.13 Characterization of the influences of ice and snow on the radiometric field emanating from cooling lakes at cold site power plants

Sponsor: Savannah River National Laboratory (SRNL), Department of Energy (DOE)

Principal Investigator(s): Dr. Carl Salvaggio

Research Team: Dr. Carl Salvaggio, May Arsenovic, Michael Richardson, Dr. Robert Kremens, Don McKeown, Jason Faulring, Nina Raqueño, Dr. Alfred Garrett (SRNL)

Project Description:
The Department of Energy at their Savannah River National Laboratory (SRNL) has used remotely-sensed

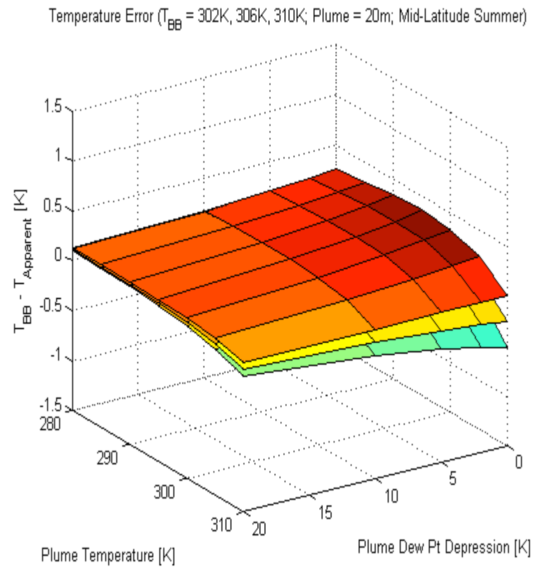


Figure 3.12-18: The apparent temperature error as a function of plume temperature and plume dew point depression is shown for 310 K, 306 K, and 302 K plume (from top to bottom) exhausted into a MODTRAN mid-latitude summer atmosphere.

thermal infrared imagery for many years to evaluate the operating condition of power plants, specifically the determination of the plant operating level from the observed input and output cooling water temperature and their three-dimensional hydrodynamic code ALGE. This research effort is directed at assisting the SRNL scientists in extending this capability to perform in situations where the cooling lake is partially covered by ice in cold regions (Fig. 3.13-19). At these locations, the complete extent of the observable warm water discharge plume is not visible as it is partially obscured by the ice layer that forms at the surface. The ice not only obscures the plume, but based on its thickness, serves as an insulator that prevents heat loss from the lake therefore making the cooling system less efficient. The determination of the plant operating level is then based upon the determined temperature of the water in the melted region of the lake, the size of the melted area, and an estimate of the ice thickness across the frozen portions of the lake and the insulating effect that results.

As a result, RIT has entered into an agreement with Midland Cogeneration Venture power plant in Midland, MI to conduct a series or experimental collections over this plant during the 2008-2009 winter season. Collections will include calibrated airborne thermal infrared imagery of the entire lake collected with RIT's WASP sensor package, "ground"-based buoys that will measure water temperature profiles at several locations in the lake (in and out of frozen regions), ice thickness at these same locations using one or more of several technologies currently under investigation, as well as complete meteorological information including temperature, pressure, relative humidity, wind velocity and downwelling visible and thermal radiance. Advanced investigations will also be exploring the use of passive millimeter wave sensors operated from an airborne platform for use in the remote determination of ice thickness.

The experimental design team is currently taking on development projects for all the ground-based observations and testing their operation in the harsh winter conditions that will be encountered. The team is also designing and building an in-flight calibration system for the thermal infrared channel of the WASP sensor package that will for the first time allow production of at sensor radiance imagery. Additionally, the team is experimenting with ultrasonic techniques, mechanical techniques, and optical techniques for ice

Figure 3.13-19: Midland Cogeneration Venture power plant in Midland, MI. This gas-fired power plant receives cooling water from and discharges to a closed cooling lake originally designed to support cooling of a planned nuclear plant at this site. Due to the oversized nature of this lake, it does partially freeze during the winter months.

sheet thickness measurements - of which one or more methods will be implemented on the buoys for this upcoming collection season.

Project Status:
This project is in the first of three years. Experiment designs have been established and methods for ground truth evaluation are being investigated.

3.14 Techniques for Oblique Angle Hyperspectral Image Analysis

Sponsor: VirtualScopics, Naval Research Laboratory (NRL)

Principal Investigator(s): Dr. David Messinger
Research Team: Dr. David Messinger, Dr. Emmett Ientilucci, Joe Bishoff

Project Description:
A key question in target detection in hyperspectral imagery is how to place the target properties and image properties in similar "domains". For example, in reflective hyperspectral imaging, the target is generally described by its reflectance properties, but the image is collected in digital counts and generally calibrated to radiance. Consequently, there are two possible methodologies for processing the data: in the reflectance or radiance domains. The reflectance domain is preferential when the scene can be accurately converted to estimated surface reflectance.

Under this program, target detection using a proposed highly oblique hyperspectral imaging sensor was investigated. The general question investigated is in which of the two domains should the imagery be processed, radiance or reflectance? In these highly oblique collection geometries accurate atmospheric calibration is unlikely, so radiance domain processing should prove the more successful methodology. For this work, a non-operational, but highly accurate method of estimating surface reflectance was developed and implemented to approximate the best possible reflectance domain processing. Results from this processing were compared to results from radiance domain processing, in which the long slant path atmospheric effects (inherent in oblique imagery) were modeled. Results show that the radiance domain processing either meets or exceeds the performance of processing the data in the best possible case of almost perfect atmospheric compensation.

Project Status:
This project has completed the first of two years. It will continue through January of 2009. One MS student has participated in this program and will defend his thesis in July 2008.

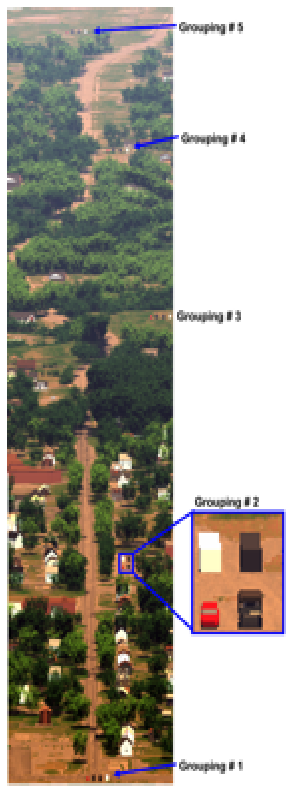


Figure 3.14-20: RGB image of DIRSIG hyperspectral oblique target detection scene with embedded targets.

3.15 Persistent Surveillance Data Collection

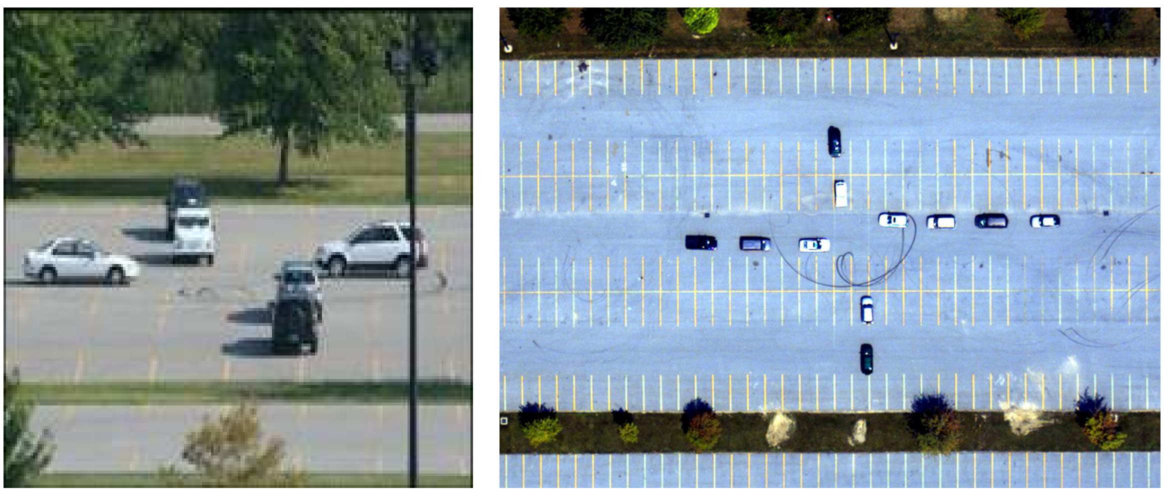
Sponsor: Georgia Tech. (SENSIAC), Army Research Office (ARO)

Principal Investigator(s): Dr. David Messinger
Research Team: Dr. David Messinger, Michael Richardson

Project Description:
The purpose of this data collection experiment was to capture and process visible RGB/HSV, SWIR, MWIR, and LWIR airborne imagery at various times of the day to determine if variations in natural illumination

and shadow effects impact the detection of vehicles, and also to explore the utility of Hue-Saturation-Value conversion from RGB under variable illumination. RIT's WASP airborne multiband mapping camera was used to collect data for use in this experiment. WASP consists of four co-boresighted cameras that operate in the visible, SWIR, MWIR and LWIR.

The area imaged was a parking lot on the RIT campus. This area was chosen because it provided an asphalt background and enabled control of the vehicles in the scene for many hours during the day. A total of 11 vehicles of varying make, model, and color were positioned in the parking lot to simulate an urban intersection. Airborne collects over the simulated intersection were made at three times during the day starting at approximately: 6:40am, 10:10am, and 12:30pm. The aircraft made six passes over the test site for each collection time period. After Collection Passes 3, 9, and 15, two of the eleven vehicles were repositioned to simulate movement through an intersection and imaged three additional times by the airborne sensor before being re-positioned back to the starting location in preparation for the next collection window.



(a) (b)

Figure 3.15-21: Vehicles positioned in the RIT parking lot to simulate an urban intersection for a persistent surveillance data collection experiment. (a) Ground level image. (b) Airborne image.

Data were segmented into "chips" to isolate individual targets in each image. These smaller image chips were blurred to the desired spatial resolution using multiple blurring kernels to simulate the effects of multiple sensor acquisitions on the same target. Spatial and spectral identification features were then computed for each target for use by the classification algorithms developed by Georgia Tech.

Project Status:
This project was completed in 2007.

3.16 Characterization of Physically Derived Signatures Spaces for Improved Spectral Unmixing

Sponsor: Naval Research Laboratory (NRL), National Geospatial-Intelligence Agency (NGA)

Principal Investigator(s): Dr. Emmett Ientilucci
Research Team: Dr. Emmett Ientilucci, Dr. David Messinger

Project Description:
This project supports an effort at NRL to develop a new generalized method for analyzing hyperspectral / multispectral data, based on the linear mixing approach. In this method, the concept of an endmember vector is generalized to an endmember subspace. This approach allows for modeling of the within-class variation of a material in a scene, while allowing for traditional mixture analysis, such as demixing/abundance estimation and fraction plane analysis, to proceed as usual. The method allows for virtual endmembers which are derived through use of physically derived signature spaces (PDSS). These virtual endmembers can produce an unmixing plane that is synonymous with typical target detection results. The project supplies NRL with signature spaces as well as user friendly tools (*i.e.,* ENVI plugins) that produce spaces based on a reduced set of MODTRAN runs.

Project Status:
To date, ENVI plugin tools have been created that allow the user to create full signature spaces with an overall reduction in the number of MODTRAN runs (see Figure 3.16-22). The user inputs the desired levels for each parameter. Based on this information, a minimal set of levels is automatically generated. This small set of levels is run in MODTRAN and used for model training. The algorithm then produces the full set of radiance vectors originally specified.

3.17 Characterization of Gaseous Plumes in the LWIR Using Bayesian Model Averaging

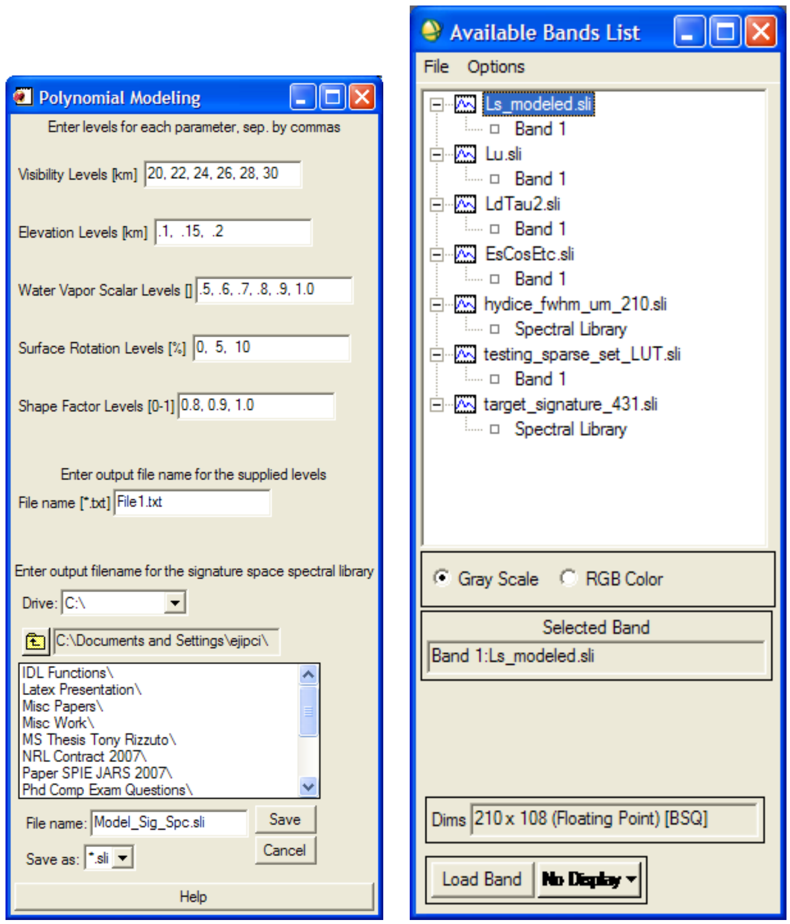
Sponsor: Pacific Northwest National Laboratory (PNNL)

Principal Investigator(s): Dr. David Messinger
Research Team: Dr. David Messinger, Shawn Higbee

Project Description:
The US Department of Energy has an interest in monitoring industrial facilities for a variety of reasons such as environmental impact monitoring and treaty enforcement. One methodology proposed for this purpose is thermal hyperspectral imaging for the detection and characterization of gaseous effluent plumes. However, the identification and separation of multiple gas species present in a single detected plume can be a complex task due to the nature of the radiometric signatures collected by the sensor and attributable to the presence of the gas plume. Previous work has used a stepwise linear regression approach to select the most appropriate "model" for a given pixel. This model contains the statistically most likely species to be present in that particular pixel.

Here, the approach is to use a Bayesian methodology for the model selection. Bayesian statistical analyses, unlike traditional "frequentist" approaches, utilize a prior probability model for unknown variables in the process and thus, allow the user to incorporate previous knowledge into the ultimate estimate. Here, several methods are being identified and evaluated for use on this specific problem. These include a Markov Chain Monte Carlo (MCMC) method to develop the posterior probability density functions for each species under test to predict the most likely species in a previously detected plume pixel. The method will leverage multi-temporal images to help understand the prior probabilities associated with the background materials and temperatures. Additionally, physical models of the spatial dispersion and cooling of the plume will be incorporated into the models to better constrain the results.

The project builds off previous work done under the ONR MURI on the use of physics-based models in atmospheric compensation and temperature / emissivity separation in LWIR hyperspectral imagery. This technique, termed the Optimized Land Surface Temperature Emissivity Retrieval algorithm, or OLSTER, allows researchers to extract the surface emissivity and temperature properties from a calibrated LWIR hyperspectral image. This capability is being used in several ways on this program. First, it is used to understand the background material variability in real imagery collected by the Advanced Hyperspectral



(a) (b)

Figure 3.16-22: Custom ENVI widget (a) allowing user to enter parameters and levels needed to generate a modeled signature space. (b) The modeled signature space, and its components, are then displayed in the ENVI bands list dialog box.

Imager (AHI, built and operated by the University of Hawaii) over a petrochemical facility during the summer of 2004. Secondly, it allows us to build well characterized semi-synthetic images of realistic scenarios containing plumes of known position and composition. This semo-synthetic dataset will be shared with the PNNL researchers and used extensively on this project, providing a quantitative measure of algorithm effectiveness.

Project Status:
This project is still ongoing and is scheduled to be completed in the summer in 2009.

3.18 WorldView-2 Band Assessment Study

Sponsor: DigitalGlobe

Principal Investigator(s): Dr. Anthony Vodacek

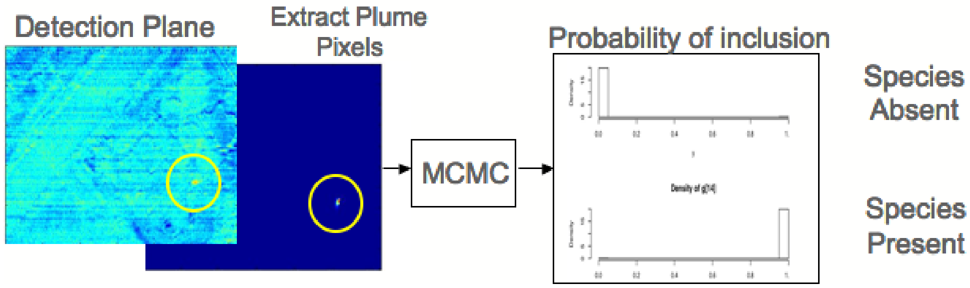
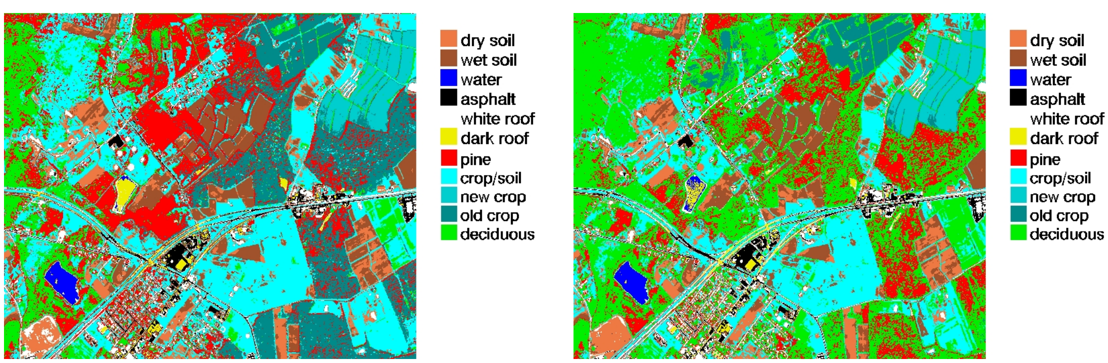


Figure 3.17-23: Outline of the Bayesian approach and results for identification of gaseous plumes in thermal hyperspectral imagery. MCMC stands for Markov Chain Monte Carlo.

Research Team: Dr. Anthony Vodacek, Dr. David Messinger, Dr. Emmett Ientilucci, Dr. Rolando Raqueño, Michael Richardson

Project Description:
We conducted a study to survey and quantify suitable exploitation applications for the 8 visible and near infrared bands of WorldView-2, the new DigitalGlobe sensor to soon be launched. We focused on the new bands (i.e., coastal blue, yellow, red-edge and the additional longer wavelength near infrared band) to establish what improvements and/or unique applications are enabled by these extra bands, either by themselves, or in combination with any or all of the WorldView-2 bands. This study also surveyed algorithmic approaches for processing the WorldView-2 multispectral imagery that are currently available or under development in the research community.



(a) (b)

Figure 3.18-24: (a) A Gaussian Maximum Likelihood land cover classification result for a QuickBird spectral response image of Pocomoke, MD. (b) Same result but for WorldView-2 spectral response. The classification accuracy for the QuickBird image is less than 50% while the accuracy of the Worldview-2 class result is over 75%.

Project Status:
We took a comparison approach in this study by applying various spectral analysis tools to the four QuickBird bands and to the additional four bands available for WorldView-2 data. Since WorldView-2 data are not yet available, we used spectral resampling of several airborne hyperspectral images with ground resolution similar to images expected from the satellite sensors. We spectrally resampled the hyperspectral

images to both the QuickBird and the WorldView-2 multispectral bands. As expected, various spectral analysis tools applied to the WorldView-2 images had demonstrably better results compared to the results when the same tools were applied to the QuickBird images. Figure 3.18-24 illustrates the differences in a Gaussian Maximum Likelihood land cover classification for the QuickBird bands (a) and the WorldView-2 bands (b). The original image is a low altitude AVIRIS image of Pocomoke, MD obtained from the AVIRIS Data Facility.

3.19 LACOSTE Modeling

Sponsor: Air Force Research Laboratory (AFRL)

Principal Investigator(s): Mr. Scott Brown
Research Team: Scott Brown, Niek Sanders

Project Description:
The general scope of this project is to provide systems engineering evaluation support for DARPA's Large Area Coverage Optical Search-while-Track and Engage (LACOSTE) program. The LACOSTE program is developing a wide FOV coded aperture imaging system that operates in the mid-wave infrared (MWIR) for conducting day/night tracking of vehicles in the urban environment. RIT's involvement with the project focuses on providing AFRL with the DIRSIG software and support to perform independant evaluation of the proposed LACOSTE designs. This support includes delivering an initial large-scale scene that could be used for sensor evaluation, improving the MWIR spectral databases and conducting a study on introducing dynamic scene content (moving vehicles).

Project Status:
During the past year, the DIRSIG model has undergone a series of small imporvements to support this project. The primary thermal model (THERM) was rewritten from the original Fortran into C++ and optimized to reuse internal calculations when possible and to limit the number of time steps used to predict temperatures. The overall speed increase was 2x to 8x speed up depending on the scene and view geometry used in the simulation. To help import high fidelity vehicle thermal model outputs, a set of tools were introduced to import temperature attributed IFS geometry supplied by the National Ground Intelligence Center (NGIC) and the weather files used to model those vehicles. A scene rendering generated by AFRL is shown in Figure 3.19-25.

3.20 Automated 3D Terrain Mission Profile Generation

Sponsor: Impact Technologies

Principal Investigator(s): Dr. David Messinger
Research Team: Dr. David Messinger, Nina Raqueño, Christina Kucerak

Project Description:
This Phase 1 Small Business Innovative Research (SBIR) project was a collaboration with Impact Technologies, a small engineering firm in Rochester, NY. The goal of this initial investigation was to study the use of classification maps derived from remotely sensed, multispectral imagery (see Figure 3.20-26) to assess terrain characteristics. Ultimately, these terrain characteristics will be used in a mission profile generation tool for analysis of vehicle maintenance and degradation. Surface material properties, derived from the remotely sensed imagery, will be correlated to terrain characteristics that impact vehicle condition. Spectral imagery is used in conjunction with estimated texture features (see Figure 3.20-27) to estimate surface terrain conditions. This work resulted in the submission of a Phase 2 SBIR proposal submitted in June 2008.

Figure 3.19-25: An MWIR image of MegaScene #1 featuring target vehicles developed with AFRL to support the LACOSTE program.

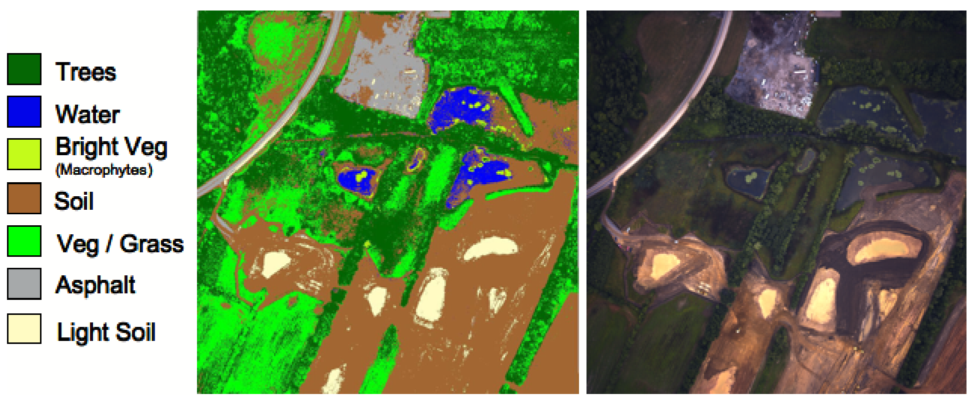


Figure 3.20-26: (left) Classification map generated from WASP airborne imagery (right) of a portion of the RIT campus.

Project Status:
This Phase 1 SBIR project was completed in the spring of 2008. A Phase 2 SBIR proposal has been submitted by the sponsor of this project, and DIRS was included as a contributor to this proposed research effort.

3.21 Gitam Technologies SBIR Support

Sponsor: Gitam Technologies, Air Force Research Laboratory Sensors Directorate

Principal Investigator(s): Dr. John Kerekes

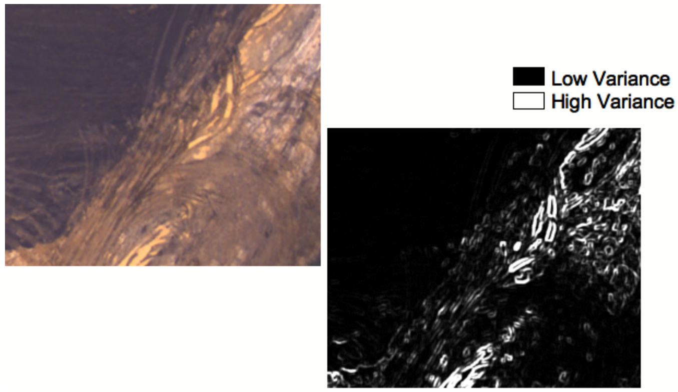


Figure 3.20-27: Texture feature map generated from the RGB image of the RIT campus.

Project Description:
Several research efforts (described below) are being conducted in partnership with Gitam Technologies, a small business located in Dayton, Ohio.

Project Status:
During 2007-08 RIT was a partner with Gitam on two Phase I's and one Phase II Small Business Innovative Research (SBIR) grants. The two Phase I's have been completed while the Phase II was just initiated in early summer 2008.

3.21.1 Network Centric Urban Vigilance (SBIR Phase I)

Research Team: David Pogorzala, David Nilosek

Project Description:
The primary goal of this effort has been to develop novel and effective HSI-based algorithms for multiplatform and cued fingerprinting, detection, recognition and tracking of dismounts, vehicles and other man-made objects in urban scenarios. In support of this goal, researchers at the Rochester Institute of Technology have contributed in the following four ways.

In this effort, RIT contributions have led to supporting a few conclusions. One conclusion was that when using a target spectrum collected at one altitude to detect the target in an image collected at a second altitude, the best detection performance is obtained under the scenario where the original target is observed at low altitudes and then detected again from a high altitude sensor. This is explained by the typical situation of using an average spectrum of the 1st observance to detect a target that is averaged spatially in the lower resolution high altitude observation. Attempts to detect targets from lower altitudes using the high altitude observation suffer from the fact that the targets will be more fully resolved and have expanded variability in the lower altitude image and the high altitude target spectrum will look less like the targets. Another conclusion reached through the FASSP modeling was that it is harder to use an off-nadir target spectrum to detect the target than using a nadir-collected spectrum. This was true whether detecting the second occurrence of the target in nadir or off-nadir viewing geometries. While time did not permit further analysis of the DIRSIG-generated imagery, it can be concluded that simulations provide a valuable tool in studying the sensitivity of target detection under well-known truth conditions.

Project Status:
This project was completed in February 2008.

3.21.2 Advanced Signature Matched Hyperspectral Change Detection (SBIR Phase I)

Research Team: Dr. Michael Gartley, David Nilosek

Project Description:
The primary goal of this effort was to support the development of signature-based Change Detection (CD) algorithms with the capability to locate particular signatures in an observation scene, where prior knowledge about the target or the background might be available from a previous pass.

DIRSIG simulations of three test ground-based hyperspectral images confirmed that high quality synthetic images can be made for a real scene and used for quantitative comparisons. The investigation of the CHARM 2006 HyMap airborne hyperspectral imagery for change detection algorithm development determined the data were not suitable for detecting small changes of interest (vehicle movements), at least using the baseline covariance equalization algorithm considered. This was most likely due to the subpixel nature of the targets and the few-pixel misregistration error between the change images.

Project Status:
This project was completed in February 2008.

3.21.3 Hyperspectral Detection of Chemical and Biological Agents Using Biosensors (SBIR Phase II)

Research Team: Danielle Simmons

Project Description:
The goal of this project is to investigate the ability of hyperspectral imaging systems to detect subtle phenomenological changes in plants that have been genetically engineered to stop producing chlorophyll when exposed to trace amounts of hazardous chemicals or explosives. This research is in partnership with biologists at Colorado State University who are producing the genetically modified plants.

Sensor system design studies and scene simulations are being performed as part of engineering studies on the performance capabilities and design requirements to detect the subtle changes in the plant spectral reflectance with remote observing hyperspectral imaging sensors.

Project Status:
This project was initiated in late 2007 and will continue through 2009. Preliminary measurements of the plants after exposure have been made but additional data collections are planned.

3.22 Remote Sensing Data Assimilation with Physical Models of the Environment: Fire Propagation Modeling

Sponsor: National Science Foundation (NSF)

Principal Investigator(s): Dr. Anthony Vodacek
Research Team: Dr. Anthony Vodacek, Dr. Zhen Wang, Alvin Spivey, Yushan Zhu, Dr. Robert Kremens

Project Description:
This project is a collaboration with researchers at NCAR, U Kentucky, CU- Denver and TAMU. The goal of this project is to develop a dynamic data driven system for modeling the propagation of wild land fires. The end product will give wild land fire managers a tool for predicting the propagation of wild land fire with steering of the modeling results by data from ground sensors and remotely sensed data. RIT is developing the interface to use thermal imagers such as WASP or WASP-Lite as airborne data sources of fire location. Dr. Kremens is also continuing to develop ground sensor measurement capabilities and experimental data

on the optical and thermal radiation emitted by fires. RIT is creating synthetic images from the model output to facilitate comparison to the ground sensor and airborne remote sensing data to provide steering of the model results. We are also using DIRSIG as a visualization tool for generating synthetic 3D fire scenes including the 3D structure of flames.

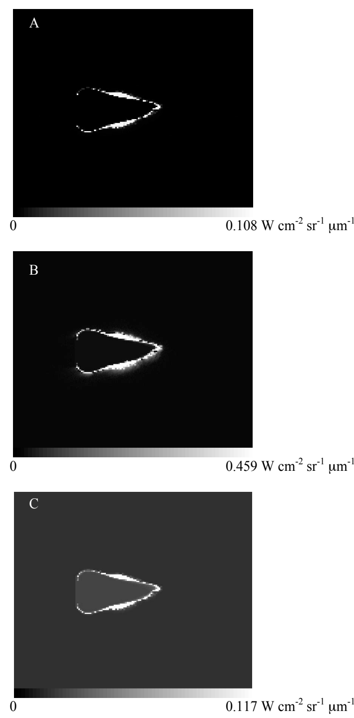


Figure 3.22-28: DIRSIG rendering of the infrared grassfire scene about 1 hour after ignition using the WASP sensor specifications. (a) shortwave infrared channel (0.9-1.7 μm) (b) midwave infrared channel (3-5 μm) (c) longwave infrared channel (8-11 μm).

Project Status:

Ph.D. student Zhen Wang completed her dissertation this year. Her project took the output of the fire propagation model variables and using a knowledge of fire physics and radiometry, derived the necessary inputs for a DIRSIG rendering of a wildland fire as the fire would be observed by the WASP camera system (Figure 3.22-28). The method was validated against published methods of analyzing fire radiance and provides a very high resolution (spatial and spectral) wildland fire scene. This collaborative project has also produced an efficient physics-based model of fire propagation and data assimilation methods. The data assimilation methods use the synthetic scene in the numerical process for incorporating the real images into the propagation model in an adjustment step.

We are building up to a test case for the modeling system based on the Esperanza Fire in Southern California in 2005. We have obtained a QuickBird image of the active fire and are collaborating with Philip Riggan of the US Forest Service who had his FireMapper sensor flown over the fire for the collection of thermal images. We are contributing to the development of the data transfer system in the model by providing the remote sensing data in a consistent and repeatable format using geospatial standards.

3.23 NGA University Research Initiative - Dynamic Analysis of Spectral Imagery

Sponsor: National Geospatial-Intelligence Agency (NGA)

Principal Investigator(s): Dr. David Messinger
Research Team: Dr. David Messinger, Dr. Bill Basener (RIT Mathematics Department), Ariel Schlamm, Tim Doster

Project Description:
This project is a cross departmental collaboration with faculty and students from CIS and the RIT School of Mathematical Sciences. The goal is to develop novel methods for extracting information from complex hyperspectral images using advanced mathematical techniques based in topology and graph theory. The application of interest is detection of man made activity in a large area search operational modality. The hypothesis is that the presence of man made material in a relatively small section of a large image will alter the distribution of the data in the spectral space in a predictable manner. This program seeks to develop methods to quantify this change in the distribution so regions of man made activity in a very large image can be highlighted for further analysis.

Initial activities under this program have focused on three primary applications: improved anomaly detection methods, improved image classification methods, and a fractal-based estimation of the inherent dimensionality of the data. Traditional methods to achieve these goals use the mathematics of simple statistics of linear projective geometry. Our approaches do not leverage such assumptions as multivariate normality and linearity on the data. Instead, our methods are entirely data driven. The classification and anomaly detection algorithms are based on treating the data as a graph, with individual points in the hyperspace treated as vertices, connected by edges if they meet criteria for similarity to other pixels in the scene.

The anomaly detection routine is termed Topological Anomaly Detection (TAD) and has been shown to perform as well or better than traditional statistics-based methods, particularly in cluttered scenes. The classification algorithm it called Gradient Flow and uses an estimation of the density of the points in the hyperspace to identify cluster centers and affiliations. Results from application of this algorithm to a hyperspectral scene are shown in Figure 3.23-29. The inherent dimensionality estimation procedure uses a technique taken from the mathematics of the fractal math community and is based on a point density estimation procedure. Both the TAD and dimensionality estimation procedures have been implemented into the IDL / ENVI software package for ease of use.

Project Status:
This project is in the middle of the first year of two base funding years. The project currently is supporting a MS student in the School of Mathematical Sciences and a Ph.D. student in the Center for Imaging Science. The project has already produced two conference proceedings and a journal paper submission.

3.24 Laboratory for Advanced Spectral Sensing Consortium (LASS)

Principal Investigator(s): Dr. John Schott
Project Description:
The LASS was established to conduct research aimed at improving multidimensional remote sensing. The goal is to study the end-to-end process with an emphasis on looking at fundamental phenomenology and new sensing techniques. Because of the fundamental nature of this work the participants share in the funding and the results are shared with all sponsors.

Project Status:
This year saw the continuation of several multiyear efforts including many which seek to improve the DIRSIG modeling environment as well as areas such as the role of spectral analysis in persistent surveil-

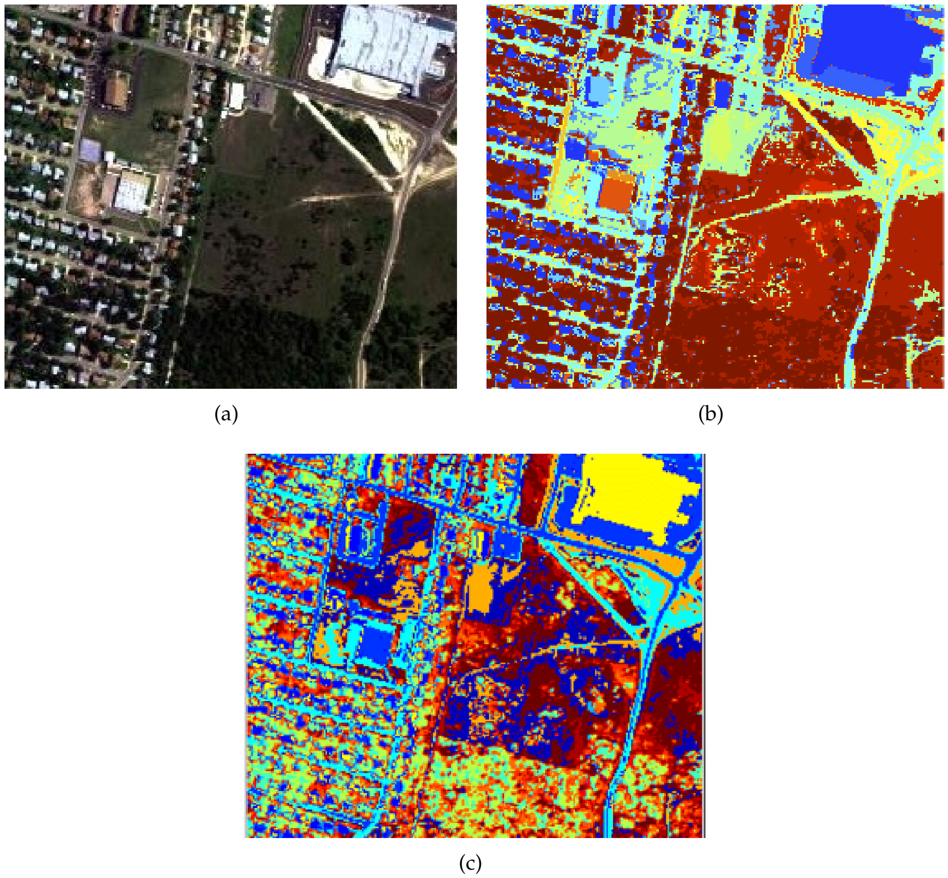


Figure 3.23-29: (a) RGB image taken from the hyperspectral image of an urban scene collected with the HYDICE sensor. (b) Results from classification of the urban scene with the Gradient Flow algorithm. (c) Results from classification using the standard k-means algorithm. The Gradient Flow algorithm produces a more consistent, cleaner classification map than the statistics-based algorithm in this case.

lance, polarimetric remote sensing, 3D laser remote sensing (LIDAR), sparse aperture imaging system analysis, and spectral quality metrics. The extensive range of LASS research tasks are summarized below.

3.24.1 MegaScene 2

Sponsor: LASS Partners

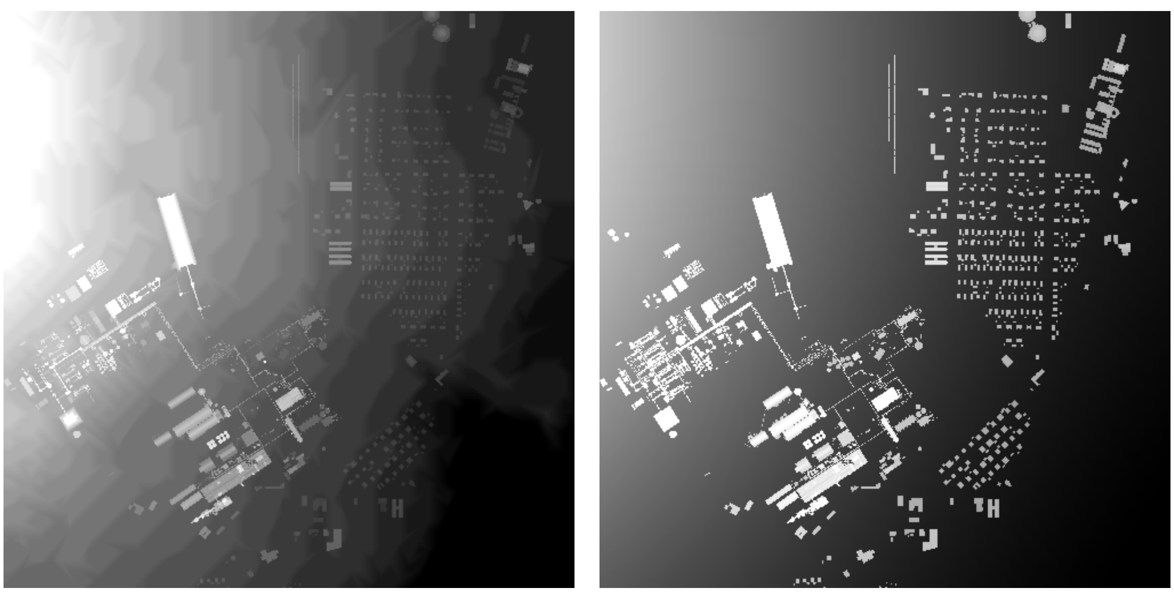
Research Team: David Pogorzala, Eugenie Song, Phillip Salvaggio, Scott Brown, Niek Sanders

Project Description:
Large-scale simulated scenes, dubbed MegaScenes, are highly-useful synthetic models developed for use in the DIRSIG environment. Due to their high degree of spatial and spectral fidelity, as well as a large spatial extent measured in kilometers, these scenes are extensively used by the DIRSIG community for a wide variety of imaging tasks.

MegaScenes are created to be a model of a real-world location. This is to enable the use of real overhead imagery of the site in question to drive the mapping of terrain materials. The location chosen for MegaScene 2 was Trona, CA, a small town situated near Death Valley. This site was chosen because of its arid, mountainous, sparsely-populated environment. These characteristics are a contrast to the flat, heavily vegetated, suburban location of MegaScene 1, a recreation of suburban Rochester, NY. A prominent feature of Trona, CA is a large chemical processing plant. The presence of both the plant and its surrounding land-use areas (evaporating ponds, waste discharge ponds...) provide new challenges both in the creation of, as well as new uses for, the finished scene. Once the first generation of the scene is complete the DIRSIG user community will be able to simulate imagery of an area that is 6km by 8km at a spatial resolution of slightly larger than 0.5m. Subsequent enhancements to the scene will allow for the incorporation of new LWIR texture generation methods.

Project Status:
As of the time of this publication, MegaScene 2 is nearly complete. All objects, both in the chemical plant and in the surrounding residential region, have been modeled in a CAD environment. In addition, during the course of this past year all of these objects have been attributed with their real-world material properties. These properties, predominantly their spectral reflectance properties, have been drawn from first-hand measurements of the corresponding buildings and structures in Trona. In instances where such data was not available, suitable surrogate material measurements were used.

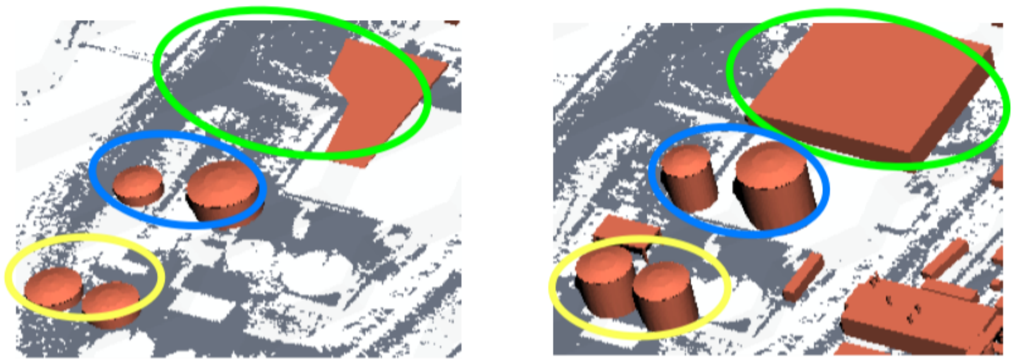
Also accomplished during the past year was the improvement upon the facetized terrain model. The first iteration of the terrain model was too coarse in many areas of the scene. This was because the majority of available facets were being used in the mountainous region in the northwest corner of the scene. This resulted in a chunky appearance to the terrain model in the areas in which the terrain was relatively flat. An example of this is shown in Figure 3.24-30(a), which depicts the z-height of a small area of MegaScene 2 as a function of pixel value, with brighter pixels denoting a higher z-value. To address this, a new terrain model was created by combining three separate models, one for the mountainous northwest corner, one for the flat northeast corner, and a third for the entire southern half of the scene. The improved terrain model is shown in Figure 3.24-30(b).



(a) (b)

Figure 3.24-30: DIRSIG Z-hit map showing (a) the old terrain model and (b) the new terrain model.

The chemical plant was modeled as a single, large, geometric entity. Because of this, the entire plant was created as though every building lay atop a perfectly flat terrain. However once the actual terrain model was introduced, several instances of either floating or buried objects arose within the plant. This led to an extensive readjustment of each element of the chemical plant to ensure that the buildings lay upon the terrain in a realistic fashion. An example of a portion of the plant both before and after its height readjustment is shown in Figure 3.24-31.



(a) (b)

Figure 3.24-31: DIRSIG rendering of a region of the chemical plant (a) before and (b) after the height readjustment.

Another development in MegaScene 2 was the creation of a three-band texture map. A texture map is used by DIRSIG in conjunction with a material map to assign materials and material variability to the terrain. Both maps are typically created from real imagery. For this scene, the real imagery used was a collection of several hundred individual RGB frames taken by RITs WASP sensor. The creation of a well color-balanced mosaic of such a large number of individual shots was considered a significant accomplishment. Once the mosaic was complete the texture maps were created from each of the three color channels.

The final component necessary to complete the initial release of MegaScene 2 remains the material map. This map can be considered a cartoon of the scene in which terrain regions that share the same material attributes share the same pixel value in the map. Typically this map is created by performing a material classification of the texture map and assigning the resulting regions to classes such as grass or asphalt. In the case of MegaScene 2 however, the terrain is not a simple collection of easily discernible classes such as these. Instead the terrain is comprised of material classes such as dried salt beds, borax, coal and sand, as well as regions that are a mixture of two or more of the aforementioned classes. Due to this complexity the creation of the final material map is still underway.

With the new additions of the final terrain model, the attributed geometry, the inclusion of a texture map and the beginnings of a material map, the current status of MegaScene 2 is best shown by the RGB rendering depicted in Figure 3.24-32.

3.24.2 Polarimetric Imaging

Sponsor: LASS Partners

Research Team: Dr. John Schott, David Pogorzala, Scott Brown, Chabitha Devaraj

Figure 3.24-32: RGB rendering of a portion of MegaScene 2. All current inputs and abilities are used in this rendering.

Project Description:
This project is aimed at conducting an end-to-end simulation and evaluation of the utility of polarimetric sensing using DIRSIG. The first years effort (last year) focused on evaluation of the DIRSIG implementation of the polarized version of MODTRAN to ensure that the polarized scene illumination field was properly modeled. Work this year has focused on evaluation and improvement of the polarimetric bidirectional reflectance distribution models used to model energy matter interactions in DIRSIG (see Figure 3.24-33) and design of the experiments that will be used to evaluate the potential for using DIRSIG in an end-to-end analysis. A significant effort has also gone into implementation of a method that will be used to register the raw polarized images to each other at a subpixel level (see Figure 3.24-34).

Project Status:
The next years work will begin to implement the experiment through simulation of polarimetric scenes.

3.24.3 LIDAR / HSI Fusion for Improved Target Detection

Sponsor: LASS Partners

Research Team: Dr. John Schott, Dr. David Messinger, Dr. Michael Foster

Project Description:
Recent work has demonstrated the utility of performing rare point target detection in hyperspectral im-

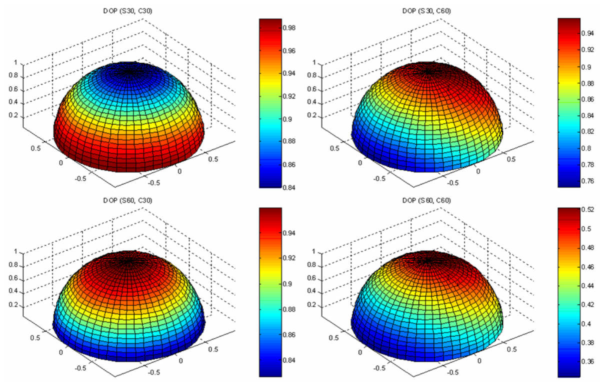


Figure 3.24-33: Color coded version of the Degree of Polarization reflected from locations on a hemispheric surface illuminated and viewed at $S\theta_{in}$ and $C\theta_{out}$ in the principle plane.

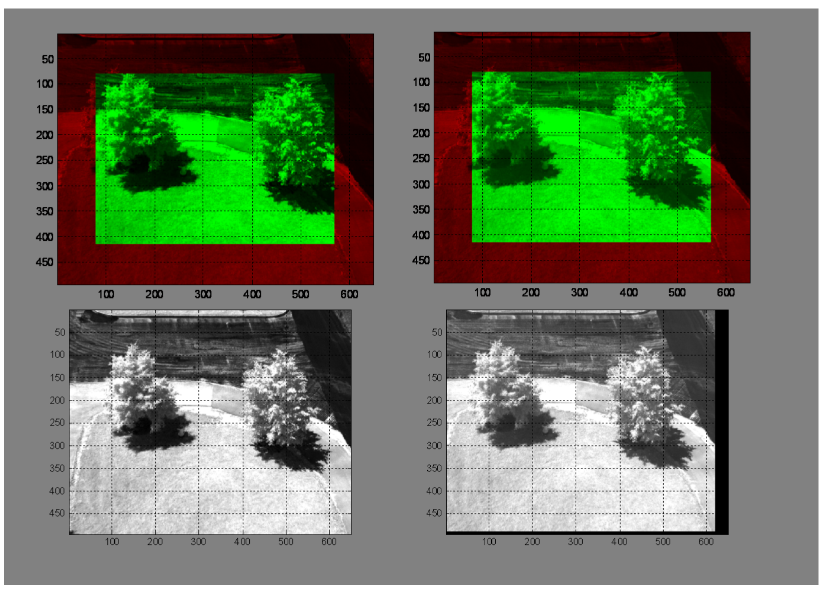
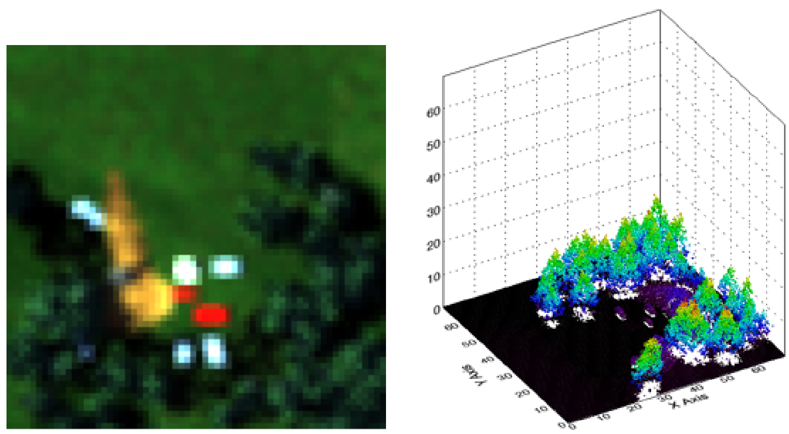


Figure 3.24-34: Illustration of polarimetric image registration. Top left: Image 1 in red misregistered and Image 2 in green; top right: registered images; bottom left: Image 1 and bottom right Image 2 after registration.

agery in the calibrated radiance domain, instead of the (atmospherically compensated) estimated surface reflectance domain. This is achieved by using a physics-based forward model to predict how the target signature (reflectance) will be manifested in the radiance image under a variety of partially known atmospheric conditions. Typical methods use MODTRAN to model the atmospheric contributions to the measured signal, but ignore or over simplify any local geometric impacts on the signal. In this work, we developed a methodology that utilizes a co-temporal, but low resolution LIDAR point cloud to improve target detection by constraining the geometric terms in the forward model. The three dimensional LIDAR point cloud is used to estimate, on a per-pixel basis in the hyperspectral image, fractional solar illumination, exposure to the full sky, surface normal, and subpixel presence of a target based on three dimensional target detection of a geometric target model. The method employed for the spatial target detection is subject to high false alarm rates, but when combined with the spectral information can be used to mitigate against challenging scenarios such as targets in hard canopy shadows. The method has been demonstrated on both real and synthetic data.

The synthetic data used in the study was generate using the DIRSIG scene simulation tool for both the hyperspectral image and the LIDAR point cloud. The input data sets are shown in Figure 3.24-35. Results from processing both modalities and fusing the information together, as well as a comparison to results from processing the hyperspectral image alone are shown in Figure 3.24-36.



(a) (b)

Figure 3.24-35: (a) Synthetic RGB image of hyperspectral image used in the HSI-LIDAR fusion study containing vehicle targets of interest. (b) Synthetic LIDAR image of same scene. Both data sets were simulated using DIRSIG.

Project Status:
This project was completed in the summer of 2007 and has resulted in several conference proceedings and one journal paper.

3.24.4 Persistent Surveillance Spectral / Temporal Trade Study

Sponsor: LASS Partners

Research Team: Dr. John Schott, Dr. David Messinger, Dr. Andrew Adams

Project Description:
The goal of a successful surveillance system to achieve persistence is to track everything that moves, all of the time, over the entire area of interest. The thrust of this work was to identify and improve upon the motion detection and object association aspect of this challenge by adding spectral information to the equation. Traditional motion detection and tracking systems rely primarily on single-band grayscale video, while more current research has focused on sensor fusion, specifically combining visible and IR data sources. A further challenge in covering an entire area of responsibility (AOR) is a limited sensor field of view, which can be overcome by either adding more sensors or multi-tasking a single sensor over multiple areas at a reduced frame rate. As an essential tool for sensor design and mission development, a trade study was conducted to measure the potential advantages of adding spectral bands of information in a single sensor

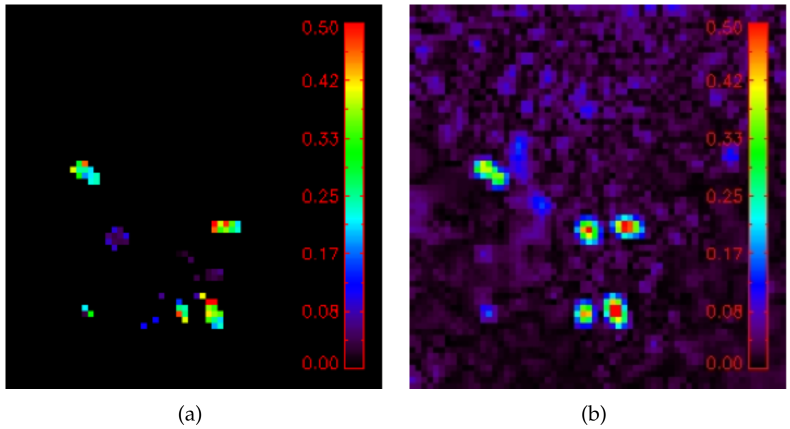


Figure 3.24-36: (a) Results from target detection using the fused information from both imaging modalilties. Red pixels indicated the presence of a target is more likely. (b) Target detection results using only the hyperspectral image. Note that in (a) the black pixels were never tested for the presence of target in the hyperspectral image because they lack the correct geometric signature in the LIDAR data, thus potentially decreasing the False Alarm Rate.

with the intention of reducing sensor frame rates. Thus, traditional motion detection and object association algorithms were modified to evaluate system performance using five spectral bands (visible through thermal IR), while adjusting frame rate as a second variable. The goal of this research was to produce an evaluation of system performance as a function of the number of bands and frame rate. As such, performance surfaces were generated to assess relative performance as a function of the number of bands and frame rate. Results show how the addition of spectral channels to a system provides similar detection and association performance at significantly reduced frame rates.

Figure 3.24-37 shows the result of pixel level motion detection in a 5 band multispectal set of temporal images collected off the roof of the CIS building on the RIT campus. Pixels colored in red have been detected as moving over a 7 frame temporal window. Morphological processing was then used to collect the individual pixels in object level detections for comparison against a ground truth map. Figure 3.24-38 shows the performance of the object detection algorithm, measured as number of objects missed (thus, decreased numbers are improved performance), as a function of spectral channels considered and frame rate of the sensor. Performance is worst for the case of a single band sensor. However, the addition of only two or three spectral channels shows improved performance. The number of missed objects in this case shows improvement down to frame rates as low as 2 frames per second. Not shown here are results indicating improvements in object to object association over multiple frames using spectral information as well. In this case, it is assumed that the overall tracking performance will improve with improvements in object motion detection and frame to frame association performance.

Project Status:
This project was completed in the spring of 2008. Ongoing work will use this methodology to extend the study to night imaging using both infrared sensors and intensified CCD detectors.

3.24.5 Use of Multiple Spectral Bands to Improve Night-time Persistent Surveillance

Sponsor: LASS Partners

Figure 3.24-37: Motion detection at the pixel level for multispectral images collected from the roof of the CIS building. Red pixels in the right hand image are detected as moving in the time window considered (7 frames).

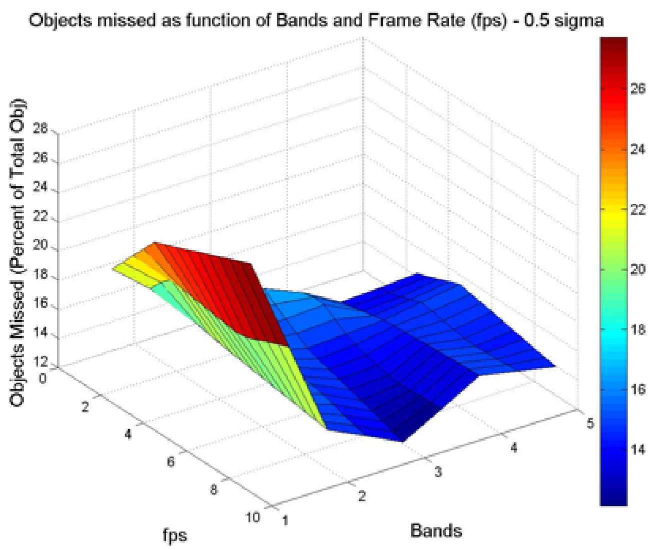


Figure 3.24-38: Missed objects as a function of frame rate and number of spectral bands used. Note that performance improves (decrease in missed objects) as you increase the number of spectral bands in the sensor, even for low frame rates down to about 2 frames per second.

Research Team: Dr. John Schott, Matt Heimbueger

Project Description:
As part of a recently completed effort (see Section 3.24.4) we showed that multispectral data could significantly improve the potential utility of persistent surveillance systems. The value demonstrated was two fold. First, there was an overall improvement in performance. Second, it was shown that comparable per-

formance could be achieved between a multispectral system at a significantly reduced frame rate compared to a single band system. That study only considered day time reflective imaging conditions. The current study is aimed at repeating the earlier study using imaging systems that can operate at night.

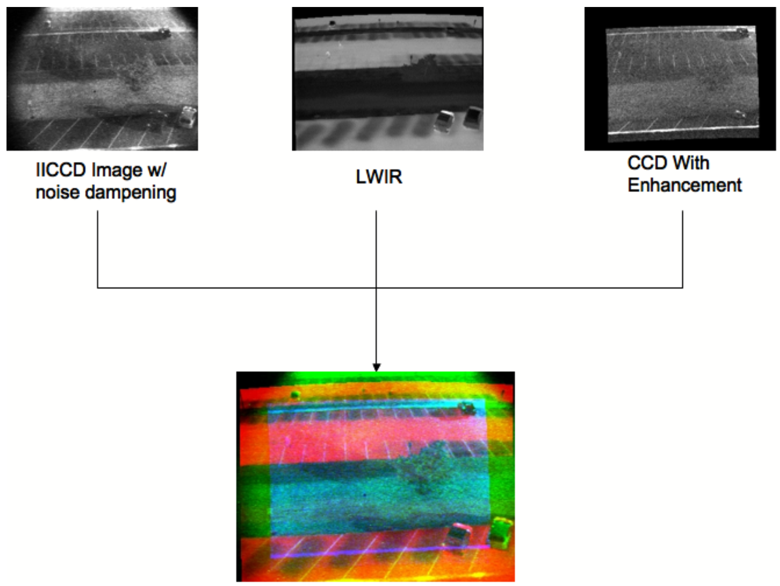


Figure 3.24-39: Example images acquired for night time persistent study. Left: image intensified CCD image, Center: long wave infrared image, Right: high gain CCD and Bottom: registered image.

The initial effort has focused on acquiring an appropriate data set to use as the basis for the study. This was accomplished with a collection that included a conventional CCD camera operated at high gain to capture artificial (*i.e.*, man made) illumination, an image intensified camera (IICCD) to capture reflected low light signals and a longwave infrared (LWIR) camera to capture emitted energy (see Figure 3.24-39). The data from this collection are being registered to form the input data for the motion detection trade study which will form the core of this study.

Project Status:
The baseline data set has been acquired and is in preprocessing. The results from this initial study should be available next year and take on the form similar to those of the previous day time study.

3.24.6 Simulated Thermal Texture Improvements

Sponsor: LASS Partners

Research Team: Scott Brown, Dr. Jason Ward, Niek Sanders, Dr. John Schott, Dr. David Messinger

Project Description:
The focus of this project was to explore methods to increase the accuracy of the DIRSIG model to predict temperature variations within a material class. The existing "texture" algorithm utilizes a large database of spectral emissivity curves to introduce spatial changes in that optical property. Although this approach can recreate most of the variability in the reflective region, the natural variability of emissivities in the thermal infrared is dramatically less. Instead, most of the observed variability within a material class in the thermal regions is due to temperature variations resulting from variations in the thermodynamic properties.

Under this effort, a mechanism to derive spatially varying thermodynamic properties was created and the interfaces to supply them to the DIRSIG model were introduced.

Project Status:
The methodology to create spatially varying thermodynamic properties utilizes a sequence of thermal infrared images acquired throughout the diurnal cycle. These images are then used to optimize a set of thermodynamic properties using a stand-alone version of the THERM temperature prediction model embeded within the DIRSIG model (see Figure 3.24-40). The specific properties optimized by the method included the surface orientation (zenith and azimuth angle), thermal conductivity, heat capacity, broad-band thermal emissivity, broad-band solar absorption and the exposed area.

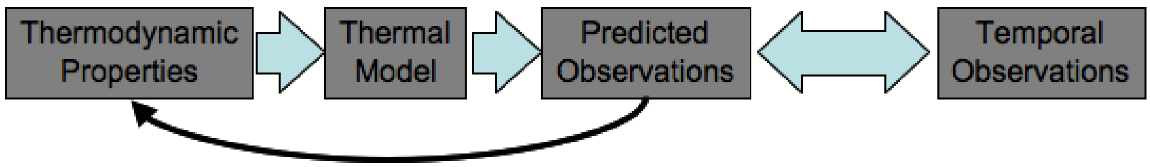


Figure 3.24-40: The per-pixel optimization performed to create per-pixel thermodynamic property maps for use with the updated interface to THERM in DIRSIG.

A temporal sequence of Long-Wave Thermal Infrared (LWIR) images of a patch of dessert at the MegaScene #2 site in Trona, CA are shown in Figure 3.24-41. The top row of images were acquired by the RIT WASP sensor. The first three images (times) were then used to optimize a set of thermodynamic property maps to drive the THERM temperature prediction model in DIRSIG. The bottom row of images are simulations by the DIRSIG model of the same three times used for training and the prediction of a fourth time not used in the training process. Although further improvements are planned, this new approach dramatically improves not only the spatial fidelity but also the temporal fidelity of a DIRSIG thermal simulation of natural backgrounds.

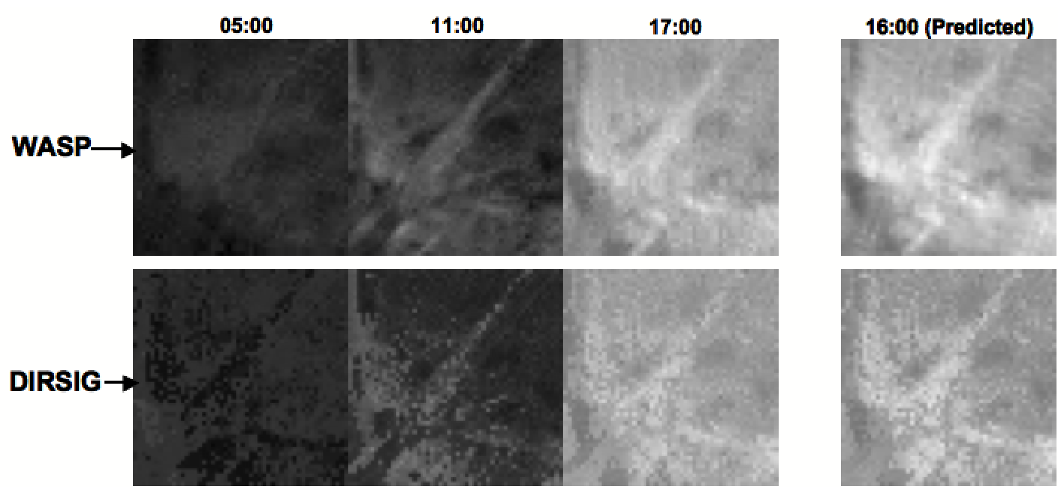


Figure 3.24-41: Thermal infrared images of a patch of dessert sand acquired by the RIT WASP sensor and simulated by the DIRSIG modeling using the new thermodynamic property maps.

3.24.7 Enhanced DIRSIG User Interface

Sponsor: LASS Partners

Research Team: Scott Brown, Niek Sanders

Project Description:
During the past year, the modeling team wrapped up a project to expand the file based interface and graphical user interface (GUI) to the DIRSIG model. The focus of this project was to provide the user with a modern GUI that worked in conjunction with a dramatically overhauled set of input files to describe a simulation.

Project Status:
The most important aspect of the new user interface is that it starts to unlock a lot of the power that has been hidden inside the new DIRSIG4 code base. The new user interface is the result of a dedicated effort by the development team to focus on creating, intuitive and well organized interfaces. A screen capture of the main window in the new user interface is shown in Figure 3.24-42. At this top level the user has access to the top-level components of a simulation including the scene, the atmosphere conditions, the imaging platform, the platform motion and the data collection parameters.

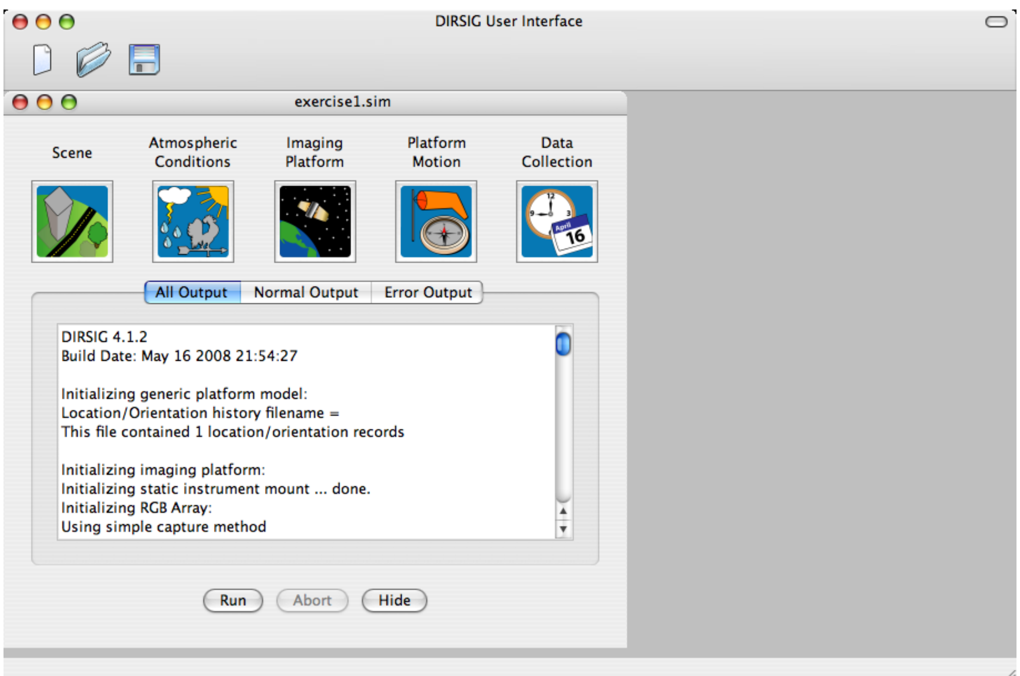


Figure 3.24-42: The main window of the new Graphical User Interface (GUI).

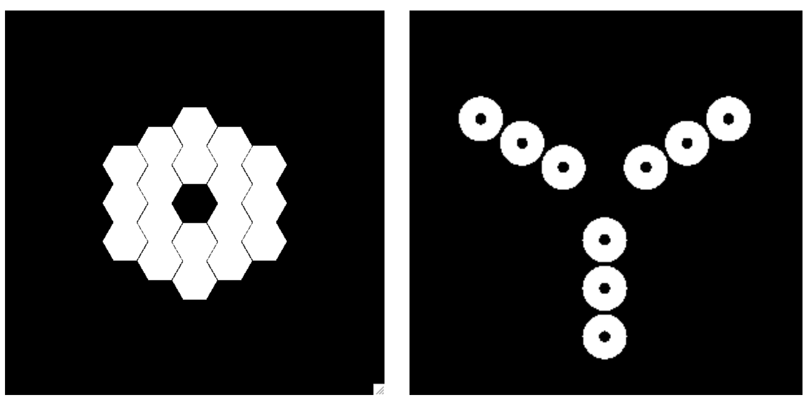
These top-level components of a simulation are conveniently captured in a set of new XML descriptions. The new XML input files were designed to make the major simulation components more self-contained and portable by eliminating external data references. As a result, the DIRSIG 4.2 release also introduced the new "component mode" command line interface which we hope will help users streamline trade studies by adding an easy way create combinations of scenes, sensors, taskings, etc. via the command line.

3.24.8 Sparse / Segmented Aperture Image Quality Modeling

Sponsor: LASS Partners

Research Team: Dr. John Schott, Brian Daniel, Michael Zelinski, Jason Smith

Project Description:
In order to place large aperture (high resolution) telescopes in space, the remote sensing and astronomy communities have begun to explore the potential value of sparse and segmented aperture telescopes. These systems can potentially be folded for launch and deployed in space to provide large effective apertures with corresponding high resolution in the reconstructed images. A major limitation to this approach is that the deployed sparse or segmented aperture (see Figure 3.24-43) components are not rigidly mounted relative to each other. This results in aberrations due to the fact that the optical path differs from the ideal across the telescopes pupil function. This optical path difference (OPD) from the ideal causes phase errors that degrade the recorded image. If these phase errors are small enough the degraded images can largely be restored. However, the restoration process requires a good estimate of the phase error that caused the aberrations. One method to estimate the phase error is to analyze in focus and defocused images of a scene. These images have different OPDs and a phase diversity algorithm can be used to estimate the phase error.



(a) (b)

Figure 3.24-43: (a) Segmented and (b) sparse (TRI-ARM 9) aperture pupil functions.

One focus of the years work at RIT was to model the effect of scene content, particularly spectral scene content, on the image quality of fully restored images from sparse aperture systems. To accomplish this, an image chain model (see Figure 3.24-44) was implemented that fully models the spectral, spatial and noise, character of the image formation, implements a phase retrieval algorithm and performs image restoration on the aberrated images (see Figure 3.24-45). Ongoing work is focused on evaluating the impact of various image characteristics on image quality. This includes development of algorithms and metrics designed to characterize image artifacts introduced by the sparse aperture image formation process.

A second task initiated this year is aimed at modeling image quality/utility for segmented optical systems where the individual segments may be made up of extremely light weight mirrors that result in significant OPD within an optical element. Figure 3.24-46 shows an interferogram of the OPD for a segment of such a telescope. Ongoing work is aimed at modeling and evaluating the utility of imaging the earth from geostationary obits using very large segmented aperture telescopes.

Project Status:

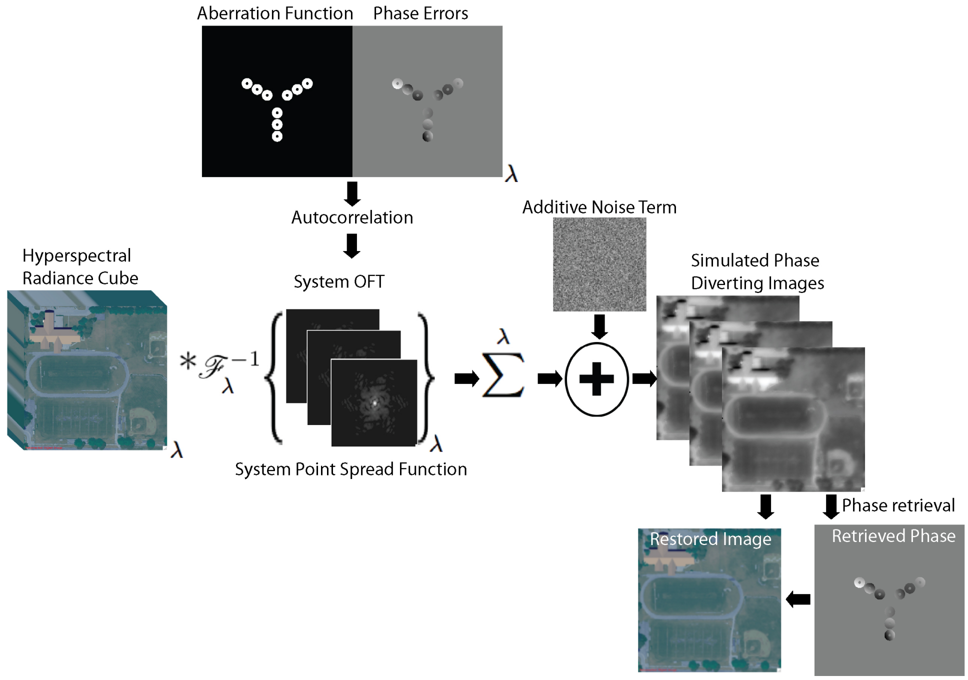


Figure 3.24-44: Image chain model of the image formation and reconstruction process.

The sparse aperture/phase diversity component of this study is moving to the image quality evaluation stage and should be completed next year. The very large segmented mirror portion of the study will focus next year on the utility of such a design to study moving objects. This task is also planned for completion next year.

3.24.9 Spectral Image Utility Metric

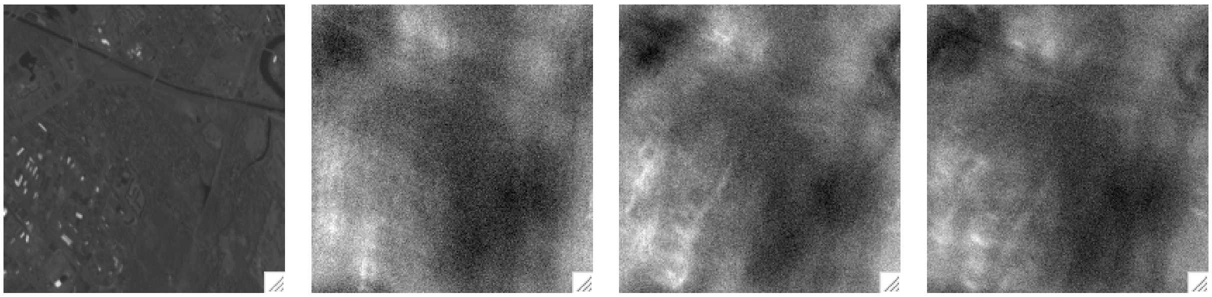
Sponsor: LASS Partners

Research Team: Dr. John Kerekes, Dr. Marcus Stefanou

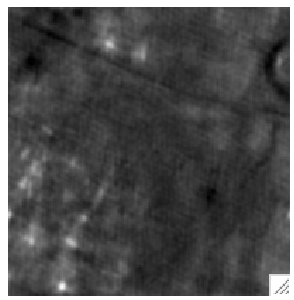
Project Description:
This research explored the assessment, prediction and sensitivity of a quantitative metric for spectral image utility in the context of sub-pixel target detection. Spectral image utility in this application was defined as the area under the receiver operating curve summarized across a range of target detection scenario parameters.

The utility of a given spectral image was assessed through the detection analysis of a sub-pixel target synthetically planted in every pixel of the image. The target signature was taken from a reference library and included variability as observed in real data collections. The resulting metric was then a quantitative representation of the ability to find a similar target in the image.

The prediction of spectral image utility was performed by computing statistics from an image and then using a linear forward propagation model to predict the ability of finding a target in the image without having to actually apply the assessment approach described above. This method offered up to two orders of magnitude speed-up in the utility estimation of images.



(a) (b) (c) (d)



(e)

Figure 3.24-45: (a) Input image to the phase diversity processing and reconstruction process (b) First defocus image is negative two waves (c) The in-focus image (d) The second defocus image is positive two waves (e) The reconstructed image.

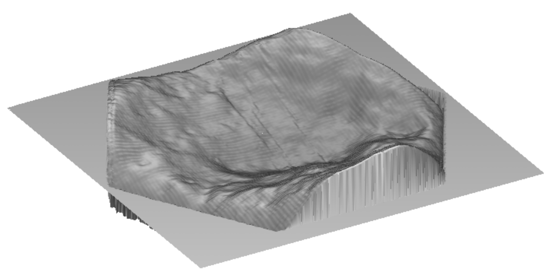


Figure 3.24-46: Illustration of the OPD in a very light weight (flimsy) segment of a segmented aperture telescope.

The sensitivity of spectral utility to a variety of scenario parameters was studied through a simulation approach. The quantitative sensitivity of various parameters was found to be very dependent upon the scenario and the selection of the range of parameters studied.

Project Status:

This project ended with the successful Ph.D. defense of Marcus Stefanou in July 2008. Further research in this topic is anticipated.

4 RIT Funded Core Research

4.1 DIRSIG Infrastructure

Principal Investigator(s): Mr. Scott Brown
Research Team: Scott Brown, Niek Sanders, Dr. Michael Gartley, and Dr. Adam Goodenough

Project Description:
In addition to the sponsored research projects that address the enhancement of the DIRSIG model, RIT has been slowly increasing the amount of internally funded staff time that is spent working on infra structural DIRSIG development. This ranges from the purchasing and maintenance of the server used to distribute the model to the general maintenance of the software and supporting software development systems. We also internally fund a great deal of the strategic software development that allows us to accomplish research already in-house and compete for new research opportunities. One of the fundamental funding streams for DIRSIG core development has been the DIRSIG Training Courses, which was offered on three (3) different occasions during the last calendar year.

Project Status:
During most of the past year, the development team focused on Release 4.2. The important milestone of this effort cycle were the release of the new graphical user interface (GUI). A screen capture of one window in the new user interface is shown in Figure 4.1-47.

Another important new feature was the beta release of the new run-time MODTRAN atmosphere that migrates the MODTRAN interactions to "just in time" operations during the rendering of a DIRSIG scene. This new run-time atmosphere also provides the user with a lot more control over the extents and resolution of the internal MODTRAN look-up tables. The sequence of images in Figure 4.1-48 illustrate how this new approach includes a temporal dimension that could not be modeled with the previous atmospheric database approach. In this image sequence created from a single simulation, a stationary camera is simulated with a scan period of many hours. The new atmospheric model populates the temporal dimension of the internal look-up tables on-the-fly to reproduce the angular dependence in upwelled (path) radiance observed at various times of the day due to changes in the sensor to Sun geometry.

We also demonstrated the ability of DIRSIG 4.2 to model clouds. This exploration grew out of multiple inquiries over the years about how to incorporate clouds into DIRSIG simulations. The low-level radiometry tools required to model a cloud were introduced last year by Adam Goodenough to support of in-water radiation transfer using photon mapping. To simulate a cloud, these same tools were simply reused by creating cloud geometry and assigning the associated bulk (or medium) material the absorption and scattering properties of a cloud. The first cloud simulation is shown in Figure 4.1-49.

During the next year, the development team will continue to provide the user community with improved versions of the DIRSIG model with an increased focus on integration into the modeling workflows used by the user community. This upcoming year will also see more additions to the new user interface and expanded documentation and training to educate the user community.

4.2 Advanced ANalyst Exploitation Environment (AANEE)

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Dr. David Messinger, Michael Richardson, Scott Brown, Jacob Clement,

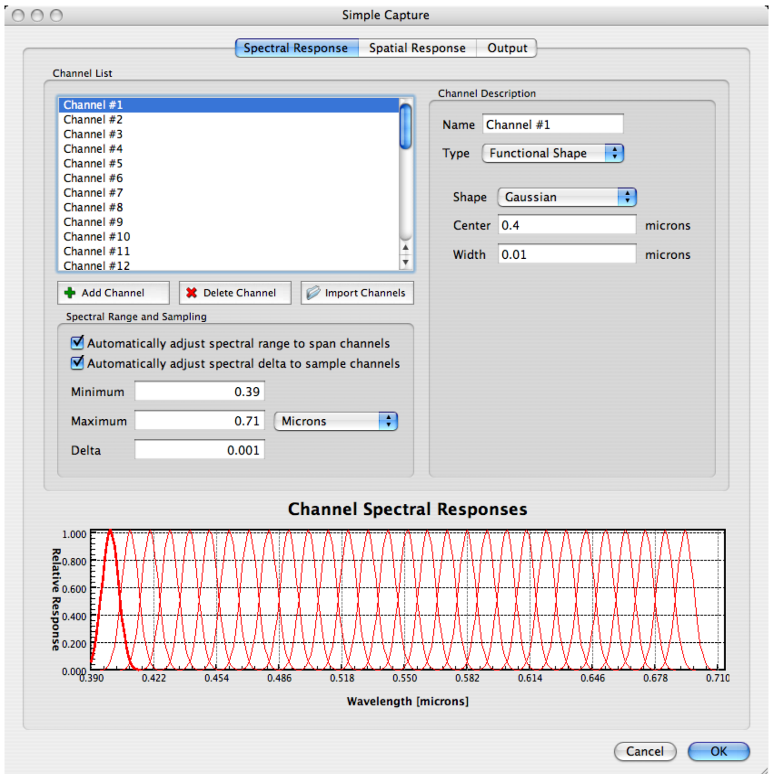


Figure 4.1-47: The spectral response window in the focal plane configuration window of the new Graphical User Interface (GUI).

(a) (b) (c)

Figure 4.1-48: An image sequence of MegaScene #1 from a stationary camera acquired at (a) dawn, (b) midday and (c) dusk demonstrates the temporal aspects of the new run-time MODTRAN linkage with DIRSIG.

Karl Walli, Colin Doody (RIT Computer Gaming Department)

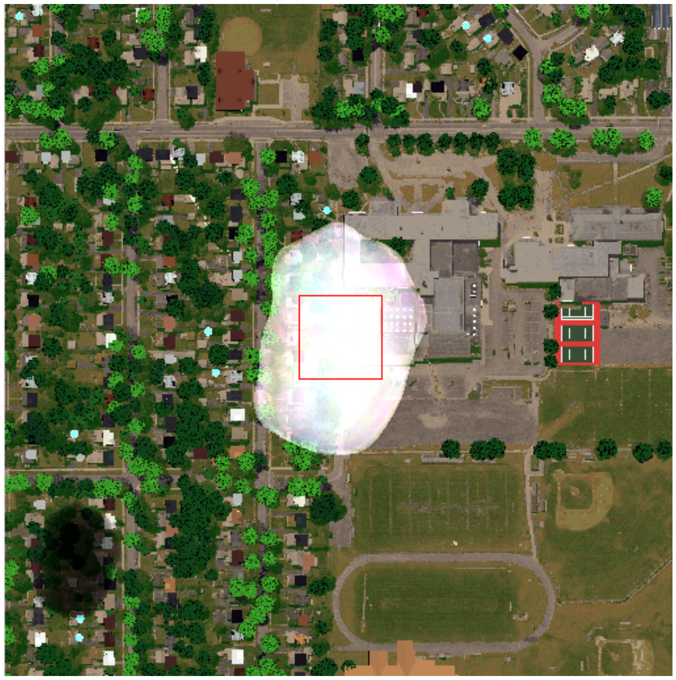


Figure 4.1-49: A color image of the first cloud simulated in MegaScene #1. The scene location was modified to simulate a high sun angle so the cloud shadow falls within the image.

Project Description:

This is a long term study aimed at developing new approaches for analysts to interact with and analyze multisensor data. It is based on the premise that advanced analysis will require an analyst to extract a range of information from a wide variety of sources. Because of the wide range of sensors and databases potentially available, the analyst can easily be overwhelmed with the volume of data and the lack of a coherent organization to the data. RIT has committed to explore a number of aspects of the enormous challenge posed by this problem. We have begun to describe and assemble an exploitation environment where an analyst can interact with data in new ways using techniques adapted from the computer gaming community (drawing on RITs expertise and degree programs in this area). Because of our expertise in imaging we have begun with the interaction with image data (see Figure 4.2-50) but intend to explore a wide range of image and non-image data.

In order to fuse disparate types of data we have begun to build databases with appropriate metadata to allow search but also with appropriate geospatial integrity to allow visual and/or quantitative analysis. Therefore an aspect of the AANEE research is to explore ways to provide high levels of data registration when required and to understand what level of registration is required to support various analyst requirements. To support the high end of this task we have identified the need to register image data with very diverse geometries (*e.g.*, vertical, oblique and ground based electro-optical data with night time thermal, radar and LIDAR data). Because of the various projection geometries (see Figure 4.2-51) this drives us to develop three dimensional image registration tools. The 3D image registration task on this effort was initiated this summer with a doctoral student focused on evaluating existing tools and developing a tool(s) for use in AANEE. The output from such a registration process is image data registered to a 3D representation of the world. This means that we will have a 3D model of the scene derived from multisensor/mutlimodel data. These data will be fed as needed to the new gaming based interaction tools described above (see Figure 4.2-52).

Figure 4.2-50: The AANEE visualization software can be used to explore and interact with large scenes in a three dimensional space. Shown is the Van Lare Water Treatment Facility in Rochester, NY.

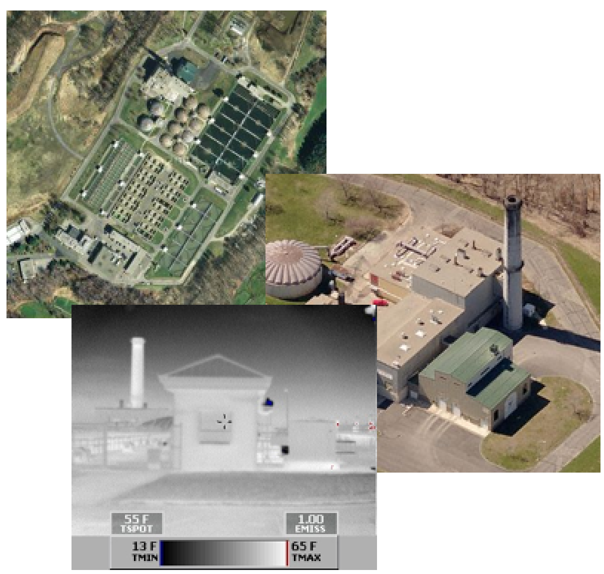


Figure 4.2-51: View of site from vertical multispectral sensor, oblique sensor and ground based long wave infrared sensor.

With tools evolving to organize and interact with the data we also want to explore ways to analyze data that might exist in this new environment. To this end, we are exploring model based exploitation tools. Model here takes on multiple meanings. From the 3D registration work described above, we will have 3D wire frame models of a site of interest and in many cases, 4D models (3D spatial plus time) of sites observed over time. With RITs DIRSIG tools, we can take advantage of these 3D models to perform a number of synthetic scene simulations to show an analyst what a site might look like to different sensors (see Figure 4.2-53) or with different hypotheses about the structure or makeup of some aspect of a site (*e.g.*,

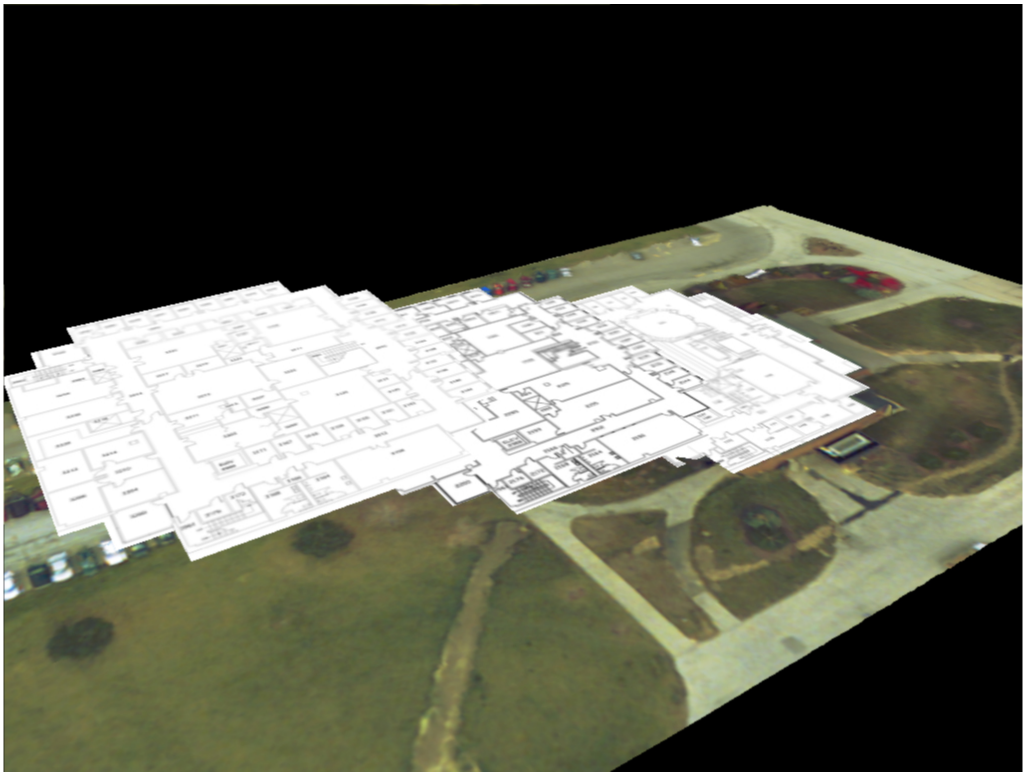


Figure 4.2-52: Interaction with a site is critical for the AANEE visualization software. Here, a user explores the floor plans of a building seamlessly integrated into the three dimensional environment.

cooling tower running or not or stack emitting chemical X at concentration Y). However, the new modeling thrust, that we are interested in exploring as part of the AANEE effort, incorporates all of these concepts into consideration of process models of what is going on at a site. The hard problems facing analyst often require them to assess what is going on at a site or within a region (*e.g.*, is the site enriching uranium or producing chemical weapons?). To help with this effort, we will be exploring ways to convert hypotheses about a site into predicted observables and then ways to link a less than perfect set of observables to the model based predictions to assess the likelihood of the hypothesis (see Figure 4.2-54).

Project Status:

This is a long term internally funded (i.e. shoe string budget) effort. The three aspects described above have been initiated. An initial site has been selected to serve as a test bed for the various tools. A number of visualization tools which have been developed and applied to other data sets are ready to be applied to the target site as the databases are assembled.

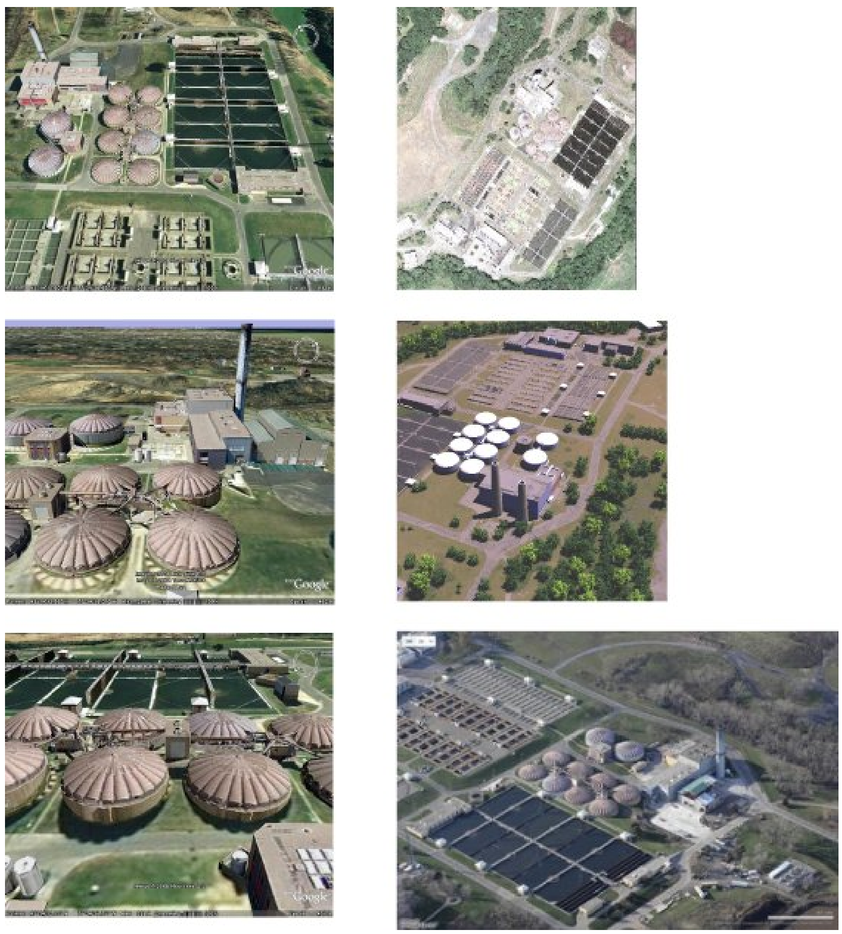


Figure 4.2-53: (left) Examples of actual imagery projected onto 3D wire frames of a site. (right) Two DIRSIG images of the site and a real oblique airborne image.

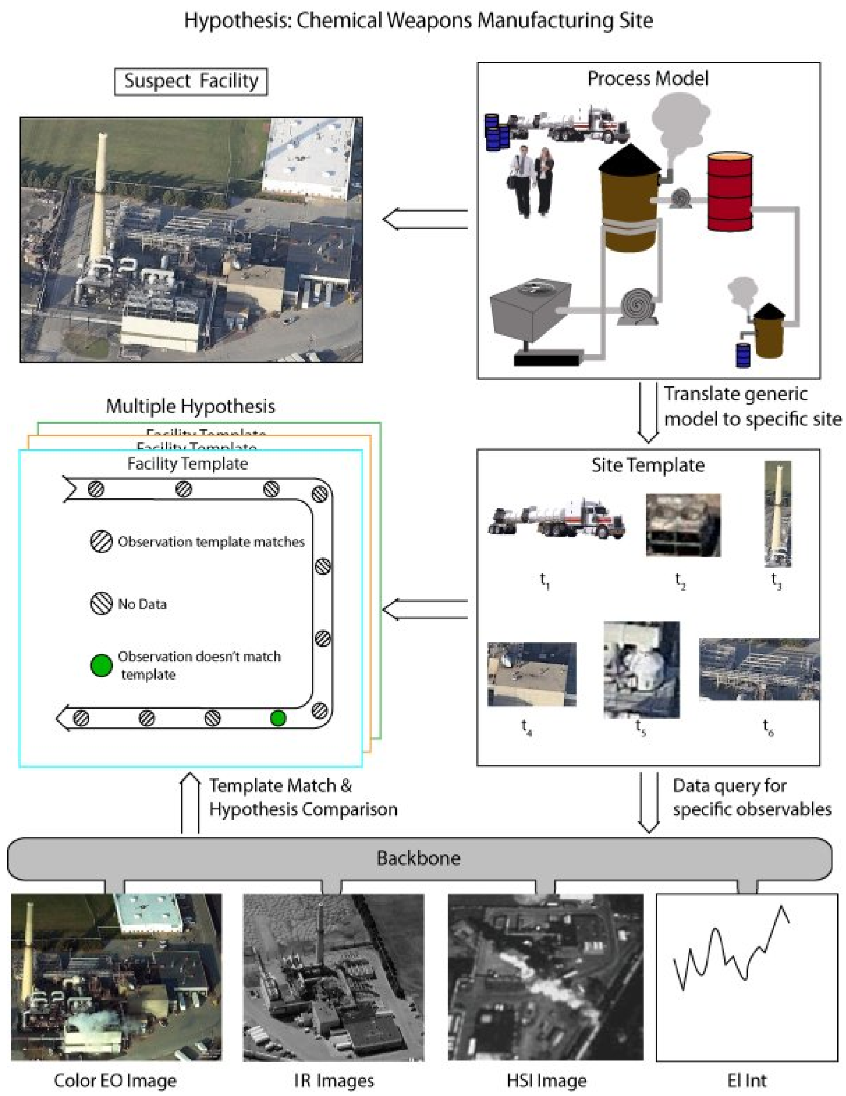


Figure 4.2-54: Illustration of how process models can be merged with site specific data and models to generate observables that can be compared to acquired data to build up ways to match hypothesis templates and real data.

4.3 Photon Mapping Validation and Verification in DIRSIG

Principal Investigator(s): Dr. John Schott
Research Team: Dr. John Schott, Scott Brown, Jacqueline Speir, Dr. Adam Goodenough

Project Description:
In the fall of 2007, Adam Goodenough successfully defended his Ph.D. dissertation titled "In-water Spectral Radiative Transfer Modeling using Photon Mapping" which introduced a new set of tools within the DIRSIG model for computing the contributions of multiply scattered photons. This follow-on effort is intended to rigorously validate these radiative transfer approaches via a comparison to analytical computations, other numerical models and experimental results.

Project Status:
The verification and validation of the DIRSIG model at the top-level is best performed by sequentially evaluating the radiometry components that combine to produce the total solution. In this case, the total radiance from a water body is composed of the return from the water surface (the air-water interface), the water medium and the bottom. Within the DIRSIG model, these different contributions are separately computed by "radiometry solvers" associated with the surface, medium and bottom (see Figure 4.3-55). A Fresnel equation based radiometry solver is associated with the surface and studies to verify and validate the refraction, reflection and transmission computed by this solver have been completed. Within the medium, the photon-mapping (PM) mechanism is used to compute various scattering terms including the backscattered radiance that is captured above the water surface. At the bottom, the impact on reflected radiance as a function of background and sky fraction contributions has been evaluated.

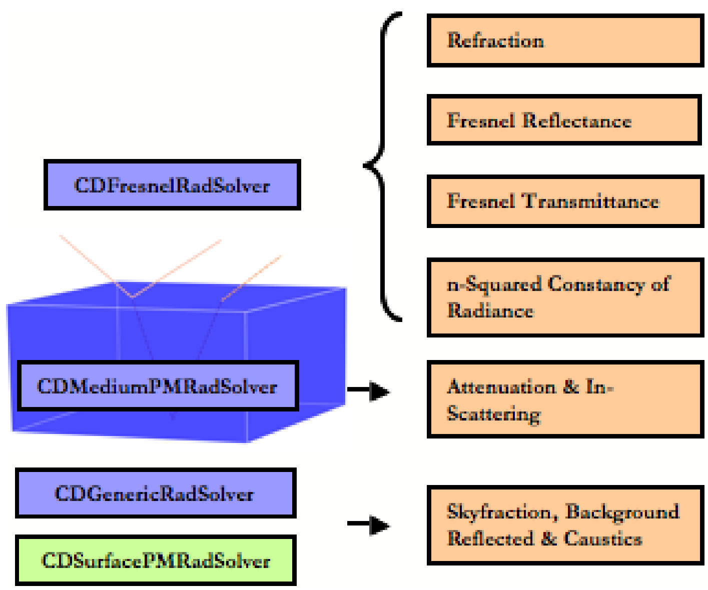


Figure 4.3-55: A diagram of the various radiometry components being verified and validated under this effort.

Future tasks include developing analytical expressions for the radiative transfer equation (RTE) using small angle approximations, creating experimental scenarios that illustrate beam-spread, caustics and ship-shadowing and evaluating the scattering induced point spread function.

4.4 CHARM Data Web Site Development

Principal Investigator(s): Dr. John Kerekes
Research Team: David Snyder

Project Description:
The purpose of this project is to provide for the research community an independent means for development, test, and verification of hyperspectral target detection algorithms. HyMap data collected as part of the Cooke City Hyperspectral Airborne Repeat Measurement (CHARM) experiment under the RASER project (section 3.10) was further processed and packaged for distribution as a web site.

The web site contains two images (a self-test and a blind-test), target spectra and locations (for the self-test) and other documentation. The user is encouraged to download the self-test data and truth maps for preliminary investigations, and then to apply their target detection algorithm to the blind test image. The user then uploads their detection results to the web site and a score is automatically reported. The score represents the number of false alarm pixel resulting for perfect detection of the pixel containing the target of interest. Several targets are included in the images (see Figure 4.4-56).

Project Status:
This project has completed the implementation of the web site (http://dirsapps.cis.rit.edu/blindtest). Further test and verification is currently underway.

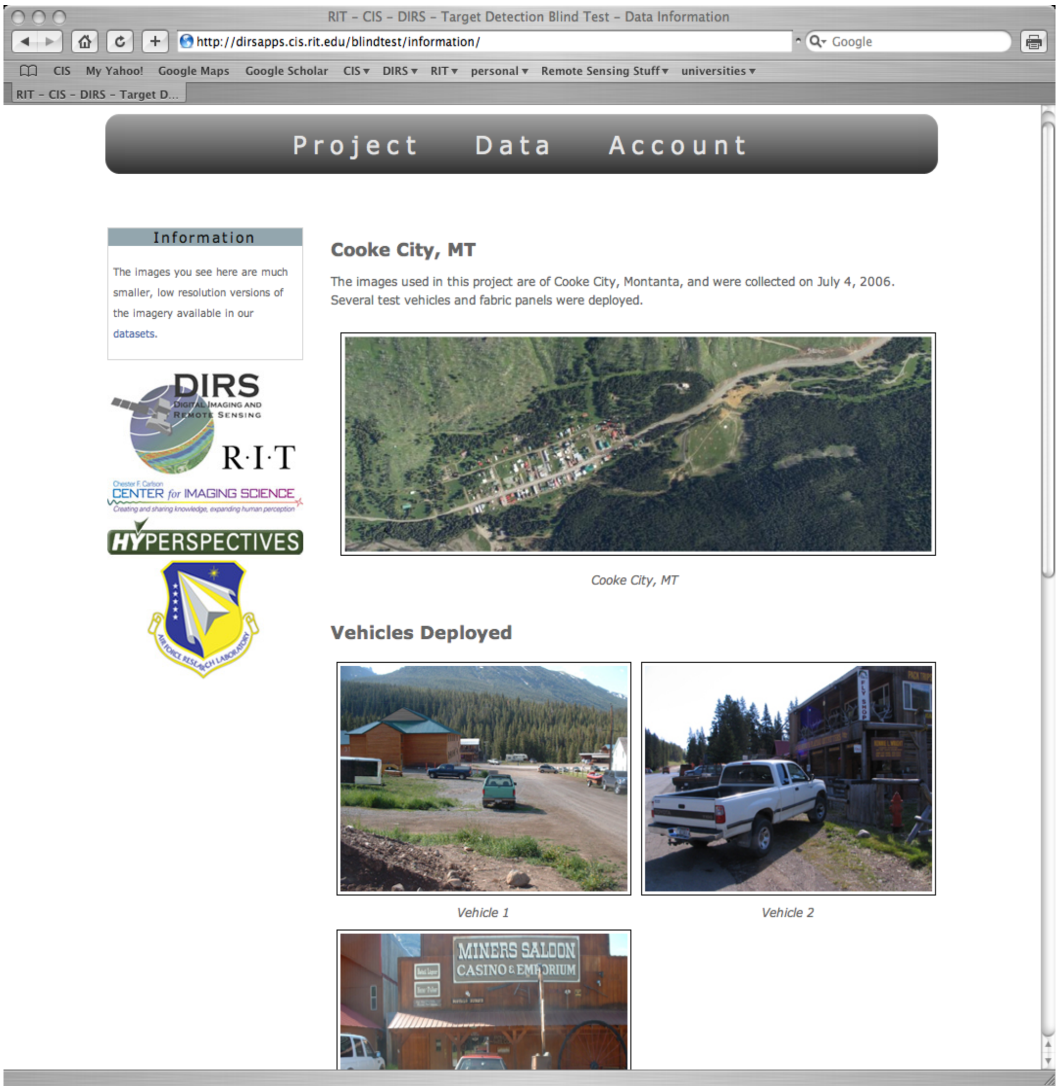


Figure 4.4-56: Blind test website for target detection using the CHARM hyperspectral data.

5 Publications

This section lists the publications of the DIRS team over the last year.

5.1 Books and Journal Articles

J. E. West, D.W. Messinger, J. R. Schott, "Comparative evaluation of background characterization techniques for hyperspectral unstructured matched filter target detection", Journal of Applied Remote Sensing, Vol. 1, 013520, July 2007.

J. A. Barsi, S. J. Hook, J. R. Schott, N. G. Raqueño, B. L. Markham, "Landsat 5 Thematic Mapper Thermal Band Calibration Update", IEEE Geoscience and Remote Sensing Letters, Vol. 4, Number 4, pp. 552-555, October 2007.

D.W. Messinger, C. Salvaggio, N.M. Sinisgalli, "Detection of Gaseous Effluents from Airborne LWIR Hyperspectral Imagery Using Physics-Based Signature Predictions", Int. Journal of High Speed Electronics and Systems, Vol. 17 (4) December 2007.

J. Mandel, L.S. Bennethum, J.D. Beezley, J.L. Coen, C.C. Douglas, M. Kim, A. Vodacek, "A wildland fire model with data assimilation", Mathematics and Computers in Simulation, doi:10.1016/j.matcom.2008.03.015, In press, available online April 2008.

J.P. Kerekes, "Receiver Operating Characteristic Curve Confidence Intervals and Regions", IEEE Geoscience and Remote Sensing Letters, vol. 5, no. 2, pp. 251-255, April 2008.

Y. Li, A. Vodacek, N. Raqueno, R. Kremens, A.J. Garrett, I. Bosch, J.D. Makarewicz, T.W. Lewis, "Circulation and stream plume modeling in Conesus Lake", Environmental Modeling and Assessment, Vol. 13, pp. 275-289, May 2008.

M. Foster, J. Schott, and D. Messinger, "Spin-Image Target Detection Algorithm Applied to Low Density 3D Point Clouds", Accepted for publication in the Journal of Applied Remote Sensing, Jun. 2008

Ientilucci, E., Bajorski, P., "Stochastic Modeling of Physically Derived Signature Spaces", Journal of Applied Remote Sensing (JARS), Accepted for publication, 2008

Hattenberger, T.J., Fairchild, M.D., Johnson, G.M., and Salvaggio, C. "A psychophysical investigation of global illumination algorithms used in augmented reality", ACM Transactions on Applied Perception, in press (2008)

Z. Wang, A. Vodacek, J. Coen, "Generation of synthetic infrared remote sensing scenes". International Journal of Wildland Fire, In press, June 2008.

Ientilucci, E., Bajorski, P., "Stochastic Modeling of Physically Derived Signature Spaces", Journal of Applied Remote Sensing (JARS), Vol. 2, 023532, 2008.

5.2 Published Proceedings

M. Stefanou and J. Kerekes, "Spectral image utility prediction", Proceedings of the 2007 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Barcelona, Spain, July 2007.

B. Bartlett; and J. R. Schott, "Atmospheric inversion in the presence of clouds: an adaptive ELM approach", Proceedings of SPIE, Vol. 6661, San Diego, August 2007

Basener, B., Ientilucci, E., Messinger, D., "Anomaly Detection using Topology", in Proc. SPIE, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIII, Vol. 6565, (Orlando, Fla), April 2007.

M. S. Foster, J. R. Schott, D. W. Messinger, and R. V. Raqueño, "Use of LIDAR data to geometrically constrain radiance spaces for physics-based target detection", Proceedings of SPIE, Vol. 6661, San Diego, August 2007

M. G. Gartley, S. D. Brown, A. D. Goodenough, N. J. Sanders, and J. R. Schott, "Polarimetric scene modeling in the thermal infrared", Proceedings of SPIE, Vol. 6682, San Diego, August 2007

Gillis, D., Bowles, J., Ientilucci, E., and Messinger, D., "Linear Unmixing using Endmember Subspaces and Physics Based Modeling", in Proc. Imaging Spectrometry XII, Vol. 6651, ISBN: 9780819468093, (San Diego, CA), August 2007.

M. K. Jakubowski, D. Pogorzala, T.J. Hattenberger, S. D. Brown, and J. R. Schott, "Synthetic data generation of high-resolution hyperspectral data using DIRSIG", Proceedings of SPIE, Vol.6661, San Diego, August 2007.

P. Gurram, H. Rhody, J. Kerekes, S. Lach and E. Saber, "3D scene reconstruction through a fusion of passive video and lidar imagery", Proceedings of the Applied Imagery Pattern Recognition Workshop, Washington, DC, October 2007.

B.J. Daniel, M.R. Bolcar, J.R. Schott, and J.R. Fienup, "Phase Retrieval in Sparse Aperture Systems with Phase Diversity: A Trade Space Study", Proceedings of SPIE, Vol. 6958, Orlando, March 2008.

M. G. Gartley, S. D. Brown, and J. R. Schott, "Micro-scale surface and contaminate modeling for polarimetric signature prediction", Proceedings of SPIE, Vol. 6972, 697213, Orlando, March 2008.

Gillis, D., Bowles, J., Ientilucci, E., and Messinger, D., "A Generalized Linear Mixing Model for Hyperspectral Imagery", in Proc. SPIE, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIV, Vol. 6966, (Orlando, Fla), March 2008.

M. Montanaro, C.Salvaggio, S.D. Brown, D.W. Messinger, and A.J. Garrett, "Apparent Temperature Dependence on Localized Atmospheric Water Vapor;;, Proceedings of SPIE, Vol. 6966, 696618, Orlando, March 2008.

H. Peng, R. Rao, and D.W. Messinger, "Spatio-spectral bilateral filters for hyperspectral imaging", Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIV, Proceedings of SPIE vol. 6966, Orlando, FL, March 2008.

A. Schlamm, D.W. Messinger, and W. Basener, "Geometric estimation of the inherent dimensionality of a single material cluster in multi- and hyperspectral imagery", Proceedings of SPIE, Vol. 6966, Orlando, March 2008.

Sarkar, A.; Fairchild, M.; Salvaggio, C. "Integrated daylight harvesting and occupancy detection using digital imaging", Proceedings of the SPIE, Sensors, Cameras, and Systems for Industrial/Scientific Applications IX, Volume 6816, 68160F, doi: 10.1117/12.765961 (2008).

J. D. Beezley, S. Chakraborty, J.L. Coen, C.C. Douglas, J. Mandel, A. Vodacek, Z. Wang, "Real-Time Data Driven Wildland Fire Modeling", Computational Science - ICCS 2008, Lecture Notes in Computer Science. Springer. Vol. 5103. p. 46-53, June 2008.

5.3 Technical Reports

Ientilucci, E.J., Messinger, D., and Pogorzala, D., "Oblique Hyperspectral Radiometric Phenomenology Study", Task Report for NRL and Virtual Scopics, Inc., December, 2007.

J. Kerekes, J. Casey, D. Snyder, I. Fairweather, S. Hager, J. Shive, and R. Crabtree, "Vehicle Tracking in an Urban Environment with Multitemporal Airborne Hyperspectral Imaging," DIRS Project Report 07-61-176, Digital Imaging and Remote Sensing Laboratory, Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, Rochester, New York, February 2008.

5.4 Presentations

Schott, J.R., "Landsat Remote Sensing Research at RIT", joint meeting of the IEEE GRSS Western New York Chapter and the Central New York Region of ASPRS, Rochester Institute of Technology, September (2007).

Vodacek, A., "Assimilating remote sensing with dynamic data-driven environmental models", Department of Mechanical and Aerospace Engineering, University at Buffalo, October (2007).

Vodacek, A., "Assimilating remote sensing with dynamic data-driven environmental models", Department of Mechanical and Aerospace Engineering, Texas A&M University, October (2007).

J. Kerekes, "Hyperspectral imaging capabilities for natural disaster assessment", presented at the Conference on Natural Disasters in Small Communities: How Can We Help, Center for GeoHazards Studies, State University of New York, Buffalo, New York, March (2008).

Vodacek, A., "Improving environmental forecasts using remote sensing data assimilation", Department of Earth and Environmental Sciences, University of Rochester, March (2008).

Vodacek, A., "Improving environmental forecasts using remote sensing data assimilation", Department of Civil, Structural, and Environmental Engineering, University at Buffalo, April (2008).

Vodacek, A., "Water Quality in Rwanda: A Study Using Remote Sensing", CGIS-NUR, KIST, and Office of Science and Technology, June (2008).

Raqueño, R.V; Salvaggio, C. "The practicals of grid computing with ENVI/IDL: Case studies in high throughput computing (HTC) using Condor and ENVI/IDL for physics-based remote sensing algorithms and applications", Presentation delivered at 2008 ENVI User Symposium (ENVIUS 2008), Heritage Conference Center, Chantilly, VA, May (2008)

Messinger, D.W., "Overview of Spectral Image Exploitation Development Research in Remote Sensing at RIT", NGA Algorithms Technical Exchange Meeting, June (2007)

Messinger, D.W., "Overview of the Digital Imaging and Remote Sensing Laboratory and Remote Sensing Algorithm Research", Presented to a special workshop meeting at the NRO, July (2007)

Messinger, D.W., "(Hyper)Spectral Remote Sensing for the Detection of Point Targets and Man-Made Activity in Large Area Search Applications", Conference on Mathematical Methods in Counterterrorism, Rochester, NY, Sep. (2007)

Messinger, D.W., "Topological Approaches to Exploitation of Hyperspectral Imagery: Beyond Statistics and Linear Geometry", Invited Presentation to the Telops Hyperspectral Workshop, Washington, DC, October (2007)

Messinger, D.W., "Topological Approaches to Spectral Image Processing for Remote Sensing Applications", Invited Presentation to the SUNY Geneseo Physics Department, Geneseo, NY, April (2008)

Messinger, D.W., "Fusion of LIDAR Point Clouds and HSI for Improved Target Detection", Spectral Analyst Exchange Forum, St. Louis, MO, April (2008)

Messinger, D.W., "MSI Persistent Surveillance Performance: Spectral Band / Frame Rates Trade Study", Spectral Analyst Exchange Forum, St. Louis, MO, April (2008)

Messinger, D.W., “Spectral Image Utility Assessment and Prediction”, Spectral Analyst Exchange Forum, St. Louis, MO, April (2008)

Messinger, D.W., “Geometric Estimation of the Inherent Dimensionality of Single and Multi-Material Clusters in Hyperspectral Imagery”, 2008 ENVI User Symposium, Chantilly, VA, May (2008)

6 Special Events

6.1 The DIRS Annual Research Symposium, May 28 - 29, 2008

The 2008 DIRS Annual Research Symposium was held on May 28 and 29, 2008. The goal of the annual research symposium is to update the research sponsor community and potential new sponsors on the breadth of research activities accomplished over the previous 12 months. This years meeting was a significant success with over 40 outside visitors and active participation by the students, faculty, and research staff.

Activities started with a gathering at MacGregors Tap Room on the evening of May 27. Food, drink, and stories were in abundant supply. The main research presentations occurred on May 28 and covered the following topics:

- Welcome - Don Boyd, RIT VP of Research
- DIRS Update - David Messinger, Faculty and Interim Lab Director
- Modeling and Simulation Research Update - Scott Brown, Research Staff
- MicroDIRSIG - Michael Gartley, Research Staff
- NURI: 3D Model Generation from LIDAR Data - Stephen Lach, Graduate Student
- Modeling of a Sparse Aperture Telescope System - Brian Daniel, Graduate Student
- Algorithms Research Update - David Messinger, Faculty and Interim Lab Director
- Radiometric Modeling of a Mechanical Draft Cooling Tower - Matt Montanaro, Graduate Student
- Spectral Utility Metric - Marcus Stefanou, Graduate Student
- Persistent Surveillance: spectral vs. temporal trade - David Messinger, Faculty
- Civil Remote Sensing Research Update - John Schott, Faculty
- ***A***dvanced ***AN***alyst ***E***xploitation ***E***nvironment (AANEE) - Jake Clements and Colin Doody, Graduate Students

The day concluded with the DIRS Board of Advisors meeting. This is an opportunity to interact with sponsors and potential sponsors to gain valuable insight on research projects reviewed, as well as, future research directions.

The morning of May 29 was used to hold concurrent workshops with attendees in three technical areas; modeling and simulation, algorithms, and remote sensing applications. The intention of these workshops was to allow for more interactive discussions in each of the technical domains. The workshops were moderately successful with some good discussion, but also suffered from varying levels of concrete discussion topics. Additional thought is going to go into the best way to conduct future workshops. The day concluded with a golf outing at Mill Creek CC that did not disappoint.

6.2 Outreach to Rwandan Ministry of Education

Figure 6.2-57: The RIT delegation with Dr. Romain Murenzi, Rwandan Minister of Science and Technology. Left to right, Dr. Mbonye, Minister Murenzi, Dr. Vodacek, and Dr. Boyd.

Project Scope:

Dr. Anthony Vodacek was part of an official RIT delegation invited by the Rwandan Ministry of Education to visit Rwanda in June 2008. The purpose of the trip was to extend the existing educational program between RIT and the Rwandan government and to create new joint faculty development and research programs between RIT and Rwandan universities. The other RIT delegation members were Dr. Eulas Boyd, Assistant Provost, and Dr. Manasse Mbonye, physics faculty member and a native of Rwanda. Dr. Vodacek was invited because of his research interests in environmental remote sensing and the wide potential for applying this technology in developing countries. The concept explored during the visit was to outline potential research projects in Rwanda, where Rwandan students could come to RIT for imaging science degrees, but perform their dissertation work on a remote sensing topic in Rwanda. This would provide the eventual new Rwandan PhD's the opportunity to continue their research after they complete their degrees and return home. By also collaborating with faculty at the Rwandan universities on these research projects, RIT can have access to local expertise and provide good faculty development opportunities for the Rwandan faculty.

Project Status:

The delegation met with several Rwandan ministers, including the Minister of Education, the Minister of Science and Technology, the Minister of Natural Resources, and the Minister of Energy. The delegation also visited the Kigali Institute of Education, the National University of Rwanda, and the Kigali Institute of Science and Technology, where they met with the Rectors, Deans, and faculty in disciplines such as engineering, computing, physics, water resources, and agriculture. During the visit Dr. Vodacek gave three seminars on his current research in remote sensing data assimilation in environmental models. Dr. Vodacek also met with the staff of the Centre for Geographic Information Systems and Remote Sensing at the National University of Rwanda. Water resources were high on the list of potential research projects because of the problems with erosion and water quality throughout Rwanda.

7 DIRS Student Capstone Projects

In recognition of the contribution of our students over the years we list their capstone projects here.

7.1 Ph.D. Students

Snyder, W., "An in-scene parameter estimation method for quantitative image analysis", Unpublished doctoral dissertation, Rochester Institute of Technology, New York 1994.
Feng, X., "Design and performance evaluation of a modular imaging spectrometer instrument", Unpublished doctoral dissertation, Rochester Institute of Technology, New York 1995.
Gross, H., "An image fusion algorithm for spatially enhancing spectral mixture maps", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 1996.
Kuo, D., "Synthetic image generation of factory stack and cooling tower plumes", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 1997.
Fairbanks, R., "A characterization of the impact of clouds on remotely sensed water quality", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 1999.
Sanders, L., "An Atmospheric Correction Technique for Hyperspectral Imagery", Unpublished doctoral dissertation, Rochester Institute of Technology, New York 1999.
Hernandez-Baquero, E., "Characterization of the Earth's surface and atmosphere from multispectral and hyperspectral thermal imagery", Unpublished doctoral dissertation, Rochester Institute of Technology, New York 2000.
Bishop, Jonathan, "Modeling of Plume Dispersion and Interaction with the Surround of Synthetic Imaging Applications", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 2001.
Burton, Robin, "Elastic LADAR Modeling for Synthetic Imaging Applications", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 2002.
Meyers, Jason, "Modeling Polarimetric Imaging using DIRSIG", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 2002.
Lee, Kyungsuk, "A Subpixel Target Detection Algorithm for Hyperspectral Imagery", Unpublished doctoral dissertation, Rochester Institute of Technology, New York 2004.
Introne, Robert, "Enhanced Spectral Modeling of Sparse Aperture Imaging Systems", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 2004.
Ientilucci, Emmett, "Hyperspectral Sub-Pixel Target Detection using Hybrid Algorithms and Physics Based Modeling", Unpublished doctoral dissertation, Rochester Institute of Technology, New York 2006.
Shell, James, "Polarimetric Remote Sensing in the Visible to Near Infrared", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 2006.
Blevins, Daniel, "Modeling Scattering and Absorption for a Differential Absorption LIDAR System", Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York 2006.
Li, Yan, "An Integrated Water Quality Modeling System with Dynamic Remote Sensing Feedback", Unpublished doctoral dissertation, Rochester Institute of Technology, Rochester, NY 2006.
Li, Ying, "Remote Sensing Algorithm Development for Wildland Fire Detection and Mapping" Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2006.

Gartley, Michael, "Polarimetric Modeling of Remotely Sensed Scenes in the Thermal Infrared" Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2007.
Wang, Zhen, "Modeling Wildland Fire Radiance in Synthetic Remote Sensing Scenes"' Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2007.
Foster, Michael, "Using LIDAR to Geometrically Constrain Signature Spaces for Physics Based Target Detection", Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2007 US Air Force.
Boonmee, Marvin, "Land Surface Temperature and Emissivity Retrieval from Thermal Infrared Hyperspectral Imagery", Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2007.
Bartlett, Brent, "Improvement of Retrieved Reflectance in the Presence of Clouds", Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2007.
Goodenough, Adam, "In-water Spectral Radiative Transfer Modeling using Photon Mapping" Doctoral dissertation, Rochester Institute of Technology, New York, 2007.
Ward, Jason, "Realistic Texture in Simulated Thermal Infrared Imagery", Doctoral dissertation, Rochester Institute of Technology, New York, 2008, US Air Force.
Adams, Andrew, "Multispectral Persistent Surveillance", Doctoral dissertation, Rochester Institute of Technology, New York, 2008, US Air Force.

7.2 M.S. Students

A.J. Sydlik, 1981, "A technique for calculating atmospheric scattering and attenuation effects of aerial photographic imagery from totally airborne acquired data", Canadian Forces
Arthur Byrnes, 1983, "A Comparison Study of Atmospheric Radiometric Calibration Methods for Aerial Thermgrams", Canadian Forces
Lawrence Maver, 1983, "The effects of shadow visibility on image interpretability"
George Grogan, 1983, "A model to predict the reflectance from a concrete surface as a function of the sunobject-image angular relationship"
Ian. Macleod, 1984, "An airborne thermal remote sensing calibration technique", Canadian Forces
William Volchok, 1985, "A study of multispectral temporal scene normalization using pseudo-invariant features, applied to Landsat TM imagery"
Joseph Biegel, 1986, "Evaluation of quantitative aerial thermography"
Tim Hawes, 1987, "Land cover classification of Landsat thematic mapper images using pseudo-invariant feature normalization applied to change detection", U.S. Air Force
Carl Salvaggio, 1987, "Automated segmentation of urban features from Landsat thematic mapper imagery for use in pseudo-invariant feature temporal image normalization"
Wayne Farrell, 1987, "Investigation of the Accuracy of Array Radiometry for Measuring Pulsed Radiation Sources", Canadian Forces
John Francis, 1989, "Pixel-by-pixel reduction of atmospheric haze effects in multispectral digital imagery"
Denis Robert, 1989, "Textural features for classification of images", Canadian Forces
Jan North, 1989, "Fourier image synthesis and slope spectrum analysis"
Michael Davis, 1990, "Bidirectional spectral reflectance field instrument"
Wendy Rosenblum, 1990, "Optimal selection of textural and spectral features for scene segmentation"
Eric Shor, 1990, "Longwave infrared synthetic scene simulation"
James Warnick, 1990, "A quantitative analysis of a self-emitting thermal IR scene simulation system"
Curtis Munechika, 1990, "Merging panchromatic and multispectral images for enhanced image analysis", U.S. Air Force
Xiaofan Feng, 1990, "Comparison of methods for generation of absolute reflectance factor measurements for BRDF studies"
Rolando Raqueo, 1990, "Automated boundary detection of echocardiograms", (M.S. Computer Science)

Jonathan Wright, 1991, "Evaluation of LOWTRAN and MOTRAN for use over high zenith angle/long path length viewing", U.S. Air Force
Craig Eubanks, 1991, "Comparison of ellipso-polarimetry and dark field methods for determining of thickness variations in thin films"
Marc Lapointe, 1991, "Substitution of the Statistical Range for the Variance in Two Local Noise Smoothing Algorithms", Canadian Forces
Robert Mericsko, 1992, "Enhancements to atmospheric correction techniques for multiple thermal images"
Gustav Braun, 1992, "Quantitative evaluation of six multi-spectral, multi-resolution image merger routines"
Sharon Cady, 1992, "Multi-scene atmospheric normalization of airborne imagery: application to the remote measurement of lake acidification"
David Ehrhard, 1992, "Application of Fourier-based features for classification of synthetic aperture radar imagery", U.S. Air Force
Bernard Brower, 1992, "Evaluation of digital image compression algorithms for use on lap top computers"
Donna Rankin, 1992, "Validation of DIRSIG an infrared synthetic scene generation model"
Craig Laben, 1993, "A comparison of methods for forming multitemporal composites from NOAA advanced very high resolution radiometer data"
Tom Servoss, 1993, "Infrared symbolic scene comparator"
Richard Stark, 1993, "Synthetic image generator model: application of specular and diffuse reflectivity components and performance evaluation in the visible region", U.S. Air Force
Eleni Paliouras, 1994, "Characterization of spatial texture for use in segmentation of synthetic aperture radar imagery"
Robert Rose, 1994, "The generation and comparison of multispectral synthetic textures"
Joseph Sirianni, 1994, "Heat transfer in DIRSIG an infrared synthetic scene generation model"
Gary Ralph, 1994, "Characterization of the radiometric performance of an IR scene projector", Canadian Forces
Jim Salicain, 1995, "Simulation of camera model sensor geometry effects"
Steven Nessmiller, 1995, "A comparison of the performance of non-parametric classifiers with Gaussian maximum likelihood for the classification of multispectral remotely sensed data", U.S. Air Force
Serge Dutremble, 1995, "Temporal sampling of forward looking infrared imagery for subresolution enhancement post processing", Canadian Forces
Alexander J. Granica, 1996, "Modeling of the radiometric characteristics of a simulated flourescent imager"
Todd A. Kraska, 1996, "Digital Imaging and Remote Sensing Image Generation Model: infrared airborne validation & input parameter analysis", U.S. Air Force
Frank J. Tantalo, 1996, "Modeling the MTF and noise characteristics of an image chain for a synthetic image generation system"
Russell A. White, 1996, "Validation of Rochester Institute of Technologys (RITs) Digital Image and Remote Sensing Image Generation (DIRSIG) model-reflective region", U.S. Air Force
Jeffrey Allen, 1997, "Methods of digital classification accuracy assessment"
Paul Llewellyn Barnes, 1997, "In-scene atmospheric correction for multispectral imagery"
Todd Birdsall, 1997, "The development of an analytical model for the Kodak digital science color infrared cameras and its aerial imaging applications"
Phil Edwards, 1997, "A Canadian Resource Guide for a Water Quality Study of Lake Ontario", Canadian Forces
Gary Robinson, 1997, "Evaluation of two applications of spectral mixing models to image fusion", U.S. Air Force
David Schlingmeier, 1997, "Resolution enhancement of thermal infrared images via high resolution classmap and statistical methods", Canadian Forces
Tom Haake, 1998, "Modeling Topography Effects with DIRSIG"
David Joseph, 1998, "DIRSIG: A broadband validation and evaluation of potential for infrared imaging spectroscopy"

Julia Laurenzano, 1998, “A comparative analysis of spectral band selection techniques”, U.S. Air Force
Francois Alain, 1999, “Simulation of Imaging Fourier Transform Spectrometers Using DIRSIG”, Canadian Forces
Dilkushi Anuja de Alwis, 1999, “Simulation of the formation and propagation of the thermal bar on Lake Ontario”
Daisei Konno, 1999, “Development and Testing of Improved Spectral Unmixing Techniques”
Emmett Ientilucci, 1999, “Synthetic simulation and modeling of image intensified CCDs (IICCD)”
Pete Arnold, 2000, “Modeling and Simulating Chemical Weapon Dispersal Patterns in DIRSIG”
Julia Barsi, 2000, “MISI and Landsat ETM+: thermal calibration and atmospheric correction”
Robert Gray, 2000, “Modeling Forests for Synthetic Image Generation”, Computer Science
Mary Ellen Miller, 2000, “An approach for assessment of Great Lakes Water Quality using Remote Sensing”
John Klatt, 2001, “Error Characterization of Spectral Products using a Factorial Designed Experiment” Canadian Forces
Andrew Fordham, 2002, “Band Selection and Algorithm Development for Remote Sensing of Wildfires”
Neil Scanlan, 2003, “Comparative Performance Analysis of Texture Characterization Models in DIRSIG” Canadian Forces
Karl Walli, 2003, “Multisensor Image Registration Utilizing the LoG Filter and FWT”, US Air Force
Gabriel Dore, 2004, “Multiframe Super-Resolution of Color Image Sequences Using a Global Motion Model”, Canadian Forces
Erin Peterson, 2004, “Synthetic Landmine Scene Development and Validation in DIRSIG”, US Air Force
Kris Barcomb, 2004, “High Resolution, Slant Angle Scene Generation and Validation of Concealed Targets in DIRSIG”, US Air Force
David Pogorzala, 2005, “Gas Plume Species Identification in LWIR Hyperspectral Imagery by Regression Analyses”
Erin ODonnell, 2005, “Detection and Identification of Effluent Gases Using Invariant Hyperspectral Algorithms”
Gretchen Sprehe 2005 [M.S. Environmental Science, Remote Sensing Track] “Application of Phenology to Assist in Hyperspectral Species Classification in a Northern Hardwood Forest”
Nancy Baccheschi, 2005, “Generation of a Combined Dataset of Simulated RADAR and Electro-Optical Imagery”, US Air Force
Jason West, 2005, “Matched Filter Stochastic Background Characterization for Hyperspectral Target Detection”, US Air Force
David Grimm, 2005, “Comparison of Hyperspectral Imagery Target Detection Algorithm Chains”, US Air Force
Noah Block, 2005, “A Sensitivity Study of a Polychromatic Sparse Aperture System”
Timothy Grabowski, 2006 “Effects of pixel size on apparent emissivity signatures of materials with longwave infrared spectral characteristics”
Kristin Strackerjan, 2006, “Modeling the Spectral Effects of Water and Soil as Surface Contaminants in a High Resolution Optical Image Simulation”, Canadian Forces
Pierre Chouinard, 2006, “Decision Fusion of Hyperspectral and Synthetic Aperture Radar Imagery for Trafficability Assessment”, Canadian Forces
Adam Cisz, 2006, “Performance Comparison of Hyperspectral Target Detection Algorithms”
Brian Dobbs, 2006, “The Incorporation of Atmospheric Variability into DIRSIG”
Domenico Luisi, 2007, “Conceptual design and Specification of a MICROSATELLITE Forest fire Detection System” Canadian Forces
Shari McNamara, 2007, “Using Multispectral Sensor WASP-Lite to Analyze Harmful Algal Blooms”
Manuel Ferdinandus, 2007 “Selection of Optimal Background Estimation Methods for Unstructured Detectors” US Air Force
Jason Casey, 2008, “A Comparative Analysis of Hyperspectral Target Detection Algorithms in the Presence of Misregistered Data”

7.3 B.S. Students

Jeffrey Sefl, 1983, “Determination of the transformation relationship of pseudo-invariant features of two Landsat images”
Kirk Smedley, 1986, “Imaging land/water demarcation lines for coastal mapping”
David Sapone, 1988, “Verification of a thermal model through radiometric methods”
Joshua Colwell and Eric Higgins, 1988, “Determination of the modulation transfer function of a thermal infrared line scanner”
Donald Marsh, 1989, “Photometric processing and interpretation of ratioed imagery by multispectral discriminate analysis for separation of geologic types”
Fred Stellwagon, 1989, “Classification of mixed pixels”
Brian Jalet, 1991, “Evaluation of methods of cloud removal in multidate NOAA/AVHRR imaging and its application to vegetational growth monitoring”
Michael Heath, 1991, “Perspective scene generation employing real imagery”
Stephen Ranck, 1991, “Establishment of a simple geographic information system utilizing digital data”
James Schryver, 1991, “Topographical analysis of a raster geographic information system”
Robert Rose, 1992, “Design of the information dissemination technique for a heat loss study”
Joseph Sirianni, 1992, “Production of realistic-looking sky radiance in the SIG process”
Andy Martelli, 1992, “Color calibration of an Agfa matrix QCR camera for Ektar 100 and 125 color print films”
Michael Branciforte, 1993, “An automated video tracking unit based on a matched filter segmentation algorithm”
Brian Heath, 1993, “Use of a quad cell in tracking a unit”
Debbie Wexler, 1993, “Texture generation using a stochastic model”
Michael Platt, 1994, “Evaluation of the feasibility of using digital terrain elevation models for the generation of multispectral images at Landsat resolution”
Cory Mau, 1994, “Incorporation of wind effects in IR scene simulation”
Paul Barnes, 1995, “Introduction of vegetation canopy models into DIRSIG”
Jeff Ducharme, 1995, “Atmospheric downwelled radiance”
Chip Garnier, 1995, “Integrating sphere calibration”
Jeff Allen, 1996, “Comparison of modeled and real vegetation imagery”
Emmett Ientilucci, 1996, “Blackbody calibration of MISI”
Charles Farnung, 1997, “DIRSIG camouflage phenomenology”
Peter Arnold, 1997, “BRDF approximation using a mathematical cone function”
Julia Barsi, 1997, “The generation of a GIS database in support of Great Lakes Studies”
Jason Calus, 1997, “Modeling of focal plane geometry in DIRSIG”
Arnold Hunt, 1997, “Validation of BRDF model in DIRSIG”
Michael C. Baglivio, 1998, “Error Characterization of the Alpha Residuals Emissivity Extraction Technique”
Brian Bleeze, 1998, “Modeling the MTF and Noise Characteristics of Complex Image Formation Systems”
Chia Chang, 1998, “Evaluation of Inversion Algorithms on DIRSIG Generated Plume Model Simulations”
Peter Kopacz, 1998, “Simulation of Geometric Distortions in Line Scanner Imagery”
Jason Hamel, 1999, “Simulation of Spectra Signatures of Chemical Leachates from Landfills”
Daniel Newland, 1999, “Evaluation of Stepwise Spectral Unmixing with HYDICE Data”
J. Meghan Salmon, 2000, “Derivative Spectroscopy for Remote Sensing of Water Quality”
Janel Schubbuck, 2000, “Thermal Calibration of MISI”
Matt Banta, 2001, “Lunar Calibration Techniques”
Christy Burtner, 2001, “Texture Characterization in DIRSIG”
Adam Goodenough, 2001.“Evaluating Water Quality Monitoring with Hyperspectral Imagery”
Erin O’Donnell, 2001, “Historical Radiometric Calibration of Landsat 5”
Nikolaus Schad, 2001, “Hyperspectral Classification with Atmospheric Correction”
Cindy Scigaj, 2001, “Design and Implementation of a LIDAR Imaging System”

Eric Sztanko, 2001. “Imaging Fourier Transform Spectrometer: Design, Construction, and Evaluation”
Eric Webber, 2001, “Sensitivity Analysis of Atmospheric Compensation Algorithms for Multispectral Systems Configuration”
Adam Cisz, 2002, “Multispectral Fire Detection: Thermal/IR, Potassium, and Visual”
Rose of Sharon Daly, 2002, “Polarimetric Imaging”
Matthew D. Egan, 2002, “Detection and Analysis of Industrial Gas Plumes”
Carolyn S. Kennedy, 2002, “The Testing and Assessment of Texturing Tools Used to Build Scenes in DIRSIG”
David Pogorzala, 2002, “Setting Fire to CIS, Small - Scale Combustion Chamber and Instrumentation”
Jonathan Antal, 2002, “Error Characterization of Hyperspectral Products with Emphasis on Atmospheric Correction Techniques”
Kenneth R. Ewald, 2002, “Creation of ISO Target 16067-1”
Jared Clock, 2003, “Inexpensive Color Infrared Camera”
Gary Hoffmann, 2003, “Visual Enhancement of the Archimedes Palimpsest Using a Target Detection Algorithm”
Jill Marcin, 2003, “Effects of Contamination on Spectral Signatures” Brandon Migdal, 2004, “Watermark Extraction Methods For Linearly Distorted Images to Maximize Signal-to-Noise Ratio”
Alvin Spivey, 2004, “An approach to synthetic scene completion and periodic noise removal by image inpainting and resynthesis”
Seth Weith-Glushko, 2004, “Automatic Tie-Point Generation for Oblique Aerial Imagery: An Algorithm”
Rachael Gold, 2005. “Performance Analysis of the Invariant Algorithm for Target Detection in Hyperspectral Imagery” Michael Muldowney, 2005, “Time Series Analysis of Late Summer Microcystis Algae Blooms through Remote Sensing”
Brian Staab, 2005, “Investigation of Noise and Dimensionality Reduction Transforms on Hyperspectral Data as Applied to Target Detection”
Christopher Bayer, 2005, “Development of algorithm for fusion of hyperspectral and multispectral imagery with the objective of improving spatial resolution while retaining spectral data”
Michael Denning, 2007, “Classification of astronomical infrared sources using Spitzer space telescope data”
Justin Kwong, 2007, “Impact of calibration errors on physics based target detection”
Sarah Paul, 2007, “Investigation of VisiBall glasses claims”