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

DIRS
Digital Imaging and
Remote Sensing Lab

Annual Report for the Academic Year 2009-2010

on the Activities of the

Digital Imaging and Remote Sensing Laboratory

Prepared by the DIRS Laboratory

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Laboratory Director

John R. Schott, Ph.D.
Frederick & Anna B. Wiedman Professor

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Chester F. Carlson CENTER for IMAGING SCIENCE

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1 Introduction

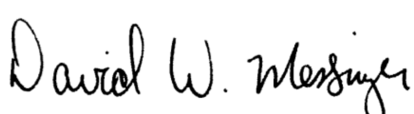
Once again we complete another academic year within the Digital Imaging and Remote Sensing laboratory in the Chester F. Carlson Center for Imaging Science. The past year saw many major accomplishments by members of the lab, and we continue to be well placed for stability and growth in the future. Towards the end of the 2009-10 academic year, it was decided by members of both the DIRS and LIAS groups (Laboratory for Imaging Algorithms and Systems, also in CIS) to merge the two organizations. Over the years, LIAS has focused more on remote sensing imaging systems and we strongly believe that the integration of the two groups will make the sum greater than the parts. The new, larger DIRS is reflected in the listing of the Faculty & Staff below, but now we count as our numbers nine faculty, 19 full time research & support staff, and over 40 students at all levels. It is our continued commitment to our students, and their outstanding efforts, that moves DIRS forward.

We had the honor of hosting Dr. Stanley Rotman from the Ben-Gurion University of the Negev during the spring and into the summer of 2010. We have worked with Dr. Rotman for several years and were fortunate that he chose to spend his sabbatical with us. While here, Dr. Rotman was supported by the Air Force Research Laboratory to perform spectral target detection algorithm development research. He additionally interacted closely with several DIRS faculty, staff, and students, expanding our horizons and helping with several research projects. We thank Dr. Rotman for his time with us and look forward to many future collaborations.

In the fall of 2009, at the Annual NGA Academic Research Program Symposium, DIRS was recognized by the NGA for our continued support to their research program. DIRS was named an NGA Science & Technology Center of Academic Excellence with support from the Office of the Director of National Intelligence.

The most dramatic, challenging, and rewarding activity for the DIRS lab was undoubtedly our support to the earthquake relief efforts in Haiti in January of 2010. These efforts are outlined below in Section 3.10.1. In short, we have been involved in research to understand the application of remote sensing technology to the disaster / emergency response community. Through these efforts, we were funded by the World Bank, in collaboration with partners at the University of Buffalo, ImageCat, Inc., and Kucera International, to fly the WASP sensor, developed here at RIT, over Haiti shortly after the devastating earthquake in January. Eventually, we deployed sensors for 7 days of flights over Haiti, covering over 250 square miles of the devastated nation. The imagery was sent back to RIT via a high speed internet link set up through participation in the Internet2 Consortium and with support from our collaborators at the University of Puerto Rico - Mayagüez. The imagery and 3D LIDAR data collected have been used to make building damage assessments, understand the structure of the fault line, and map out new flood hazard areas among a host of other applications in aid to the relief and rebuilding effort. It was only through the outstanding efforts of faculty, staff, and students in CIS and DIRS that this was accomplished.

I want to thank all members of the DIRS laboratory for their continued hard work and excellence. It is only through the advances made by the faculty, staff, and most importantly, the students, that we continue to be a leader in the remote sensing community.



David W. Messinger
Associate Research Professor
Director, 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 academia, government agencies, and private industry.

The DIRS group is made up of faculty and research staff working with over 40 students ranging from High School interns, to RIT students from the Baccalaureate through Doctoral level. Most students are degree candidates in Imaging Science, but students from other departments, such as Engineering and Mathematics, 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 Personnel

2.1.1 Faculty

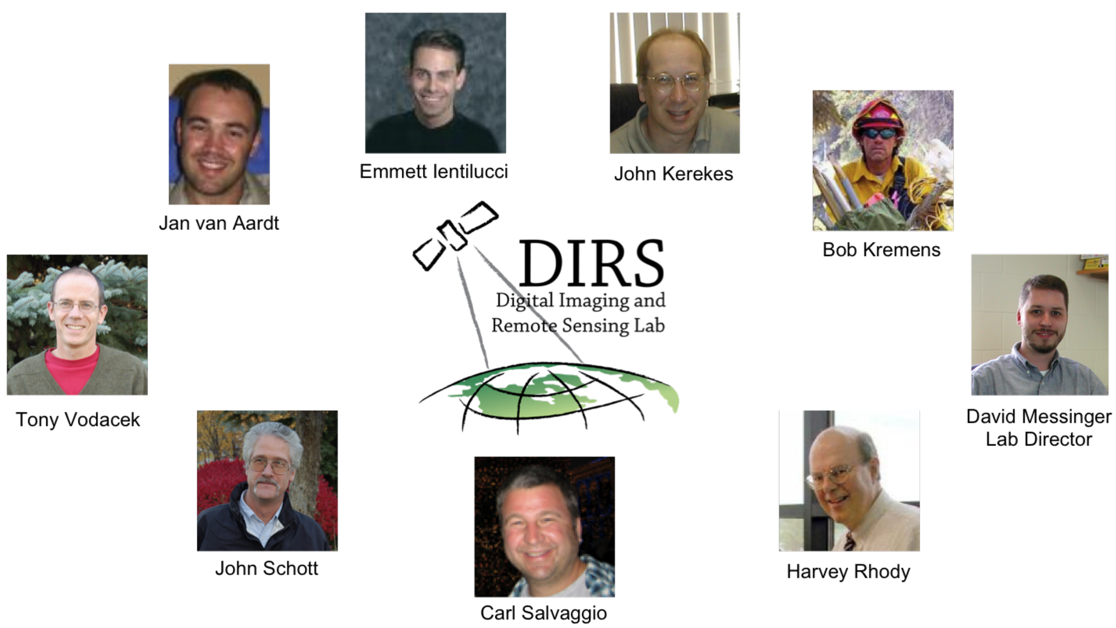


Figure 2.1-1: Faculty affiliated with the DIRS laboratory.

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

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. Bob Kremens, Associate Research Professor,
Research Interests: Remote sensing characterization of forest fires; in-situ measurement systems; fusion of in-situ and remote measurements
Contact Information: kremens@cis.rit.edu; 585-475-7286

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

Dr. Harvey Rhody, Professor,
Research Interests: Image processing algorithms and systems; three-dimensional imaging
Contact Information: rhody@cis.rit.edu; 585-475-6215

Dr. Stanley Rotman, Visiting Professor, Ben Gurion Unversity
Research Interests: Spectral target detection algorithm development
Contact Information: rotman@cis.rit.edu

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 Schott, Frederick and Anna B. Wiedman Professor
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. Jan van Aardt, Associate Professor,
Research Interests: Application of imaging spectroscopy and LIDAR for spectral-structural characterization of natural systems
Contact Information: vanaardt@cis.rit.edu; 585-475-4229

Dr. Tony 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

2.1.2 Research & Support Staff

Dr. Brent Bartlett: bartlett@cis.rit.edu; 585-475-5037
Mr. Scott Brown: brown@cis.rit.edu; 585-475-7194
Mr. Steve Cavilia: cavilia@cis.rit.edu; 585-475-4215
Mr. Jason Faulring: faulring@cis.rit.edu; 585-475-4432
Dr. Michael Gartley: gartley@cis.rit.edu; 585-475-7194
Dr. Aaron Gerace: adg7564@cis.rit.edu;585-475-5508
Dr. Adam Goodenough: goodenough@cis.rit.edu
Ms. Caitlin Hart: hart@cis.rit.edu; 585-475-5508
Mr. Bob Krzaczek: krz@cis.rit.edu; 585-475-7196
Mr. Don McKeown: mckeown@cis.rit.edu; 585-475-7192
Ms. Erin Ontiveros: ontiveros@cis.rit.edu; 585-475-4465
Ms. Nina Raqueño: nina@cis.rit.edu; 585-475-7676
Dr. Rolando Raqueño: rolando@cis.rit.edu; 585-475-6907

Figure 2.1-2: DIRS Faculty, staff, students and collaborators at the IEEE WHISPERS 2010 conference in Reykjavic, Iceland.

Mr. Michael Richardson: `richardson@cis.rit.edu`; 585-475-5294
Mr. Niek Sanders: `sanders@cis.rit.edu`
Dr. Ariel Schlamm: `aas1510@cis.rit.edu`; 585-475-5508
Ms. Cindy Schultz: `schultz@cis.rit.edu`; 585-475-5508

2.1.3 Student Researchers

Traditional students (*i.e.*, civilian) pursuing research in the DIRS laboratory as of June 30, 2010:

BS (7)

Chelsea Aures, Kevin Bloechel, Dustin Haas
David Kelbe, Michael Rodgers, Linnea Tullson
Amanda Ziemann

MS (4)

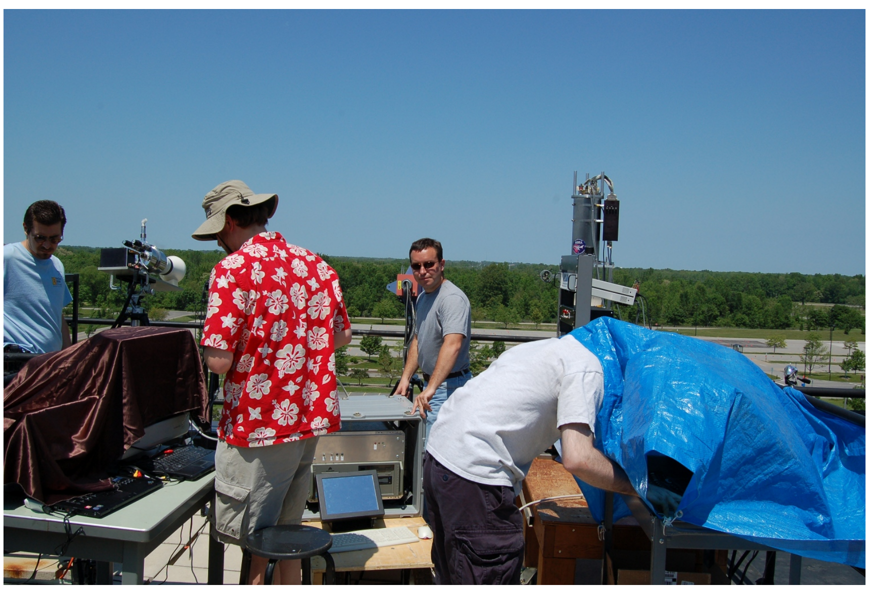
Kenny Fourspring, Joe McGlintchy, Andrew Scott, Philip Youkhana

Ph.D. (20)

Jamie Albano	May Casterline	Kelly Canham	Bin Chen
Jake Clements	Chabitha Devaraj	Shea Hagstrom	Sanjit Maitra
Troy McKay	Lingfei Meng	Ryan Mercovich	David Nilosek
Nima Pahlevan	Francesca Polo	Sarah Paul	Jacqueline Speir
Alvin Spivey	Jiangqin Sun	Weihua Sun	William Wu

Candian Forces and US Air Force officers enrolled in the MS and Ph.D. programs as of June 30, 2010 (12):

(a)



(b)

Figure 2.1-3: A rooftop experiment using the WASP-Lite sensor.

Diane Sarrazin (MS)	Sam Brisebois (MS)	Cliff Anderson (Ph.D.)	Brian Flusche (Ph.D.)
Jared Herweg (Ph.D.)	Rick Labiak (MS)	Alfredo Lugo (MS)	Jonathan Miller (MS)
Michael Pressnar (Ph.D.)	Annette Rivas (MS)	Karl Walli (Ph.D.)	Aaron Wiener (Ph.D.)

Figure 2.1-4: DIRS graduate students.

Figure 2.1-5: Canadian Forces officer Diane Sazzazin.

2.2 Theses Defended in Past Year

- Tony Rizzuto, MS, "Low-SNR Framework Incorporating Improved Nighttime Capabilities in DIRSIG"
- Mike Zelinski, MS, "Space Telescope Imaging Simulation Tool"
- Danielle Simmons, MS, "Hyperspectral Monitoring of Chemically Sensitive Plants"
- Shawn Higbee, Ph.D., "A Bayesian Approach to Identification of Gaseous Effluents in Passive LWIR Imagery"

Figure 2.1-6: US Air Force officers pursuing their graduate degrees within DIRS.

- Aaron Gerace, Ph.D., "Demonstrating Landsats New Potential to Monitor Coastal and Inland Waters"
- Ariel Schlamm, Ph.D., "Characterization of the Spectral Distribution of Hyperspectral Imagery for Improved Exploitation"

Figure 2.2-7: DIRS personnel demonstrated their work in support of the Haiti Disaster Relief Effort at the Imagine RIT festival in May 2010.

3 Research Project Summaries

3.1 Landsat Reflective Band Calibration Using Pseudo-Invariant Sites

Sponsor: NASA

Principal Investigator(s): Dr. John Schott
Research Team: Cliff Anderson (CIS - Ph.D.)

Project Description:
The long term calibration history of the Landsat 5 TM instrument has recently been defined using a time series of desert sites in Northern Africa. This correction is based on the assumption that the atmosphere is invariant and the reflectance of each site is approximately constant and Lambertian over time. As a result, the top of the atmosphere reflection is assumed constant when corrected for variations in the solar elevation angle and earth-sun distance. While this is true to first order and is the basis for all current temporal calibration, there are multiple known sources of residual error in the data. A methodology is presented for reducing the variation in pseudo-invariant site trending data based on correction for the BRDF. This work establishes a means to use DIRSIG to model the L5 calibration site. It combines a digital elevation map and desert atmosphere with a surface BRDF to reduce the residual errors in the calibration data. A set of Landsat 7 ETM+ calibration days is utilized to optimize the surface reflectance properties used in DIRSIG. These optimized parameters are then used to model the L5 TM calibration days. The results of the DIRSIGmodeling are compared to the solar elevation angle and time of year trends of the original data and analyzed for their effectiveness at describing and reducing the residual errors.

A major goal of this effort was to understand the contribution that BRDFs make to the current calibration errors and to develop methods that are robust enough to be applicable to a wider range of sites to enable extension of the methodology to earlier data sets (e.g. Landsat MSS). Additionally, while Landsat has a 30 m reflective resolution, the pseudo-invariant site calibration approach is valid for all spatial resolutions. Depending on another instrument's field of view, the BRDF error reduction technique used by L5 TM could either be used on the same desert calibration site or on a subsection of the area. The results of this study indicated the ability to correct some of the residual errors in the calibration data from sun-target-sensor geometry effects.

While the desert site data from Landsat Path 181 Row 40 (181/40) has improved the TM calibration and provided a consistent baseline for future testing, there remain unaccounted errors in the calibration data. This project examined a bidirectional reflectance distribution function[BRDF] approach to describe the data trends as a means of reducing the residual relative calibration errors as a function of time.

The initial stage of this project was to establish a baseline error for the pseudo-invariant desert dataset. Then two general error reduction paths were examined. The first of these paths applied measurements from the MODIS platform to sample the calibration site BRDFs from multiple sun-target-sensor angles. These measurements were used to find the coefficients of various BRDFs to apply to the calibration data. The second path was to model the BRDF using DIRSIG.The results from the two methods were compared to each other as well as to an independent site to determine the best solution.

Overall, these results are approaching the goal value of 1% relative error. As the DIRSIG simulations are refined using improved DEMs and surface materials, it is hoped that the relative errors will dip below 1% for every band. While the results shown in this document do not completely preclude the use of MODIS data for the relative calibration, they indicate that DIRSIG modeling may be the optimal solution.

Project Status:
This is a completed effort that was conducted jointly with South Dakota State University who was respon-

Post-Atmosphere Compensation, Self Correct						
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Original Values	1.59%	1.22%	1.10%	1.54%		1.82%
TOY Corrected	1.34%	0.96%	0.87%	1.36%		1.17%
Sol Zen, Sol Az	1.30%	0.96%	0.87%	1.40%		1.30%
Sol Zen, Sol Az, TOY	1.37%	2.47%	1.33%	1.82%		1.39%
Cos Sol Zen	1.90%					
Sol Zen TOY	1.42%	0.99%	1.16%	1.62%		1.77%
Cos Sol Zen Cos Sol Az	10.02%	11.54%	5.68%	4.52%		3.68%
Cos Sol Zen Cos Sol Az TOY	9.63%	11.35%	5.64%	12.07%		5.09%

Post-Atmosphere Compensation, Correct with DIRSIG results						
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Original Values	1.59%	1.22%	1.10%	1.54%		1.82%
TOY Corrected	1.35%	1.11%	0.93%	1.49%		1.70%
Sol Zen, Sol Az	1.34%	1.07%	0.90%	1.45%		1.68%
Sol Zen, Sol Az, TOY	1.36%	1.07%	0.89%	1.43%		1.53%
Cos Sol Zen	1.55%					
Sol Zen TOY	1.59%	1.22%	1.11%	1.55%		1.82%
Cos Sol Zen Cos Sol Az	3.04%	2.49%	1.70%	0.68%		1.50%
Cos Sol Zen Cos Sol Az TOY	2.03%	1.74%	1.57%	1.60%		1.59%

Figure 3.1-8: Calibration improvements using DIRSIG simulation of desert site.

sible for the atmospheric correction component of the data. Future studies associated with this research will likely focus on improving atmospheric knowledge of the 181/40 site for use with the atmospheric compensation techniques and the DIRSIG simulated results.

3.2 LandSat Thermal Calibration

Sponsor: NASA & US Geological Survey

Principal Investigator(s): Dr. John Schott
Research Team: Cliff Anderson (CIS - Ph.D.), Jonathan Miller (CIS - MS), Nina Raqueño

Project Description:
With the increased interest in global climate change there has been resurgence in utilization Landsat thermal data. Landsat thermal data can be traced back 28 years to the launch of Landsat 4 in July of1982. However, no post-launch thermal calibration of Landsat 4 is known to exist. RIT has applied similar calibration techniques that were developed previously for Landsat 5 historic calibration. Landsat 4 had limited scenes over the United States and there were fewer buoys deployed in the 1980s, both of which make calibration scene selection difficult.

The results shown in Figure 3.2-9 are the first glimpses into the thermal performance of Landsat 4. Buoy data from 1982-1993 was processed and compared to Landsat 4 observed Temperature. The temperature bias from the early operational period of 1982-1984 averaged 0.05 K thus no correction is warranted. During the second operational phase, post 1987, the temperature bias averaged -3.31 K. This is a significant finding and a correction was recommended to NASA.

Project Status:

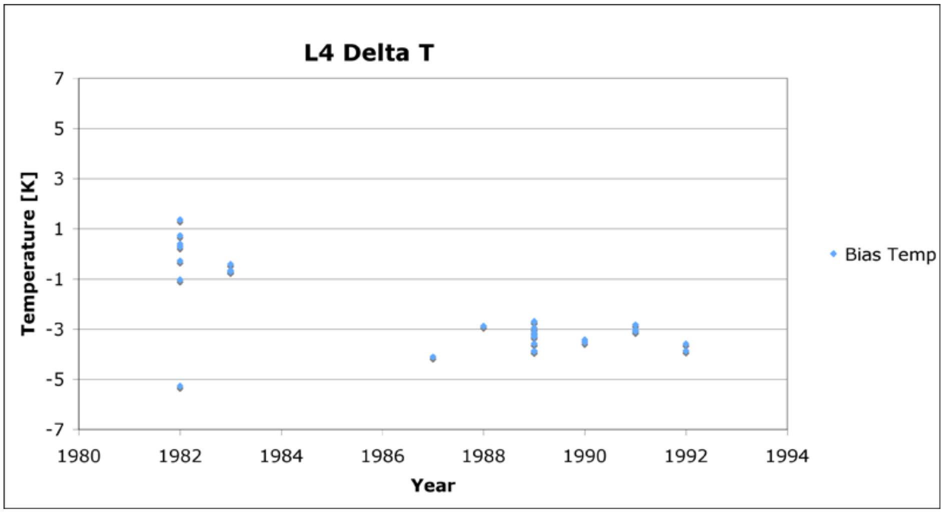


Figure 3.2-9: Calibration errors on Landsat 4.

RIT continues to monitor the thermal accuracy of both of the active Landsat instruments (5 & 7). The results generated from Lake Ontario ground truth and the buoy methodology are presented to NASAs Landsat Calibration Team twice annually. This project is funded for next year with a focus on further automation of the buoy calibration process.

3.3 LandSat Science Team

Sponsor: US Geological Survey

Principal Investigator(s): Dr. John Schott
Research Team: Dr. Aaron Gerace, Nima Pahlevan (CIS - Ph.D.)

Project Description:
The Operational Land Imager (OLI) is a new sensor being developed by the joint NASA-USGS Landsat Data Continuity Mission (LDCM). While Landsat instruments have traditionally been used for land-based studies, this five year effort evaluates LDCM's potential to be used for studying fresh and coastal waters. In the first phase of this research, we demonstrated that OLI exhibits the radiometric fidelity that is necessary to retrieve the concentrations of three important water quality parameters, i.e., chlorophyll, colored-dissolved organic matter (CDOM), and suspended materials. By modeling the improved sensor characteristics of OLI (Aerosol Blue band, 12-bit quantization, and improved signal-to-noise ratios), the constituent retrieval process was performed on simulated data and its retrieval capability compared to that of existing sensors. The ETM+ instrument onboard Landsat 7 was included in this study as it reflects the current Landsat technology while the AVIRIS imaging spectrometer was included to indicate the state-of-the-art technology. Each sensors ability to retrieve water constituents in the absence of atmospheric effects is shown in Figure 3.3-10 (errors of less than 15% are considered an acceptable goal). These results, which are first shown for a noise free scenario, next with quantization noise included, and finally with instrument and quantization noise included, indicate that LDCM's OLI instrument exhibits the potential to be a useful tool for water resource studies.

In order to realize the potential demonstrated in the first phase of this research, one must be able to ef-

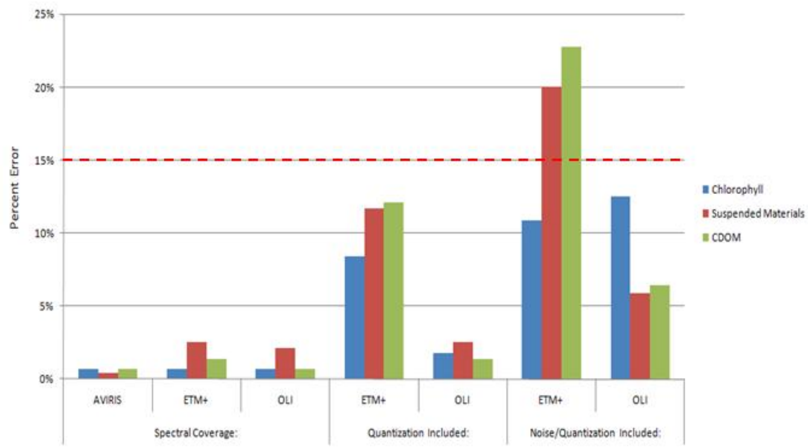


Figure 3.3-10: Average constituent retrieval errors.

fectively invert satellite observed radiances to surface reflectances through a process called atmospheric compensation. Since OLI is not equipped with the bands required by traditional water-based compensation algorithms, phase two of this research focused on developing techniques to compensate its data for atmospheric effects over water. Two techniques were developed that specifically incorporated the bands of the OLI instrument. The first method is a computationally efficient algorithm that removes the atmosphere globally while the second is an iterative method that removes the atmosphere on a pixel-by-pixel basis. To test the algorithms developed in this phase of the research, atmospheric effects for a typical mid-latitude summer scene were simulated using the Moderate Resolution Transmittance Code (MODTRAN) and incorporated into the simulated dataset used in phase one. The constituent retrieval process was again performed using the OLI sensor, the results of which are shown in Figure 3.3-11.

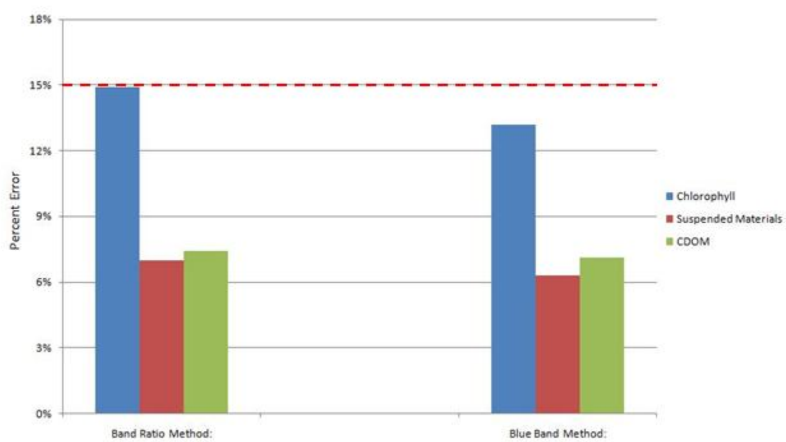


Figure 3.3-11: Average constituent retrieval errors when the OLI sensor is used in conjunction with the proposed atmospheric compensation techniques.

These results indicate that constituent retrieval errors introduced by the OLI sensor and atmospheric effects are within our goal of 15%. This is exciting for the Landsat program as this phase of the study demonstrates that the OLI sensor has the radiometric fidelity necessary for water-based studies.

Project Status:
In the final phase of this research, we are evaluating the potential to use OLI data as a tool to calibrate a hydrodynamic model of the Genesee River plume. Specifically, we are proposing that Landsat thermal data can be used to calibrate the surface temperature output of the hydrodynamic model while Landsat's reflective data can be used to calibrate the sedimentation output. Ultimately, we wish to develop an accurate three-dimensional representation of a river plume from Landsat imagery. Preliminary efforts have been made and indicate that Landsat thermal data can, in fact, be used to calibrate the hydrodynamic model's surface temperature output. The Genesee River plume was modeled for July 13, 2009 and Landsat 5 thermal data used for calibration. The results of this initial effort are shown in Figure 3.3-12.

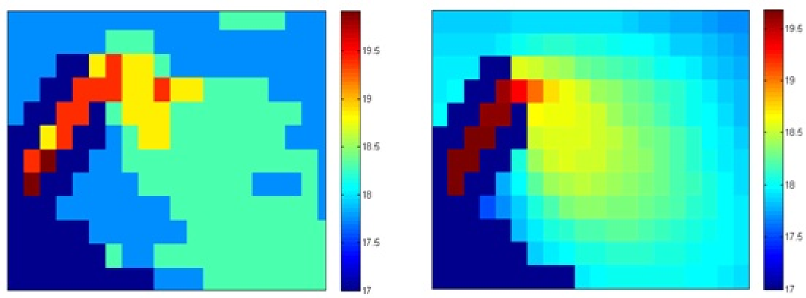


Figure 3.3-12: (Left) Landsat 5 data that was used to calibrate the hydrodynamic model. (Right) Resulting calibrated hydrodynamic simulation.

3.4 LDCM System Modeling with DIRSIG

Sponsor: NASA - Goddard

Principal Investigator(s): Dr. John Schott
Research Team: Dr. Aaron Gerace, Dr. Rolando Raqueño, Nina Raqueño, Dr. Adam Goodenough

Project Description:
This project provides support to the Landsat Data Continuity Mission (LDCM) with an emphasis on radiometric and image quality issues associated with the two new sensors to be flown on LDCM. In particular, the initial work in year one has focused on modeling the geometric properties of the Orbital Land Imager (OLI) and the Thermal Infrared Remote Sensor (TIRS) using DIRSIG and performing initial assessment of a split window approach to temperature estimation using TIRS.

Project Status:
A number of upgrades to DIRSIG were made to support simulation of the LDCM sensors. these included:
• Support in DIRSIG for orbital motion compatable with the NORAD two line element (TLE) orbital descriptors. (See Figure 3.4-13.)

• Demonstration of a capability to create DIRSIG scenes incorporating the GEOID of the earth and digital elevation models (DEMs). (see Figure 3.4-14.)

• Generation of initial OLI and TIRS sensor models incorporating a detector element pointing geometry.

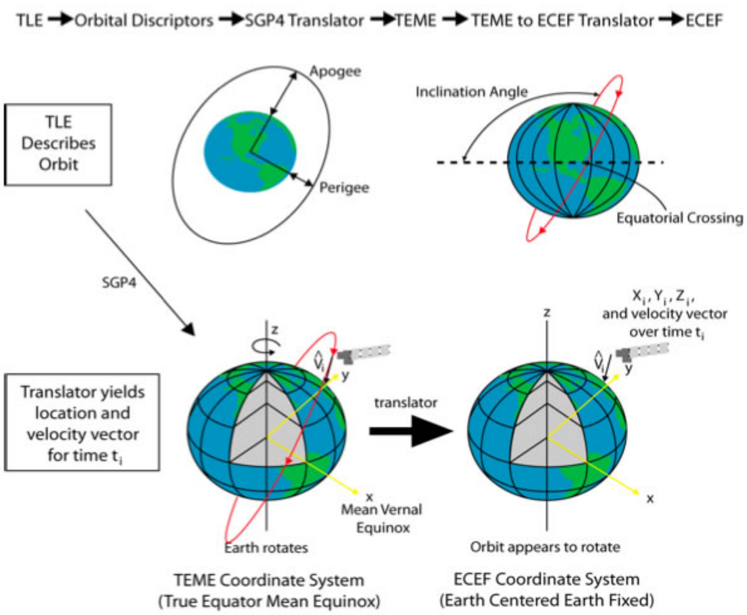


Figure 3.4-13: Illustration of the steps to go from a NORAD TLE orbital descriptor through a TEME coordinate system to an ECEF coordinate system that is needed for DIRSIG's East-North-Up (ENU) native coordinate system.

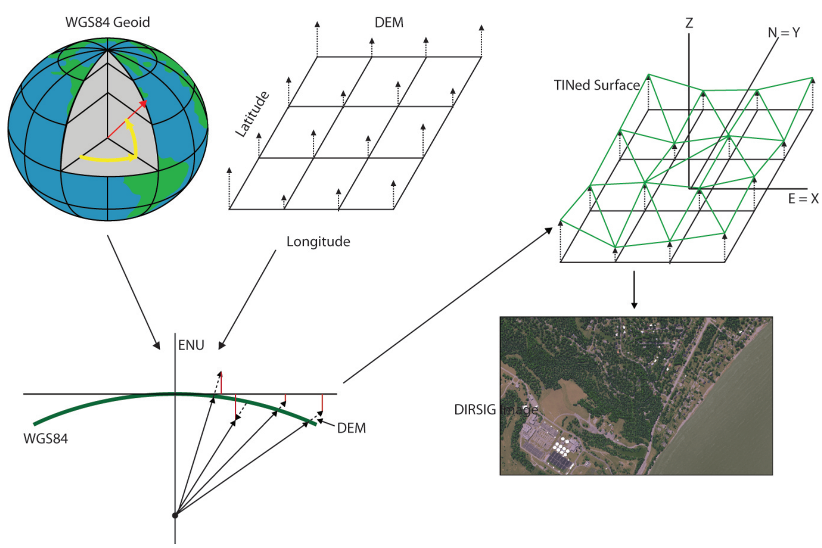


Figure 3.4-14: Illustration showing projection of DEM onto the WGS 84 Geoid which is then facitized for access by DIRSIG.

• Generation of synthetic scene with spatial and radiometric features suitable for testing the LDCM geometric capabilities. (see Figure 3.4-15.)

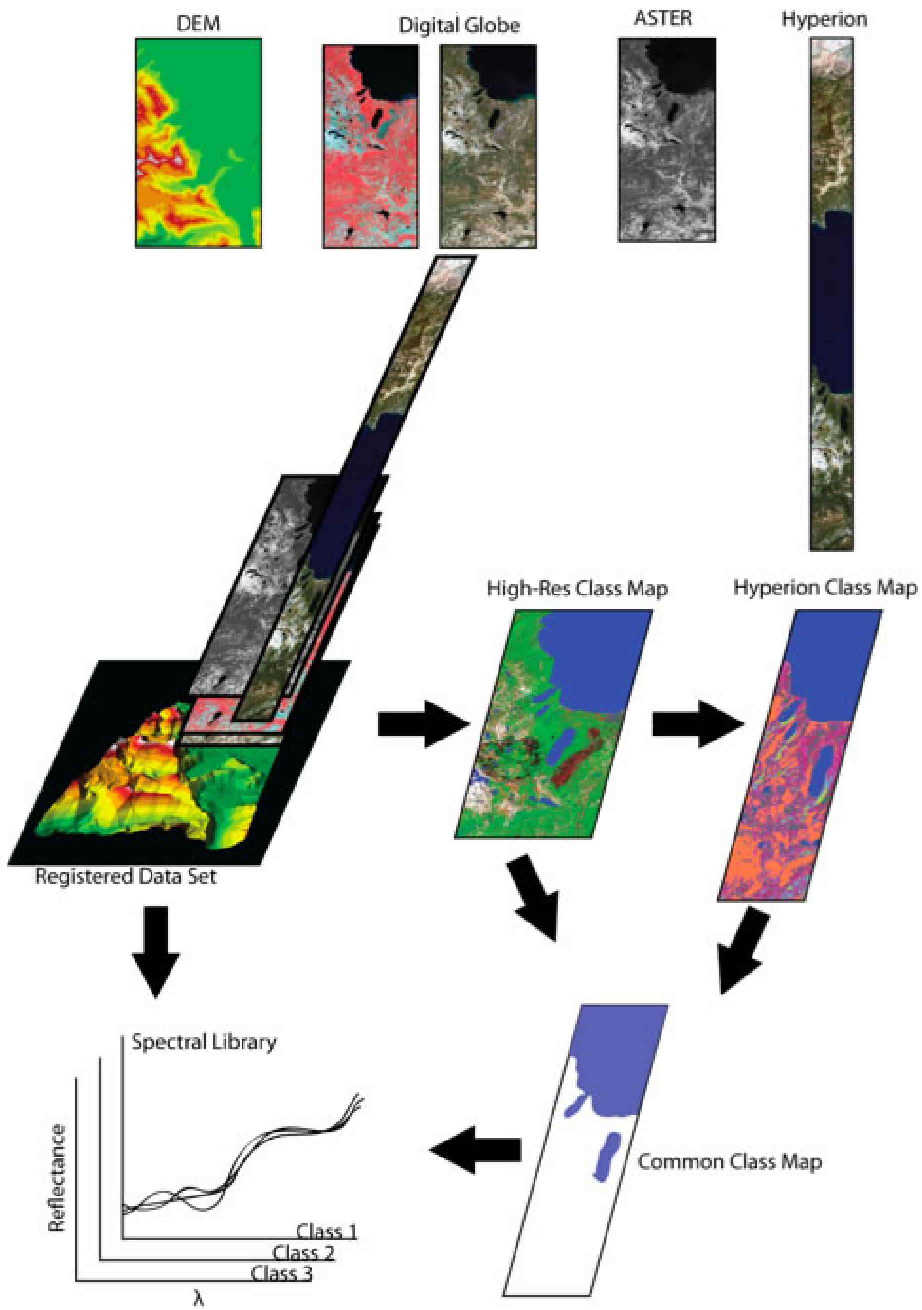


Figure 3.4-15: Components used to form the first Landsat scene in DIRSIG of southwest Lake Tahoe.

As a result of these upgrades, initial DIRSIG scenes simulating the OLI sensor were generated (see Figure 3.4-16).

Ongoing work is focused on generation of the initial TIRS scenes and enhancements to the scene and sensor models to simulate a number of the geometric and radiometric characteristics of the instruments. Initial testing of a TIRS specific split window algorithm indicates it should produce water surface temperature with

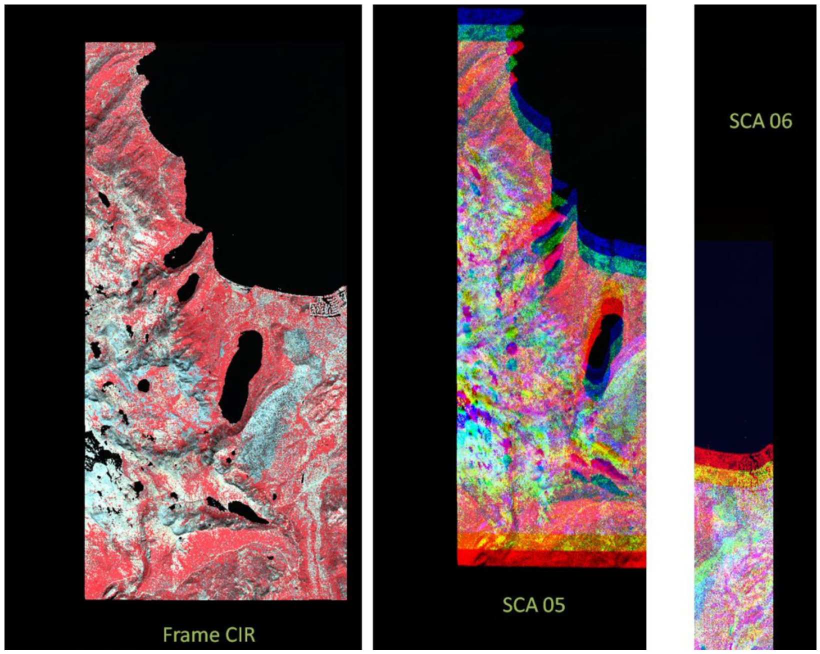


Figure 3.4-16: First DIRSIG images with a Landsat OLI sensor of the Lake Tahoe scene. Left is a false color infrared aquired with a frame camera. Right shows the same bands acquired using two focal plane arrays of the OLI sensor. The within chip and between chip offsets are due to the detector offsets on the pushbroom focal plane.

errors comparable to or smaller than currently achieved using radiative transfer models and radiosondes. This means that direct satellite measurements will achieve results equal to or better than those that currently require the time and effort of highly trained calibration scientists. Ongoing work is investigating how well these approaches can be extended to other targets (*e.g.,* soil and vegetation).

3.5 Ice Characterization Using Remote Sensing Techniques

Sponsor: United States Department of Energy - Savannah River National Laboratory

Principal Investigator(s): Dr. Carl Salvaggio
Research Team: May Casterline (CIS - Ph.D.), Jason Faulring, Dr. Brent Bartlett, Philip Salvaggio (CIS - BS)

Project Description:
The ALGE code is a hydrodynamic model developed by Savannah River National Laboratory (SRNL) to predict the 3D thermal plume injected into a cooling pong from an electric generation facility. The model's predictions are validated by observing the associated cooling pond with an aerial thermal imaging platform. Over the past two years work has been completed to extend the capabilities of the model to incorporate snow and ice as possible phenomena in the modeled environment. In order to validate the extension of the model, intensive collection of ground-based data as well as high-resolution aerial infrared imagery were collected during the winters of 2008-2009 and 2009-2010, for a combined eight months of data collection. Due to the harsh and extreme environmental conditions automatic data collection instruments were designed and deployed. A thorough and robust two-fold calibration technique was implemented within the aerial imaging chain to assess the accuracy of the retrieved surface temperatures. By design, the calibration method employed in this application uses ground collected, geo-located water surface temperatures and in-flight blackbody imagery to produce accurate temperature maps of the pond in interest. A sensitivity analysis was implemented within the data reduction technique to produce accurate sensor reaching temperature values using designed equipment and methods for temperature retrieval at the water's surface.

The process implemented to transform raw data collected by the RIT WASP sensor into calibrated thermal imagery products for the Midland, MI dataset used the on-board blackbodies. A blackbody is a material which absorbs and re-emits energy at all wavelengths with perfect efficiency. The blackbodies installed in the WASP system are near perfect blackbodies for the wavelength ranges which the thermal sensors are sensitive. The on-board blackbody calibrators provide the necessary data to execute a flight line based calibration routine as well as removal of dead pixel artifacts. For most aerial collections blackbody imagery is collected at the beginning and end of each flight line. Each reference source is driven to either a hot or cold set point and moved to fill the field of view for both sensors simultaneously. The hot and cold set points are chosen to adequately bracket the scene's thermal content of interest. After the first reference source imagery collection (at either a hot or cold set point), the blackbodies are driven to the opposite end of the thermal range during the imagery acquisition over the scene, and then re-introduced into the field of view while the aircraft is making a turn. Figure 3.5-17 is a conceptual example for how this type of imagery collection scheme is implemented.

In order to compensate for atmospheric effects and correlate to apparent ground temperature, geo-referenced ground truth measurements of the target (water surface) were collected. Using the map coordinates associated with each measurement, the corresponding calculated radiance value was extracted from the georeferenced, sensor-reaching radiance mosaic. Calibrated, ground-collected, skin temperature measurements were then compared to the geographically tagged sensor-reaching radiance values. All radiance values are corrected for the water target emissivity ($\epsilon = 0.987$). Based on the aforementioned linear relationship assumption, a linear model was fit to the radiance-temperature data pairs, producing a gain (m_g) and bias (b_g) that is used convert from sensor-reaching apparent radiance to the ground temperature of water at a given location. The relationship between the radiance temperature pairs is depicted below in Figure 3.5-18. It is important to note that all derived ground temperatures are only valid for water.

Two sets of data that were calibrated using the aforementioned process is explained below. Each data set was processed to generate both temperature maps (Figure 3.5-19) and error maps. Derived temperatures are only valid for water and each pixel's error is designated by the corresponding per-pixel error map. Shown in Table 3.5 are the mean-calculated variances for a section of approximately uniform water temperature as

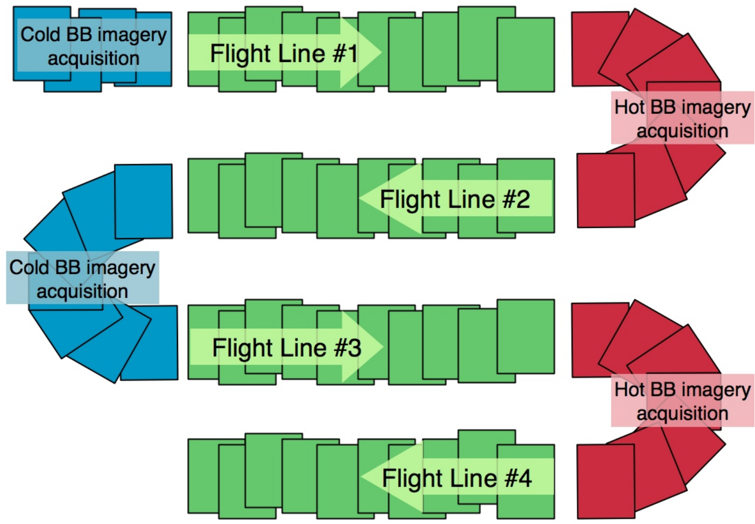


Figure 3.5-17: Flight line collection scheme for blackbody imagery collection during flight.

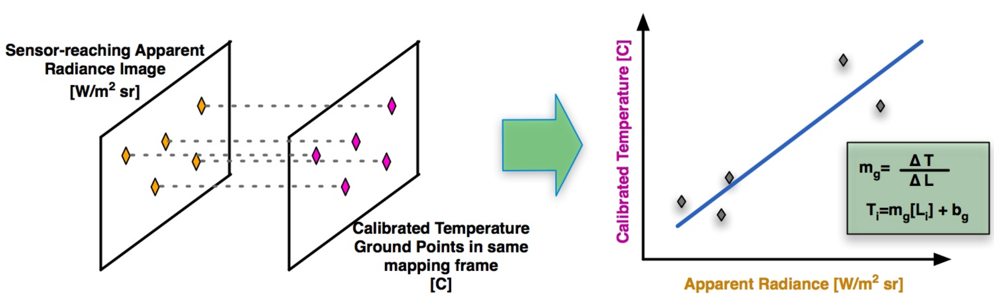


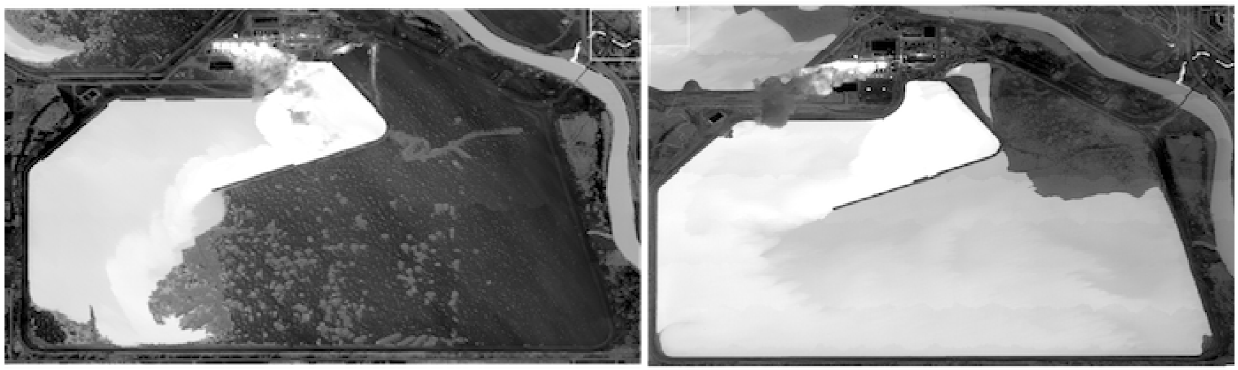
Figure 3.5-18: Apparent sensor-reaching radiance to temperature conversion. White denotes hot temperatures, while black denotes cold temperatures.

well as the amount of variation about that calculated mean.

Project Status:

Remote broadband thermal mapping approaches, such as the one described above, offer unique data collection capabilities for this particular environment in that they provide instantaneous spatial coverage of extended areas and capture the varying thermal structure of the scene. However, the sensitivity of a broadband thermal sensor is limited to extracting thermal radiance properties of only the scene's surface and sheds no light on the three-dimensional physical structure below. Given some preliminary knowledge of the physical parameters bounding the observed scene, the ALGE model can calculate the energy fluxes at the observed surface and provide estimations for physical parameters such as water column temperature profiles and ice thickness. The continuation of this work aims to thermally calibrate an entire water scene in the presence of open water, ice and snow using an aerially-validated, physics-based, hydrodynamic model that has been paired with a genetically-based optimization routine. In addition, through the marriage of the optimization technique and hydrodynamic model, physical parameters such as ice thickness, snow thickness, and surface emissivity will also result.

The overall proposed approach uses a genetically-inspired optimization algorithm, particle swarm opti-



(a) Calibrated temperature map for 11 February 2010 collect (b) Calibrated temperature map for 4 March 2010 collect

Figure 3.5-19: Temperature maps. NOTE: There is a scale difference between both images

Table 3.5-1: Statistics from uniform area of generated error maps

Date	Mean $\sigma^2_{T_{cal}}$	Standard deviation in $\sigma^2_{T_{cal}}$
11 February 2010	0.888863	0.015314
4 March 2010	0.248810	0.007750

mization (PSO), to drive the selection of inputs into a three-dimensional hydrodynamic code, By definition, the inputs into ALGE include physical parameters which describe the three-dimensional hydrodynamic and thermodynamic states of a body of water, including an ice thickness distribution and a snow thickness distribution, as well as the meteorological conditions at a given time. The outputs from the ALGE model include a surface temperature distribution and a velocity flow map of the given body of water. The PSO algorithm will push the ALGE model inputs to generate a temperature map which matches a thermally calibrated aerial image of the same pond within a defined boundary of error.

3.6 Accurate Radiometric Temperature Measurements Using Thermal Infrared Imagery of Small Targets, Physics-Based Modeling, and Companion High-Resolution Optical Image Data Sets

Sponsor: Department of Energy

Principal Investigator(s): Dr. Carl Salvaggio
Research Team: David Nilosek (CIS - Ph.D.), Sarah Paul (CIS - Ph.D.), Scott Brown, Dr. Adam Goodenough

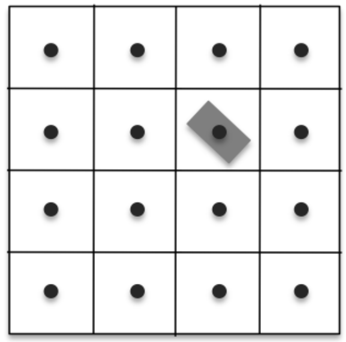
Project Description:
The goal of this project is to develop a methodology to accurately retrieve the temperature of an object that is smaller than a pixel of a thermal infrared (TIR) image using physics-based modeling. The methodology can be broken into two distinct parts. In the first part, the Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool will be used to replicate a collected TIR image based on parameter estimates from the collected image. This will be done thousands of times to build a lookup table (LUT). For the second

part, a regression model will be built from the data in the LUT and will be used to perform the temperature retrieval. We assume that the TIR image in question has been atmospherically corrected and that the sensor that captured the image has been well characterized so that sensor properties (e.g. PSF, spectral response) can be modeled in DIRSIG. We also assume that high resolution visible imagery of the target of interest is available. The high resolution imagery will be used to extract a three-dimensional model that will be imported into DIRSIG.

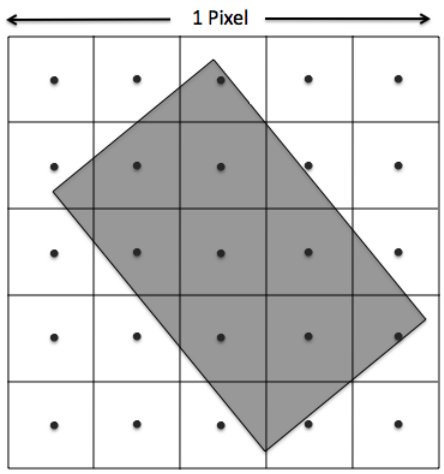
Five parameters have been identified as having an appreciable effect on the radiance coming from a pixel and are used as inputs to DIRSIG. They are: target temperature, background temperature, target emissivity, background emissivity, and target size. The location of the target within the pixel is also an important factor in the radiance from a pixel and will be taken into account by way of making the LUT and therefore the regression model dependent on the target location. In other words a regression model will be derived for one specific target location. The target location information is derived from the high resolution visible imagery. Thermal or visible imagery of the scene is exploited to determine upper and lower limits on the look up table for the remaining five parameters. Once these limits are found, the LUT is populated using a uniform distribution of values within the limits. Each point in this LUT space represents one complete DIRSIG simulation. The DIRSIG simulations were run in parallel on the Research Computing cluster at RIT. Once the simulations are complete the radiance value for the pixel containing the target of interest is pulled from each image and recorded in the LUT.

Once the lookup table is created a polynomial regression model with interaction terms is computed vialeast squares. In the regression model the target temperature is the dependent variable and the background temperature, target and background emissivities, target size, and pixel radiance are regressors. This method has been tested with synthetic data that do not include sensor effects or an atmosphere. The geometry used is a graybody cube on a flat plate that is also a graybody. The simulations are run for a single-band sensor at 8.5 μm with a ground sample distance of 1 meter. Errors in absolute temperature using a LUT with 25,000 points are between $\pm 3°$C. The largest errors occur where one or more of the LUT parameter values are near a maximum or minimum value for that particular parameter. The next step with this methodology will be to test it on real data. A set of thermal imagery has already been collected for this next phase.

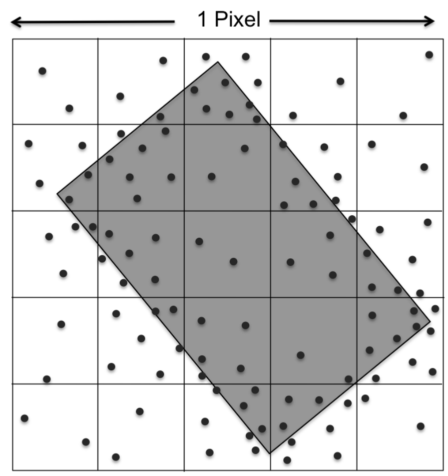
Another item of significance for the sub-pixel temperature retrieval problem has been an improvement in the way DIRSIG treats mixed pixels. Typically in DIRSIG one sampling ray is cast from the center of each detector element and calculates the radiometry for the entire pixel based upon the material the ray intersected with. This single ray sampling method will return the correct answer for a material that completely fills a pixel. Prior to the start of this project a sampling method that accounted for mixed pixels was already implemented in DIRSIG. This method uses a grid sampling approach where each pixel in the focal plane is divided into sub-elements and a sampling ray is cast from the center of each sub-element. The sampling rays from one pixel are averaged together to produce the pixel's radiance value. The sub-samples in grid sampling are spread evenly over the pixel and therefore spatially sample everything equally. An improvement to this method would be to send more samples to the important areas of a scene (e.g. areas where the point spread function is large, material boundaries) as opposed to areas of less importance (e.g. areas where the point spread function value is small, large, uniform areas). Adaptive sampling, while not new to the computer graphics community, is a new sampling scheme in DIRSIG that seeks to only send sub-pixel samples to areas of importance and is being used extensively in this research. In this method each pixel is divided into sub-elements and a sampling ray is cast from a random location within the pixel. Adaptive sampling looks for variation within and between sub-elements and sends more sampling rays where it finds variation. Sampling based on importance reduces the amount of computation time needed to arrive at a radiometrically accurate answer which is crucial when thousands of DIRSIG simulations are being produced. A schematic of the three sampling methods is shown in Figure 3.6-20.



(a) Single ray sampling of 4x4 pixels.



(b) Grid sampling of one pixel



(c) Adaptive sampling of 2 pixel

Figure 3.6-20: DIRSIG sampling schemes.

A critical requirement for the first portion of this project to be successful is the definition of the geometry of the target of interest. With recent advances in the field of computer vision, automatic and semi-automatic methods of reconstructing three dimensional point clouds of objects using multi-view images have grown. Many of these algorithms are focused on using a large database of images collected from many people to reconstruct structures that many people visit, this is often called 'phototourism' . There are many applications of the processes involved in phototourism that have been yet to be explored. One such topic is the application of these three dimensional model extraction tools on remotely sensed imagery.

The focus of this research is to apply these computer vision three dimensional reconstruction algorithms to remotely sensed imagery in order to extract a three dimensional model that can be attributed and imported into the DIRSIG physical simulation environment. This involves merging concepts from both the computer vision community and the photogrammetry community to produce an accurate three dimensional model of a target object in the scene. A workflow has been established that uses nadir imagery taken from the WASP sensor to extract structure from a scene.

This workflow is broken up into five separate parts; feature detection, correspondence,& camera pose estimation , initial 3d reconstruction/optimization, georectification, dense 3d model extraction, facetization and exporting. The first part follows the phototourism's structure from motion workflow. The feature detection and correspondence between images is handled by the scale invariant feature transform (SIFT) algorithm. Once the image to image correspondences are found the camera pose (epipolar geometry) can be derived. The second step is to estimate the initial 3d point for any given correspondence between two images. This step takes advantage of the accurate camera positioning data taken with every image and uses that information along with the correspondence to do simple photogrammetry to extract the 3d point. Once the 3d points are found an optimization using the sparse bundle adjustment algorithm is used to minimize the reprojection error between the 3d points and the camera positions. An absolute coordinate has to be applied to the point clouds and the third step does that with the georectification. The collinarity equations are used to repoject the optimized 3d points onto a georeferenced image and assign each pixel a UTM coordinate based on where it repojects in the georeferenced image.

The fourth step dips back into the computer vision community by taking advantage of epipolar geometry constraints a dense correspondence and consequently a dense reconstruction can be extracted from the image. This process requires input from the first three steps in order to be completed. The fifth step in this workflow takes the dense 3d point cloud reconstruction of an object and facetizes it so it becomes a solid three dimensional model. This is done using a modified delaunay triangulation method. Finally this process exports this model as an OBJ/ODB file for input into DIRSIG. Currently all facets on the object can only be assigned a single spectra, however future work will attempt to use classification methods to assign appropriate spectra to difference facets on the model. This entire process is illustrated in Figure 3.6-21.

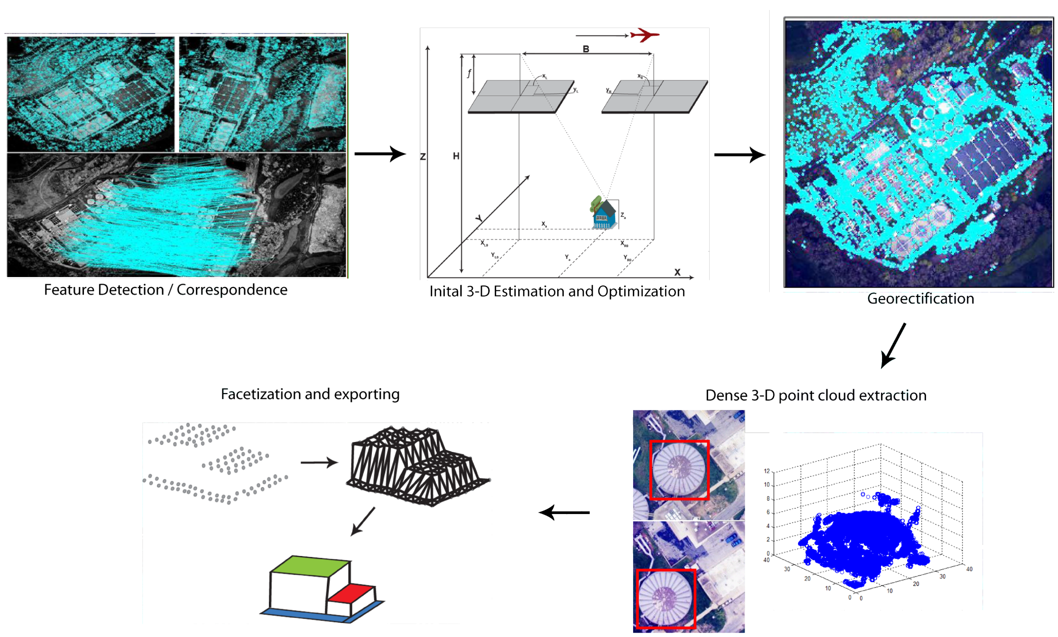


Figure 3.6-21: Dense point cloud extraction workflow

<u>Project Status:</u>
The future of this research will involve formalizing this workflow into a set of MATLAB tools than others can use. Also the advantages of higher frame rate capture and oblique capture will be incorporated into this workflow. Ultimately the goal is to develop a partially user assisted environment that can be used to quickly and easily reconstruct targets in a scene and assign the target a spectra for export into DIRSIG.

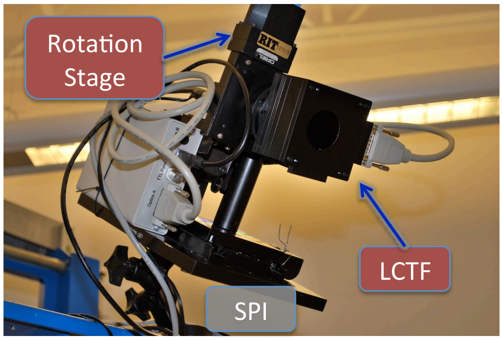
3.7 Image-Based Determination of Polarized Bidirectional Reflectance Distribution Function For In-Field Characterization of Materials

Sponsor: IC Postdoctoral Fellowship

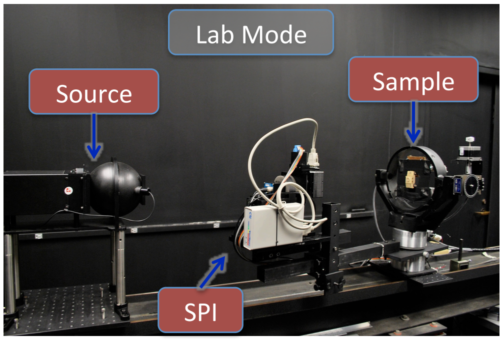
Principal Investigator(s): Dr. Carl Salvaggio
Research Team: Dr. Micheal Gartley, Dr. Brent Bartlett

Project Description:
For sensing systems that characterize the spectro-polarimetric radiance reaching the camera, the origin of the sensed phenomenology is a complex mixture of sources. While some of these sources do not contribute to the polarimetric signature, many do such as the polarization state of the downwelled sky radiance, the target and background p-BRDF (polarimetric bidirectional reflectance distribution function), the polarization state of the upwelled path radiance, and the sensor Mueller matrix transfer function. A need exists to develop a technique that retrieves the unique polarimetric signature of in-scene materials. This technique should account for the various sources of additional polarimetric signal which serve to mask the object signature. A spectro-polarimetric system is proposed to provide real airborne data to test a new retrieval technique for glossy painted surfaces.

Project Status:
A novel technique for retrieving the polarized specular portion of the p-BRDF for an object in an outdoor scene has been demonstrated using a ground based spetro-polarimetric imager (SPI). This measurement system has been developed using commercial off the shelf components and collects spectral Stokes image cubes. These cubes have a 7nm bandpass ranging from 400-720nm and uses a division of time approach to generate polarimetric contrast with an automated rotation stage. The system is controlled via USB and can be configured to operate in the field on a tripod or in the lab on a goniophotometer, which is shown in detail in Figure 3.7-22. The data collected by this equipment has been used to show that utilizing just the unpolarized diffuse spectral reflectance may not be sufficient to track an individual object as it moves spatially throughout different background types. The specular polarized reflectance component can be used to provide enough information to uniquely identify an object which is surrounded by certain background types by using a tracking vector concept (Figure 3.7-23(a)). Given the initial success with a rooftop collection, the next steps for developing an airborne spectro-polarimetric imager are being taken. This imaging system will be based off of the multi-spectral WASP-Lite platform (Figure 3.7-23(b)) and will provide four spectral bands of Stokes imagery. This data will be used to test the retrieval sensitivity relative to the target variability present in a typical scene.



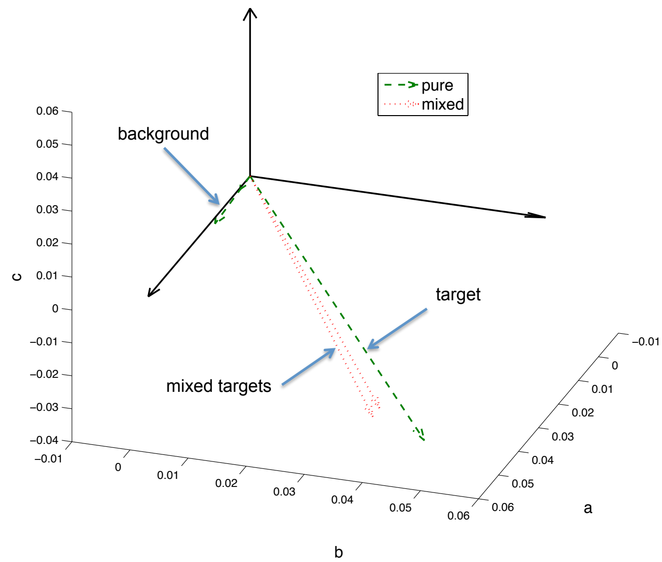
(a) Close up of SPI.



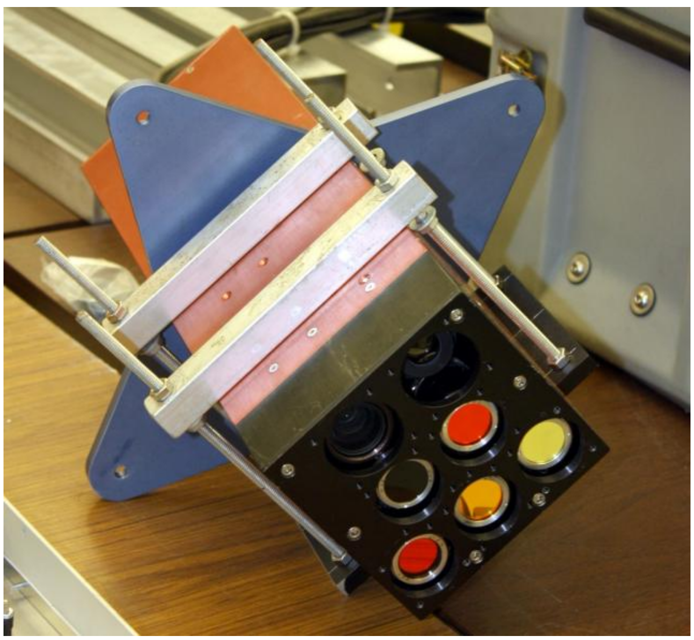
(b) SPI configured for use with goniophotometer to make p-BRDF measurements.

(c) SPI configured for field use with a tripod configuration.

Figure 3.7-22: Equipment developed to measure spectral Stokes image cubes.



(a)



(b)

Figure 3.7-23: (a) Tracking vectors for two background materials and two target mixtures. (b) Image of the WASP Lite imaging platform.

3.8 Script-to-Scene DIRSIG Geometry Creation

Sponsor: US Department of Energy / Office of Nonproliferation and Verification Research & Development / NA22

Principal Investigator(s): Dr. Carl Salvaggio
Research Team: Scott Brown, Caitlan Hart, Erin Ontiveros, Dr. Rolando Raqueño, Michael Richardson, Niek Sanders, Andrew Scott (CS - MS), Philip Youkhana (CS - MS)

Project Description:
The objective of the DIRSIG script to scene geometry description project is to define a language (in plain text) that can describe a scene to be simulated. The goal is for the user to be able to describe and visualize a scene prior to running a DIRSIG simulation as well as to easily permute the scene geometrically for algorithm testing and validation efforts. We are trying to simplify and minimize the user's input in the process of constructing a scene. The goal is to provide the user with feedback on his/her script-based description of a scene.

Project Status:
We are using the rendering program Blender (which is free, open-source, and extensible) to develop a tool to solve this problem. One of the obstacles in having a potential user use Blender to construct a scene is how daunting its user interface can be. Thus, one of our primary goals in this project is to develop our own user-friendly interface/functionalities that enables a zero-knowledge user to use the Blender environment to construct a scene. Currently, our implementation features a 3-panel Blender window (Figure 3.8-26) which consists of a rendering pane for the scene visualization, a text pane for the textual scene description, and a controlling GUI pane.

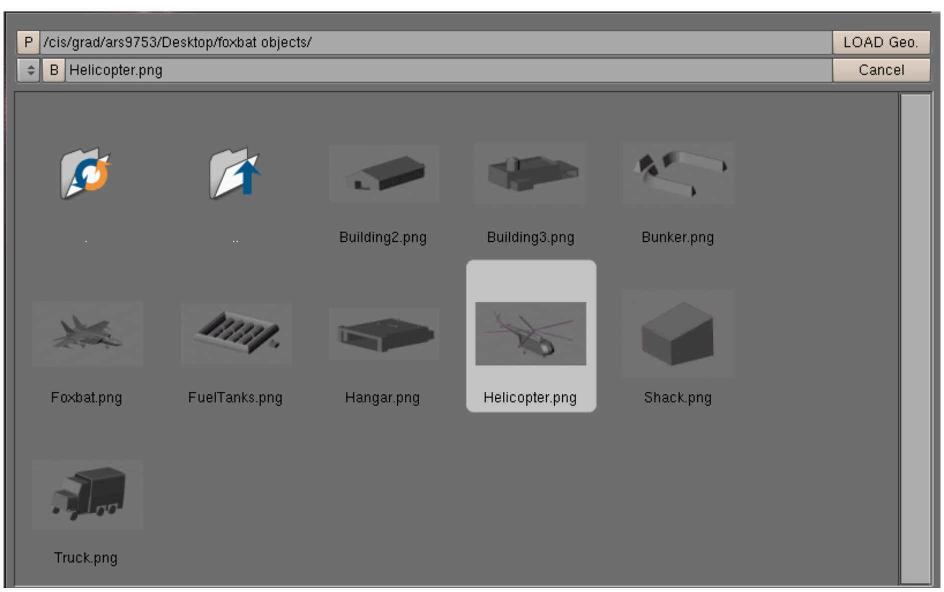


Figure 3.8-24: DIRSIG geometric database/object browsing interface.

The user will be able to write/modify a plain text script in the text pane and see it rendered in the rendering pane. The script itself is intended to be a natural English-language description of the scene, but will still have to conform to a grammar because we do not have support for artificial intelligence in Blender. The grammar shall be easy for a user to use and learn. The GUI interface will also feature intuitive click-based construction of a clause (a line of the script) to guide the user in using the correct grammar. We envision that a first-time user will use our GUI to construct clauses that conform to the grammar of the language until he/she feels comfortable enough to write clauses directly into the script. We also have a more technical-style script (similar to dot-notation) language which the user can work with if they feel so inclined. The advantage of that is the fact that there can be a 2-way mapping between that style of script and the user's current scene without loss of precise positional information.

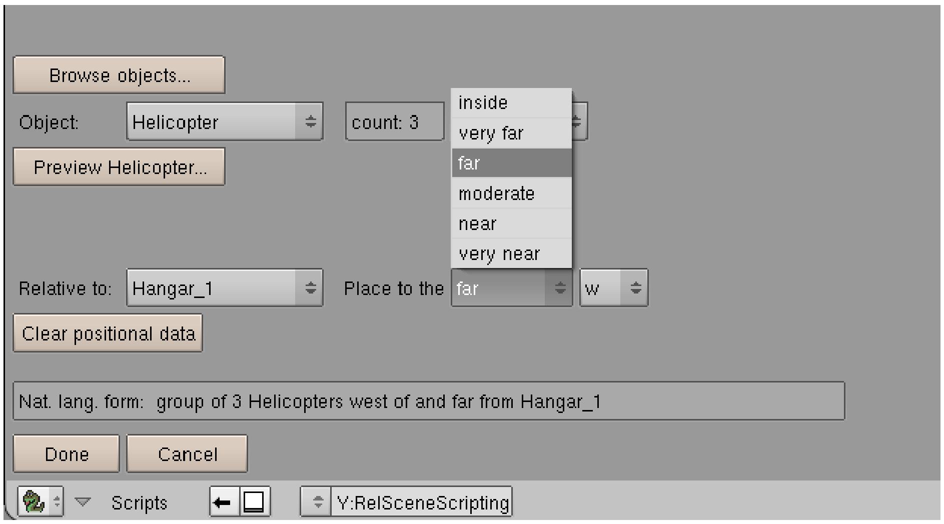


Figure 3.8-25: Object selection and script grammar construction interface.

Examples of languages:

```
NATURAL LANGUAGE
Airport {
group of 2 Hangars facing north
Plane inside 1st Hangar, facing north
FuelTanks in the near eastern region
Building southwest of FuelTanks
F-16 far above Building, facing northwest
}
```

```
DOT NOTATION STYLE
Airport {
Hangar_1 [LocXYZ="0,0,0"][RotXYZ="0,0,90"]
Hangar_2 [LocXYZ="0,35,0"][RotXYZ="0,0,90"]
Plane_1[LocXYZ="0,0,0"][RotXYZ="0,0,90"]
FuelTanks_1 [LocXYZ = "50,0,0"][RotXYZ="0,0,0"]
Building_1 [LocXYZ="10,-40,0"][RotXYZ="0,0,0"]
F-16_1 [LocXYZ='10,-40,100"][RotXYZ="0,0,135"]
}
```

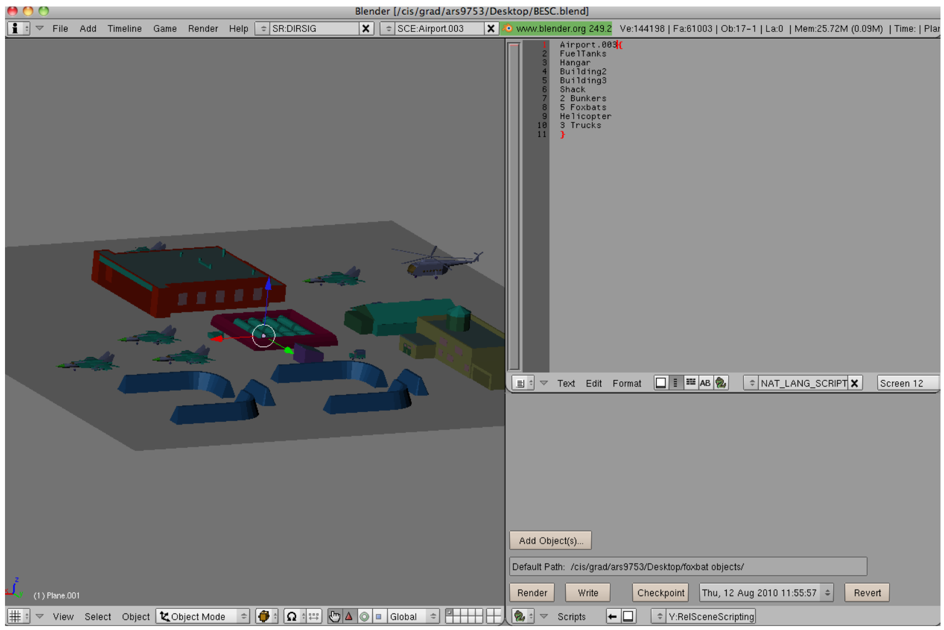


Figure 3.8-26: Preliminary 3-panel Blender-based script-to-scene interface using simple language construct for scene definition - objects placed at"best guess" location.

3.9 Lake Kivu Workshop

Sponsor: NSF

Principal Investigator(s): Dr. Tony Vodacek
Research Team: Alvin Spivey (CIS - Ph.D.)

Project Description:
Lake Kivu, located on the border of Rwanda and the Democratic Republic of Congo is one of the world's most unique lakes, and at the same time, potentially one of the most dangerous. The uniqueness and the danger of Lake Kivu arise from the carbon dioxide (CO2) and methane (CH4) gases dissolved in the deep waters of the lake. The unusual density stratification that traps the gases exists because warm, but CO2-rich, saline springs enter the lake at depth. The salt and CO2 content increases the density of the water enough that this water cannot easily mix vertically with the surface waters even though they are warmer than the surface waters, thus trapping the gas in the deep waters. These springs gain their salt and CO2 content by interacting with the widespread volcanic rocks and soils, and from CO2 degassing from the magma feeding the active Nyamulagira and Nyiragongo volcanoes adjacent to the lake. The CH4 is produced by microbes feeding on the CO2 and volcanogenic hydrogen and by microbes feeding on organic matter. The CH4 content is accessible and extraction projects are underway. The risk of a limnic eruption (or violent overturn and degassing) in the Lake Kivu system, such as has happened at Lakes Monoun and Nyos in Cameroon is high; one or a combination of several possible naturally occurring scenarios would be sufficiently energetic to overcome the density effect and raise the gas-rich water toward the surface. Possible natural scenarios include: 1) upward displacement of deep water due to a landslide into or from seismically faults beneath the lake, 2) variation in temperature or flows of the deep springs linked with changes in magmatic activity, or 3) an underwater volcanic eruption. The paleolimnologic record of Lake Kivu and genetic analysis of the

fish (extinctions) indicate that the lake has overturned due to natural causes with significant vertical mixing at least five times in the last 5,500 years, but observations are too localized to deduce the trigger(s) of those events. The Kivu rift is itself a dynamic tectonic setting, yet the locations and recurrence intervals of active faults, and volcano feeding systems remain poorly understood, preventing risk assessment and zonation. Without an understanding of the processes that led to significant and violent overturns of the past 5,500 years, it is difficult to assess the risk of a future limnic eruption.

Figure 3.9-27: Gas disturbance on Lake Kivu, Rwanda.

Project Status:
To address the unknowns related to limnic eruptions in Lake Kivu, Dr. Tony Vodacek, along with Dr. Cindy Ebinger at the University of Rochester, and Dr. Bob Hecky at the University of Minnesota-Duluth convened a workshop, funded by the National Science Foundation Office of International Science and Engineering, to assess the state of knowledge concerning the Lake Kivu System and to set priorities for future work. The multi-disciplinary group of 57 scientists and engineers assembled for the workshop identified large gaps in our knowledge of this complex system, highlighting the critical and urgent need for more data to guide large-scale extraction enterprises, to understand the natural hazard and to build a sustainable mitigation program. Workshop attendees summarized the state of scientific knowledge in the Lake Kivu system and drafted a consensus set of questions and activities for collaborative and multi-disciplinary research programs that would address the research priorities in the context of regional capacity building and development. The workshop recommendation are listed in detail in a white paper and a summary paper available online at http://dirs.cis.rit.edu/node/270

3.10 Information Products Laboratory for Emergency Response

Sponsor: NSF - Partnerships for Innovation Program

Principal Investigator(s): Dr. Jan van Aardt, Dr. Tony Vodacek
Research Team: Dr. Jan van Aardt, Dr. Anthony Vodacek, Don McKeown, Dr. Don Boyd, Abhijit Pillai (CS - MS), Sobha Duvvuri (CS - MS), Chris Scheiner (Env. Sci. - MS), Bin Chen (CIS - Ph.D.), Alvin Spivey (CIS - Ph.D.), Rick Labiak (CIS - MS), Paul Romanczyk (CIS - Ph.D.)

Project Description:
This Partnerships for Innovation (PFI) project - a partnership between the Rochester Institute of Technology

Figure 3.9-28: Participants in the Lake Kivu Workshop, Rwanda.

(RIT) and the University at Buffalo (UB) - is focused on innovation in disaster management, with specific goals of developing disaster management tools based on remote sensing research and geospatial analysis technology. The three-tiered disaster management approach: disaster planning, disaster response, and disaster recovery is ripe for innovation through knowledge and technology transfer efforts among researchers, technology companies, and public sector responders. RIT has extensive experience in applied remote sensing research, expertise in application of remote sensing to fire and flood assessment, and a history of collaboration with local emergency responders. UB team members, on the other hand, contribute expertise in geospatial analysis of a variety of natural and man-made disasters, including earthquakes and floods. The research team and public/private collaborators have been applying a systems engineering approach to define user needs in disaster management, perform targeted research, and develop commercial disaster management products.

Project Status:
(a) IPLER website: The IPLER website went online at http://ipler.cis.rit.edu. The website includes descriptions of research and product development activities, sponsors, links to all partners, and a summary of the October 20, 2009 IPLER workshop at RIT.
(b) Annual workshop: The IPLER successfully hosted its first annual workshop (10/30/2009), which was attended by disaster responders, geospatial industry partners, and researchers. Outcomes include defined disaster products in context of fire and flood events, increased collaboration between researchers and responders (e.g., Monroe County, NY, Office of Emergency Management), and provision of actual geospatial disaster data from hurricanes Katrina and Ike (e.g., Pictometry, ImageCat Inc., DigitalGlobe). Details can be found at http://ipler.cis.rit.edu/workshops.
(c) Disaster Response Case Study: Haiti earthquake response (please see below).
(d) Fire research highlights: Based on previous NSF-funded work, we are applying methods for detecting wildfires and for extracting fire line information from multispectral visible, near infrared, and thermal

infrared images that were collected in Kentucky and Florida by the RIT Wildfire Airborne Sensor Project (WASP) camera system as a technology demonstration. Research results are being transformed into robust operational algorithms by MS-level computer science students. These algorithms will be ready for transition to operational remote sensing workflows and use by IPLER partners by August 2010.
(e) Multi-modal change detection: A Ph.D. student (Bin Chen) is researching classification and change detection approaches via methodologies such as Support Vector Machines and Markov Random Fields.
(f) Flood research highlights: We have collected 3D light detection and ranging (LiDAR) data for the Seneca Nation of Indians watershed (Figure 3.10-29) and are processing these for improved hydrological modeling. Examples include ice-jam and rainfall-runoff model applications by UB and detection of streambed obstructions by RIT environmental science MS student, Chris Scheiner.

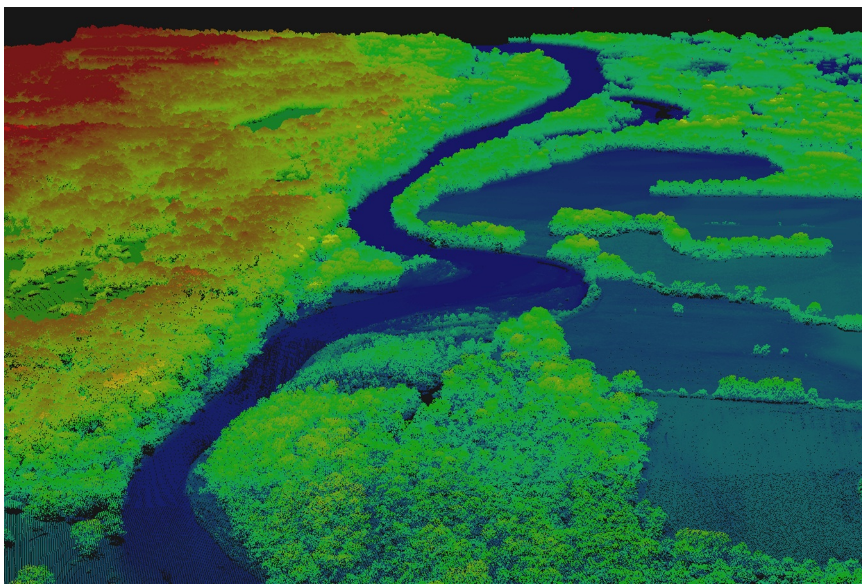


Figure 3.10-29: A LiDAR point cloud of the Seneca Nations of Indians site near Buffalo, NY. Data such as these are being used to develop algorithms to detect impediments to stream flow.

3.10.1 RIT Support to the Haiti Relief Effort

Project Description:

On January 12, 2010, a magnitude 7 earthquake struck the nation of Haiti and resulted in over 200,000 people killed and over 1 million people displaced. The need for accurate high resolution imagery (Figure 3.10-30), LiDAR data (Figure 3.10-31), and various maps became evident as the disaster unfolded. Specific remote sensing product requirements included building damage assessment, debris quantification, hydrological mapping, and fault line assessment. DIRS was contracted by the World Bank, through commercial partner ImageCat Inc., to mobilize an airborne imaging system for a large area mapping mission (Figure 3.10-32). The WASP sensor, developed under funding from NASA to support wildfire detection and mapping, and a LiDAR system were flown over the devastated area from January 21-27, 2010. This multimodal dataset provided a unique capability to characterize the damage and was used for several applications.

The effort focused on the Port au Prince area for days 1-4, while severely damaged areas outside the main

Figure 3.10-30: A poignant WASP image that clearly demonstrated the need for relief efforts in Haiti. This image was collected on January 21, 2010.

city were imaged on days 5-6. LiDAR data (2.9 billion returns) were nominally collected at a point density of 2 hits/m^2, governed by imagery collection parameters over the inhabited areas of interest, and 5 hits/m^2 for high resolution 3D mapping of the fault line (day 7). Ultimately, over 15,000 frames of imagery were collected with each of the four cameras for a total of over 60,000 frames. This was accomplished with 148 flight lines and approximately 1,933 flight line-miles covering an area of approximately 650km^2.

Data were uploaded to RIT via a high speed network connection established by the Internet2 Consortium. This proved to be a key component of the overall mission, since standard disk courier efforts take several days at minimum. Peak transfer rates of 47 MB/sec were observed and a total of 699 GB of imagery was transferred from the University of Puerto Rico Mayaguez over the course of the deployment. Data product (ortho-rectified imagery) turn around time was approximately 24 hours from collection once the workflow was established.

The high resolution optical imagery was used by the GEO-CAN (Global Earth Observation Catastrophe Assessment Network) community to identify destroyed and heavily-damaged structures in Port-au-Prince and surrounding areas. GEO-CAN over 600 scientists and engineers from over 20 different countries volunteered their services using a crowd-sourcing platform to delineate pre-earthquake footprints of severely-damaged buildings in order to estimate the amount of building floor area that was displaced by the earthquake. The results of this damage assessment are summarized in a damage assessment report prepared by the ECs Joint Research Centre, the UNs UNITAR/UNOSAT and the World Bank.

Another important information element to the relief effort was the location of Internally Displaced Persons (IDPs): damaged structures forced a large number of residents to leave their homes and live in camps.

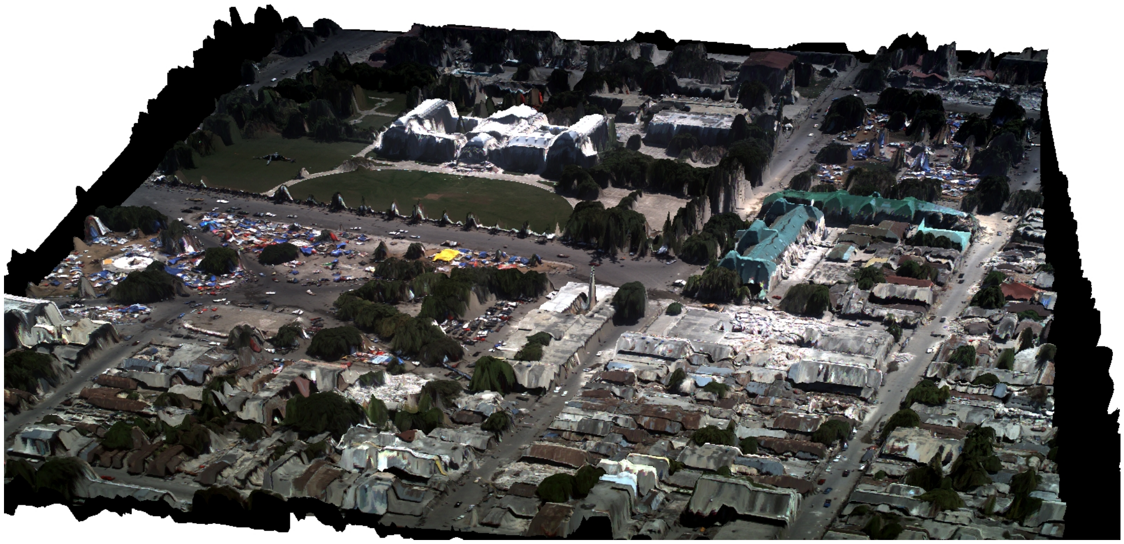


Figure 3.10-31: A drape of WASP color imagery over a 3D LiDAR raster showing the damaged Haitian palace.

Figure 3.10-32: The flight crew that deployed to Haiti (l-t-r): George Tatalovich (Kucera International), Jason Faulring (RIT DIRS), and James Bowers (Kucera International).

Questions arose as to the location and dynamics of the camps. It was demonstrated that IDPs could be located with a relatively simple Mahalanobis distance classifier that focused on blue tarps (Figure 3.10-33), a seemingly ubiquitous shelter material during the aftermath of the earthquake. The algorithm was implemented in the IDL/ENVI software package and outputs the geo-location of the tarps (utilizing the geo-information in the imagery) in Google Earth KML format. More details and data are available at http://ipler.cis.rit.edu/projects/haiti.

Figure 3.10-33: A hand-held camera photo (courtesy Jason Faulring) showing a refugee camp and the ubiquitous blue tarps.

3.11 Support to the Carnegie Airborne Observatory

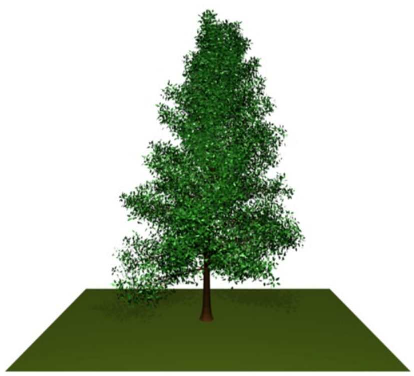
Sponsor: RIT Center for Imaging Science & Carnegie Institution for Science

Principal Investigator(s): Dr. Jan van Aardt
Research Team: Dr. Jan van Aardt, William Wu (CIS - Ph.D.), Diane Sarrazin (CIS - MS), Joe McGlinchy (CIS - MS), David Kelbe (CIS - BS)

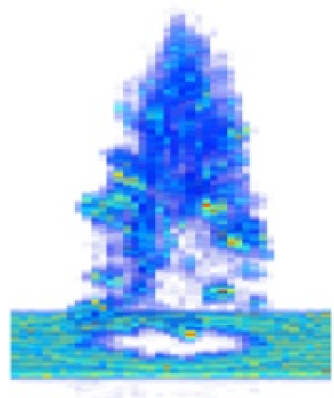
Project Description:
Small-footprint waveform LiDAR (wLiDAR) is a relatively novel technology, especially in context of natural resource remote sensing. Challenges that face researchers include validation of approaches to wLiDAR pre-processing and ensuring robustness of structural metric extraction across ecosystems and regions. Such challenges are exacerbated by the fact that knowledge related to the interaction between the illuminated object and the resultant waveform is also lacking. These topics are concurrently being addressed by researchers at Rochester Institute of Technologys (RIT) DIRS group and the Carnegie Institution for Science (CIS). The broad objective of this project is to develop approaches for structural characterization of complex forest types and canopy structures using high vertical resolution, small-footprint wLiDAR data. Specific objectives are:

- to develop advanced pre-processing approaches (workflow) for wLiDAR ecological applications. This includes de-noising, deconvolution, and de- and re-composition of waveforms to ensure high-fidelity signals (see Figure 3.11-34),

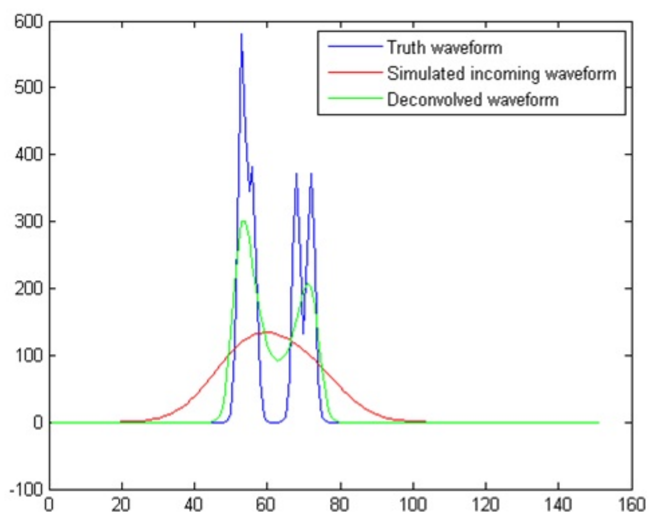
- to characterize the precise vertical thickness of overstory trees, which contain many problematic invasive species, are drivers of habitat availability, and are significant contributors to carbon pools, and
- to expand integration over larger pixels towards potentially landscape/regional assessments using signal integration approaches.



(a)



(b)



(c)

Figure 3.11-34: (a) An example of a high-fidelity virtual tree used to model waveform LiDAR interactions in DIRSIG. The exact volume and leaf area of this tree is know, which renders it invaluable as "absolute truth". (b) A voxel ("volumetric pixel") representation of waveform LiDAR interactions with the virtual tree. Voxels are 0.5 x 0.5 x 0.15 m in size and each voxel represents the relative intensity registered along the vertical trajectory of a waveform pulse. (c) A deconvolved waveform (green), derived from the received or incoming pulse (red), can now be compared against a truth waveform to evaluate various deconvolution algorithms. This specific deconvolution was performed using the Richardson-Lucy algorithm.

Project Status:
DIRS is fast establishing itself as a research center for wLiDAR processing and extraction of structural/3D metrics. Specific progress and results include:

- Waveform processing (William Wu-Ph.D.): We have developed virtual DIRSIG scenes with varying grass biomass and tree-grass (savanna) mixtures. These are being used to simulate waveforms (Figures 3.11-34(a) & 3.11-34(b)) and quantitatively evaluate deconvolution approaches (Figure 3.11-34(c)). We are also developing an entire processing chain from smoothing, deconvolution, and decomposition to angular reconstruction. This work has resulted in two papers: one was presented at the 2009 annual IGARSS conference in South Africa and the other formed part of the peer-reviewed proceedings of the 2009 Silvilaser conference in Texas.
- Hyperspectral and wLiDAR fusion (Diane Sarrazin-MS): Diane Sarrazin has completed her MS degree, using species classification and herbaceous biomass assessment as test cases for fusion. We used a PCA-based approach and although results were not conclusive, species-specific improvements were observed in the case of classification, while structural elements were selected as significant variables for biomass modeling. This work has resulted in a paper at the 2009 annual SPIE conference in Florida.
- Extracting structural elements from wLiDAR (Joe McGlinchy-MS): This research aims to extract structural components from waveform LiDAR data in terms of woody, herbaceous, and bare ground components from data collected over a savanna environment in and around Kruger National Park (KNP), South Africa. Structural components are comprised of metrics extracted from the waveforms and validated using biomass measurements made in field plots. It was found that composite waveforms resembling plot sizes (4.5m diameter) most often are able to describe more than 80% of the woody biomass variability across the entire study site. This research was presented as a paper at the 2010 annual IGARSS conference in Hawaii.

3.12 Phenomenology Study for Worldview-2 Sensor

Sponsor: DigitalGlobe

Principal Investigator(s): Dr. Tony Vodacek
Research Team: Dr. Rolando Raqueño, Dr. Aaron Gerace

Project Description:
This project is investigating the capabilities of the DigitalGlobe WorldView-2 sensor for determination of bathymetry (water depth) from images of the sea bottom. The approach builds on previous work done in DIRS to determine water constituents from spectral images of lakes and ponds using a look-up-table built using the Hydrolight radiative transfer code available from Sequoia Scientific for the water contribution and the MODTRAN radiative code for the atmospheric contribution. In this case, the Hydrolight code is run with spectral properties determined for multiple water types and bottom types while also varying the depth. A realistic set of atmospheric conditions is provided to the MODTRAN code to define the range of atmospheric conditions. The MODTRAN results are added to the Hydrolight results to produce a realistic range of radiances that could be determined by the WorldView-2 sensor from space and over shallow ocean water. By comparing this look-up-table of spectra to Worldview-2 spectral data and finding the best match, the corresponding best estimate of the depth can be found.

Project Status:
21000 Hydrolight runs, each one with a unique set of conditions were run using the RIT Research Computing cluster, allowing parallel runs of the code to shorten the processing time. The MODTRAN radiative

transfer code was run to generate a look-up-table with about 2300 atmospheric conditions. The look-up-table was delivered to DigitalGlobe for testing of the water depth determination using WorldView-2 images.

3.13 SOFIA Data Cycle System Development & Support

Sponsor: University Space Research Association; NASA

Principal Investigator(s): Bob Krzaczek
Research Team: Bill Hoagland

Project Description:
The Stratospheric Observatory For Infrared Astronomy (SOFIA) will be the premier infrared and sub-millimeter observatory in the next two decades for astronomers around the world. Jointly developed by NASA and DLR (the German Aerospace Center), SOFIA represents the next generation of airborne observatories. A Boeing 747SP aircraft has been modified to carry a 17 ton telescope whose primary mirror is 100 inches in diameter to altitudes as high as 45,000 feet, where it will make sensitive measurements of a wide range of astronomical objects. At these stratospheric altitudes, the telescope and its suite of scientific instruments can collect radiation in wavelengths from 0.3 to 1,000 micrometers.

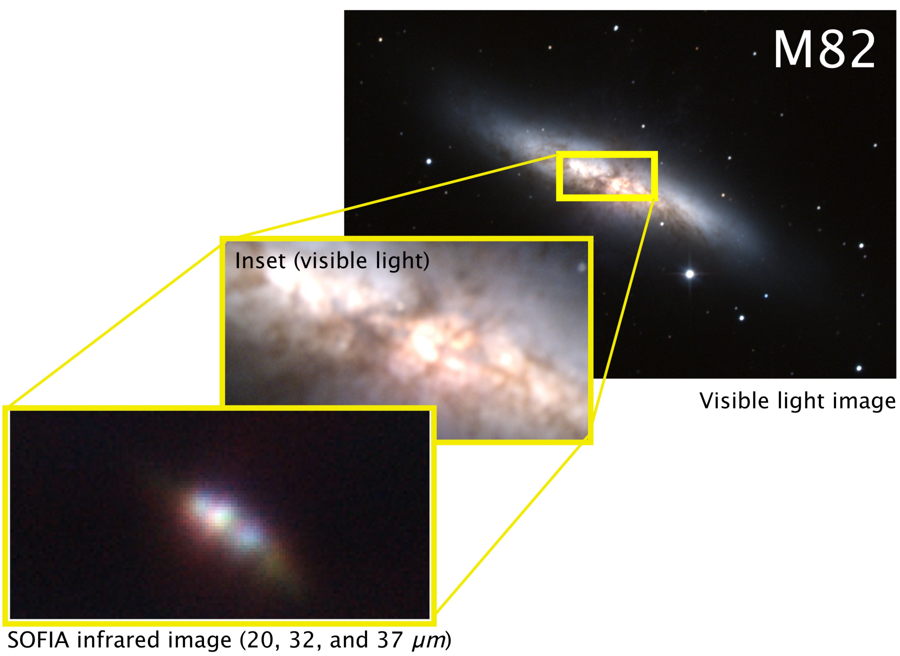


Figure 3.13-35: Infrared image of M82 from SOFIA's first light flight.

A key component of NASA's program to explore fundamental questions about the universe, SOFIA will help astronomers learn more about the birth of stars, the formation of solar systems, the nature and evolution of comets, the origin of complex molecules in space, how galaxies form and change, and the nature of the mysterious black holes lying at the centers of many galaxies including our own.

The Data Cycle System (DCS), originally designed by RIT for USRA, provides the formal structure for the "observation lifecycle" required by any major astronomical observatory. From the proposal of astronomical targets, the selection of scientific instruments, the design of those observations, the execution of those observations, the automated reduction of the raw data, to the dissemination of those data products to its users around the world, the DCS enables a global community of astronomers to interact with this new observatory entirely at a distance.

Project Status:
SOFIA has completed another important milestone in the development of any observatory: First Light. In late May of 2010, the observatory made its first in-flight, open-door, nighttime observations at altitude with an on-board mission crew of 10 scientists, engineers, and technicians. Imagery of the planet Jupiter, and of starburst galaxy M82 (nicknamed "the Cigar galaxy"), was successfully collected during this flight. Upon landing, the DCS managed the transfer, archival, and dissemination of the raw science data, all within the first hour after SOFIA landed.

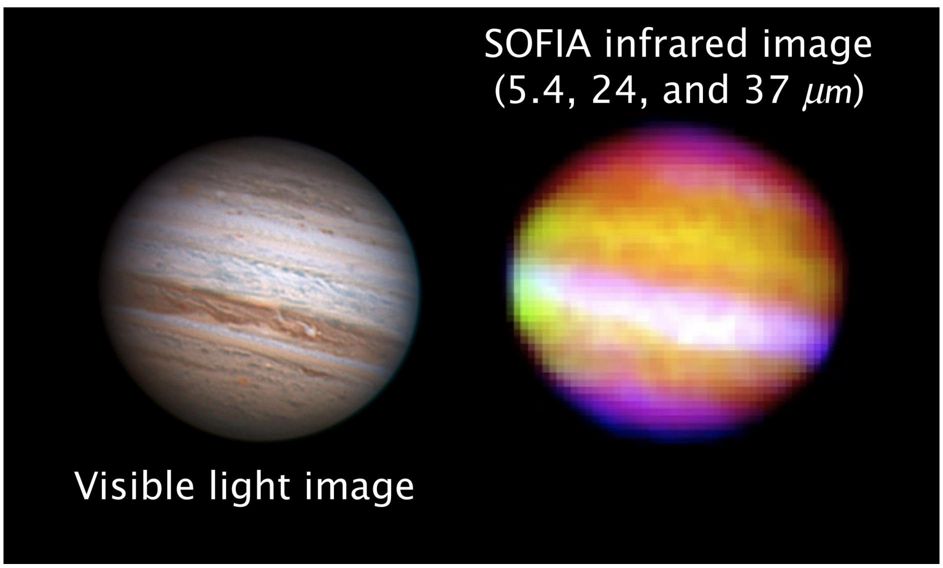


Figure 3.13-36: Infrared image of Jupiter from SOFIA's first light flight.

The DCS also successfully supported SOFIA's first Call For Proposals to the general public. Astronomers around the globe were invited to develop proposals for scientific observations during SOFIA's Early Science phase. Not only are these initial proposals being presently considered for scheduling missions during SOFIA's first year of operation, but they also provide a valuable baseline for estimating future proposal calls with the observatory.

Presently, DCS version 2.0 is being designed by RIT and USRA to extend automated data reduction with new capabilities and features requested by the various science teams working on SOFIA. Version 1.3 was released in July of 2010, version 1.4 will be delivered in October, and 2.0 is scheduled for development in 2011.

3.14 Network Centric Urban Vigilance

Sponsor: Air Force Research Laboratory Sensor Directorate, through subcontract from Gitam Technologies, Inc.

Principal Investigator(s): Dr. John Kerekes
Research Team: James Albano (CIS - Ph.D.), Dr. Emmett Ientilucci, David Pogorzala

Project Description:
The primary goal of this effort has been to develop novel and effective HSI-based algorithms for multiplatform 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 primarily through the generation of synthetic images using DIRSIG of a scene observed under varying illumination and observing conditions.

Project Status:
During this second year of the two-year Phase II SBIR effort with Gitam Technologies, several hyperspectral images were generated for investigation of a tracking and handoff scenario. First, a scene was developed by placing several dismounts (humans) in front of the school that is part of MegaScene I. Vehicles were also placed at the front of the building. A hyperspectral image was then rendered from a model sensor placed on a tower across the street (see Figure 3.14-37). A second image of the scene a few minutes later was rendered using a model sensor mounted on a low altitude oblique imaging airborne platform. A third image was then rendered several minutes later from a high altitude nadir-viewing model hyperspectral sensor where the dismounts and vehicles have now moved to the back of the school.

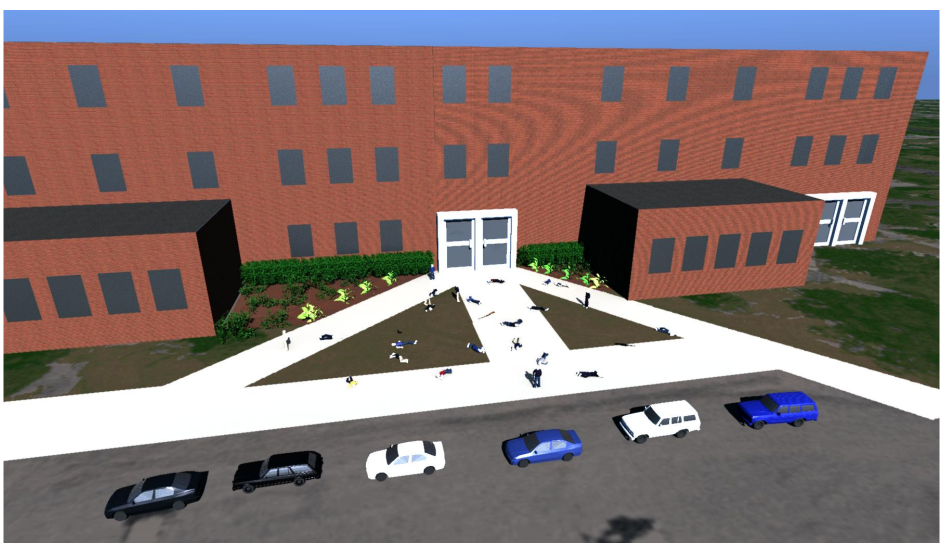


Figure 3.14-37: Simulated image of the front of the school with dismounts and vehicles present as imaged by a tower mounted sensor.

This sequence of images is enabling further analysis and development of algorithms designed to cue, handoff, and track dismounts and vehicles using hyperspectral imagery. The analysis is ongoing with the project planned to end in the Fall of 2010.

3.15 Modeling Research for Performance-driven Multi-modal Optical Sensors

Sponsor: Air Force Office of Scientific Research (AFOSR)

Principal Investigator(s): Dr. John Kerekes, Dr. Zoran Ninkov, Dr. Alan Raisanen
Research Team: Michael Presnar (CIS - Ph.D.), Lingfei Meng (CIS - Ph.D.), Kenny Fourspring (CIS - MS), and Annette Rivas (CIS - MS); collaboration with Numerica, Inc., Dayton, Ohio

Project Description:
The objective of this project is to perform basic research in the development and use of integrated microelectromechanical 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 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 using DIRSIG and Matlab 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 year was the second year of the anticipated three-year project. The emphasis this year was on a successful demonstration of the spectral feature aided tracking and adding a polarization capability to moving vehicle simulations, optical modeling and the tracking algorithms. Figure 3.15-38 shows an example of the output images generated including polarization images.

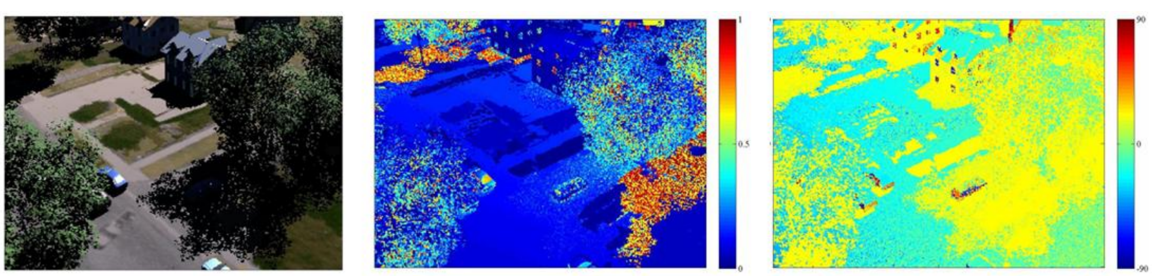


Figure 3.15-38: Simulated RGB (left), degree of linear polarization (center) and angle of polarization (right) images from the multi-modal model sensor.

Future work will focus on in-depth design and modeling of a single pixel Fabry-Perot tunable filter and the optimal integration of spectral, polarimetric, and panchromatic video in the tracking algorithm.

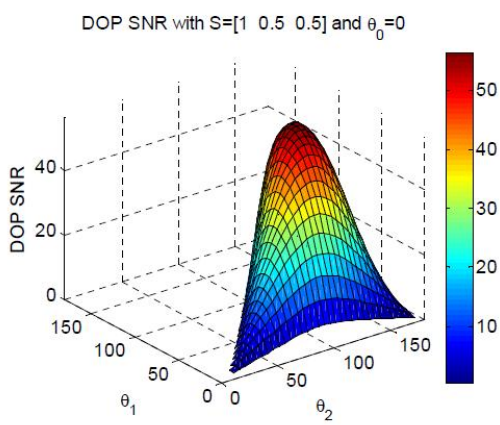
3.16 Multi-modal Performance-driven Sensing

Sponsor: Air Force Office of Scientific Research (AFOSR) through subcontract from Numerica Corporation

Principal Investigator(s): Dr. John Kerekes
Research Team: Lingfei Meng (CIS - Ph.D.) and Dr. Alan Raisanen

Project Description:
This project was a Phase I SBIR awarded to Numerica Corporation with RIT as the university partner. The objectives were to extend aspects of the research being conducted under the AFOSR-sponsored project described above in section 3.15. In particular, the effort focused on the analytical modeling of optical polarization imaging.

Project Status:
The project supported the work of PhD student Lingfei Meng during a portion of his program. During this time, Mr. Meng derived the calculations to estimate the signal-to-noise ratio (SNR) for the degree of polarization (DOP) in optical polarimetric imagery. This work was used to investigate the optimal angles for polarization filters based on DOP SNR. Figure 3.16-39 shows an example result of this effort indicating an optimal set of polarization filters at {0°, 70°, 120°} angles of orientation for polarized light with a Stokes vector as shown. Also, a tool was developed to calculate the optical throughput for Fabry-Perot etalons being developed using microelectrical-mechanical systems (MEMS) technology. The project is now complete.



θ_1	θ_2	DOP SNR
70	120	56.483
75	120	56.315
75	125	56.156
70	125	56.077
65	120	55.963
70	115	55.854
65	115	55.64
80	125	55.548
80	120	55.413
75	115	55.33

Figure 3.16-39: DOP SNR as a function of polarizer angles θ_1 and θ_2 with θ_0 fixed at 0°.

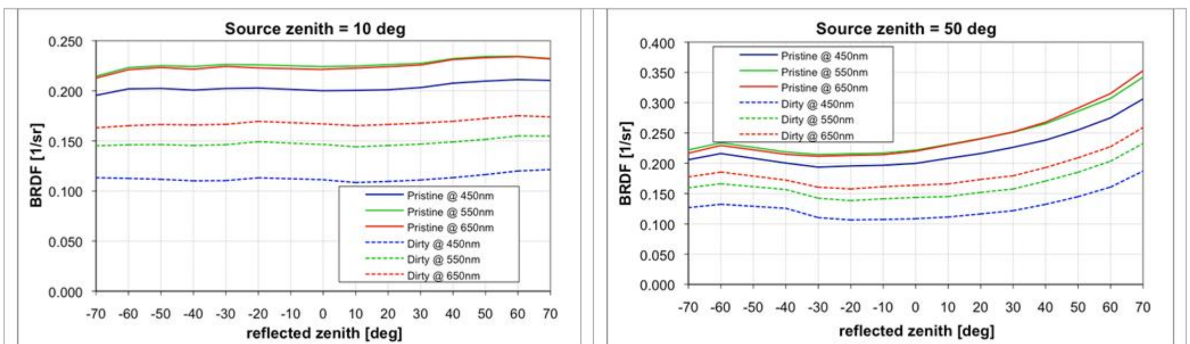
3.17 Spectral Scene and Characterization Study

Sponsor: Raytheon

Principal Investigator(s): Dr. John Kerekes
Research Team: Caitlin Hart, Dr. Brent Bartlett, Dr. Michael Gartley, Dr. William Basener

Project Description:
The primary goal of this project was to investigate the effects of variability and contamination on the spectral reflectance of various materials. This was done by selecting a variety of fabrics, exposing a subset to weathered conditions, and then measuring their spectral reflectance characteristics both with spectrophotometers as well as a polarization sensitive bidirectional reflectance distribution function (BRDF) system. A second goal was to further investigate metrics for hyperspectral scene complexity in the context of target detection through application of a target implant method to several images.

As an example of the results of the spectral characterization activity, Figure 3.17-40 shows the BRDF at three wavelengths for two source zenith angles for a fabric before and after soiling. These results demonstrate the reduction in overall reflectance for the soiled fabric but with minimal change in the shape of the BRDF function.



a) BRDF retrived for cream fabric sample with a source zenith of 10 deg.

b) BRDF retrived for cream fabric sample with a source zenith of 50 deg.

Figure 3.17-40: Effects of dirt contamination on the BRDF of a cream colored fabric sample for two incident zenith angles and three wavelengths.

Project Status:
This project was completed in early 2010 with a final report delivered to the sponsor and a paper presented at the SPIE 2010 Defense Security Sensing Symposium.

3.18 Phenomenology Study of Feature Aided Tracking of Dismounts

Sponsor: Air Force Research Laboratory Sensors Directorate

Principal Investigator(s): Dr. John Kerekes
Research Team: Jared Herweg (CIS - Ph.D.) and Dr. Emmett Ientilucci

Project Description:
The objective of this project is to investigate the phenomenology sensible by hyperspectral imagers for the purpose of detecting, identifying, and tracking humans in a cluttered environment. The Air Force is interested in this technology as part of combating terrorism and facing the increased challenges of fighting in urban environments.

Project Status:
The project was initiated in June 2010 and is planned to be conducted through the Summer of 2012.

3.19 Dynamic Analysis of Spectral Imagery

Sponsor: NGA University Research Initiative

Principal Investigator(s): Dr. David Messinger
Research Team: Dr. Ariel Schlamm, Amanda Ziemann (Math - BS/MS), Josh Zellweg (CIS - BS)

Project Description:
This project will develop a novel methodology to use the distribution of the data in the full k dimensional hyperspace (where k is the number of spectral bands collected) to identify regions of man-made activity in spectral imagery. By identifying such regions for further interrogation, the robustness of exploitation algorithms will be increased and the efficiency of data processing will also be improved. In this way, the hyperspectral imagery can be used as a "cue" for further processing, either using the spectral imagery or through other means.

Imagery analysis is traditionally performed using the "eyes on pixels" model by visual inspection. While this method is reliable for analysis of known targets of interest, semi-autonomous processing schemes are required to analyze large area coverage imagery in a search analysis. Spectral imagery provides a potential opportunity for semi-autonomous analysis based on the large amounts of material-specific information contained in the spectral content of the image. The complex nature of spectral imagery, particularly hyperspectral, necessitates the use of semi-autonomous processing schemes for exploitation. Here, analysis is being carried out on subsets of the image, or tiles, of appropriate size to ensure sufficient sampling of the data hyperspace while still providing detection of man-made activities. Methods based on the topology of the data are under development and testing for this application. Such methods seek to describe the data cloud from an individual tile without assumptions of normality or linear geometry. For all tests of man-made activity, results will be presented as indicating that a particular tile warrants further investigation, thus serving as a cue for further analysis and / or collection. The key component of the research here is the identification of subsets of the image that are interesting in the sense that they contain man-made phenomena.

Project Status:
Widely used methods of spectral clustering, target, and anomaly detection when applied to large area spectral imagery provide less than desirable results across sensor type, scene content, spectral and spatial resolutions due to the complex nature of the data. This results in a large burden placed on the analyst in terms of the amount of data needed to be processed and the ability to discern the difference between "interesting" and "uninteresting" regions in the imagery. The interest segmentation process, outlined in Figure 3.19-41, is a methodology developed for automatically labeling regions of a large area spectral image as either "interesting" or "uninteresting" in order to aid an image analyst.

A variety of data driven algorithms for spectral image analysis are applied to spatial tiles of a large area scene. These algorithms include point density estimation, topological anomaly detection, gradient flow spectral clustering, and simplex volume estimation. Metrics from these algorithms correlate to the spectral

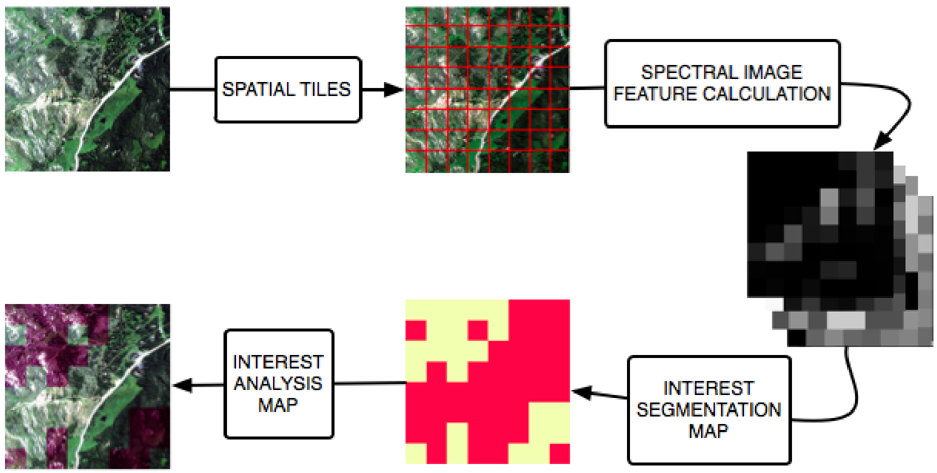
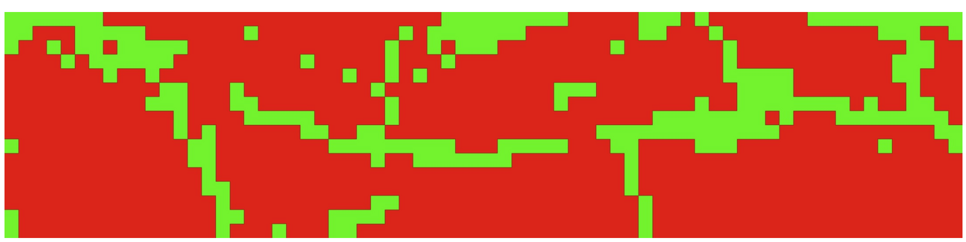


Figure 3.19-41: The interest segmentation process.

(a) RGB image of scene



(b) Interest segmentation map

Figure 3.19-42: Interest segmentation map of HyMap data.

complexity within a spatial tile, and therefore the amount of "interest" contained in the tile. These metrics are combined in order to produce a two-class segmentation map, shown in Figure 3.19-42, indicating the areas of an image are "interesting" in green. This methodology was demonstrated to work on multispectral and hyperspectral imagery at a variety of spatial resolutions.

This project has been extended with funding for an additional year through 2011.

3.20 Spatial / Spectral Large Area Search Tool Development

Sponsor: NGA University Research Initiative

Principal Investigator(s): Dr. David Messinger
Research Team: Dr. Eli Saber (RIT EE), Abdul Syed (CIS - Ph.D.), Jamie Albano (CIS - Ph.D.)

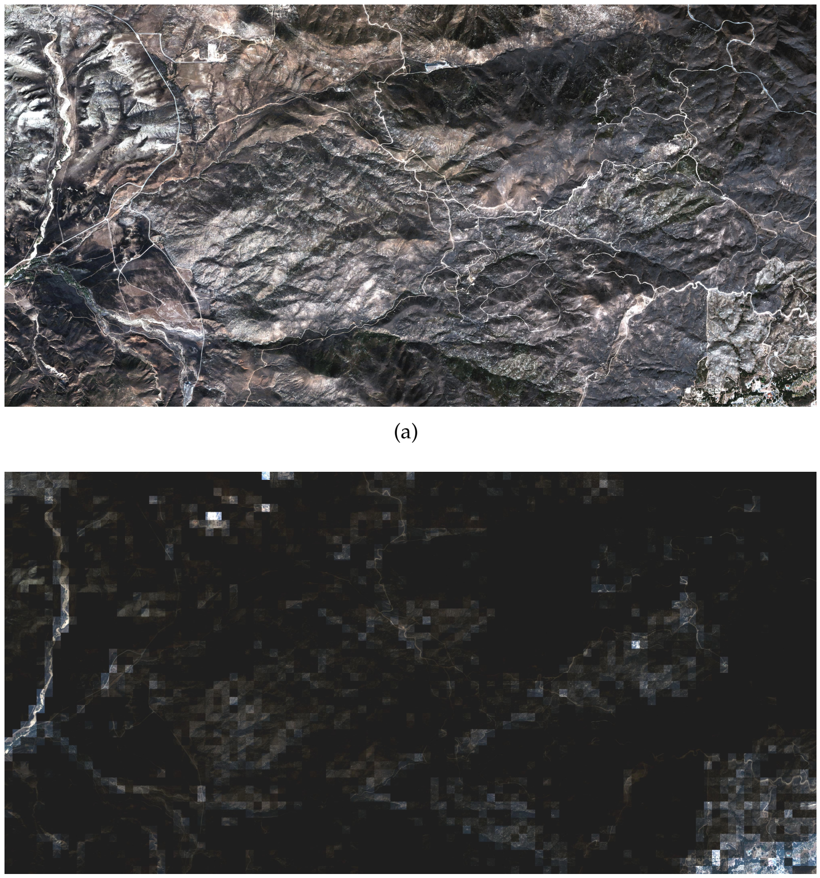
Project Description:
Large area search in imagery for GEOINT targets of interest is a challenging task through means other than visual inspection of pixels. This is largely because it is difficult to identify global mathematical models of the background patterns, textures, shapes, colors, etc. This is particularly true when the goal of the search process is to identify not a specific target of interest, but instead when the image analyst is tasked with searching a region for previously unknown targets of interest. These targets can vary in size, shape, texture, signature, etc., and methods designed to identify a particular signature are less than reliable in these circumstances. As an example of the search problem, if an analyst is considering an image that is 15,000 pixels square, they must inspect 225,000,000 pixels. However, if a scheme can reduce the 225 million pixels to something far more manageable (e.g., 225,000, or 22,500 pixels, factors of 1,000 or 10,000) without missing any new targets, this may be acceptable, providing a much more manageable set of regions requiring visual assessment. This research is developing "cueing" methods that are sensitive to changes in the natural landscape on a local scale such that analysts can dramatically reduce the overall number of pixels they must investigate.

Project Status:
The first year saw progress made on both the spatial and spectral processing tasks. Spatial processing schemes have focused on extension of existing segmentation methods, developed for RGB imagery, to multispectral remotely sensed imagery. The goal is to develop methods to characterize uniform segments at various spatial scales to build localized models of the background spatial features in the image. Consequently, methods will be developed to identify outliers from this background model as a cue to analysts to the presence of abnormal activity.

Spectral processing for the large area search problem has been focused on the development of spectral complexity metrics. The image is tiled and for each tile, the complexity of that tile is estimated. Then, the tiles that are the most complex are highlighted for further analysis while non-complex tiles are deemed "un-interesting" and they are suppressed. Tile complexity is represented by a brightness scale in the image; the most complex tiles are brightest and the least complex tiles are black. The measure of complexity is based on two simple hypotheses. Tiles that are "un-interesting" will be composed of relatively uniform materials. Tiles that are interesting will have a more diverse material content that can be assessed in the spectral domain. A more spectrally diverse material content will manifest itself in the spectral space through a larger volume of occupied hyperspace. The method has been shown to work across several types of imagery, including Quickbird (4 spectral bands), RapidEye (5 spectral bands), Worldview-2 (8 spectral bands), and HyMAP (hyperspectral with 146 spectral bands).

Figure 3.20-43 shows the results from processing a multispectral image with the Spectral Complexity Search Tool. The resultant output image shows tiles ranked by the complexity as presented via the tile brightness. Brighter tiles are more complex and warrant visual inspection first; dark tile are deemed "un-interesting" and are of much lower priority for inspection. Figure 3.20-44 shows the high resolution panchromatic image focused in on the bright tile in the middle, right portion of the full image. Note that the region was highlighted due to the presence of man-made structures, and that this region was identified without the aid of spatial or spectral signatures for these objects.

This algorithm has been implemented into the IDL / ENVI software package and has been delivered back to the NGA for assessment. The algorithm has also been delivered to ITT VIS, the company that creates and markets the IDL / ENVI software package, for potential inclusion into a future release of ENVI.



(a)

(b)

Figure 3.20-43: (a) RGB from a Quickbird image of a mountainous region in California. (b) Tiled visualization product after processing with the Spectral Complexity Search Tool. Brighter tiles indicate more complex regions of the image requiring prioritized visual inspection.

Figure 3.20-44: High resolution panchromatic image of region identified by spectral complexity search tool. Note the presence of man-made structures increasing the complexity of this region in the spectral space.

3.21 Remote Sensing for Archeological Studies of Oaxaca, Mexico

Sponsor: NASA

Principal Investigator(s): Dr. David Messinger, Dr. Bill Middleton (RIT COLA)
Research Team: Kelly Canham (CIS - Ph.D.)

Project Description:
We have been collaborating with Dr. Bill Middleton in the RIT College of Liberal Arts on archeological studies in the Oaxaca Mexico region for several years. Some of the key archeological questions under investigation are: how do ecological variables impact the development and expansion of ancient states? What is the ecological impact of state formation? Can the past inform the present as to the nature of the interaction between states and their environment? We are using space-based remote sensing as a tool to aid in answering these and other questions.

Primarily, we are collecting hyperspectral imagery from the NASA Hyperion sensor on board the EO-1 satellite platform. The sensor provides large area spatial coverage, sufficient spatial resolution (30 m), and excellent spectral coverage to allow us to perform landscape analysis in support of the archeologists in the field. Additionally, we have collected data over the same area but during different seasons to better understand how the landscape changes from the dry to wet seasons. Figure 3.21-45 shows the flightlines collected as of the end of 2009 with the Hyperion sensor. Additional, high spatial resolution imagery has

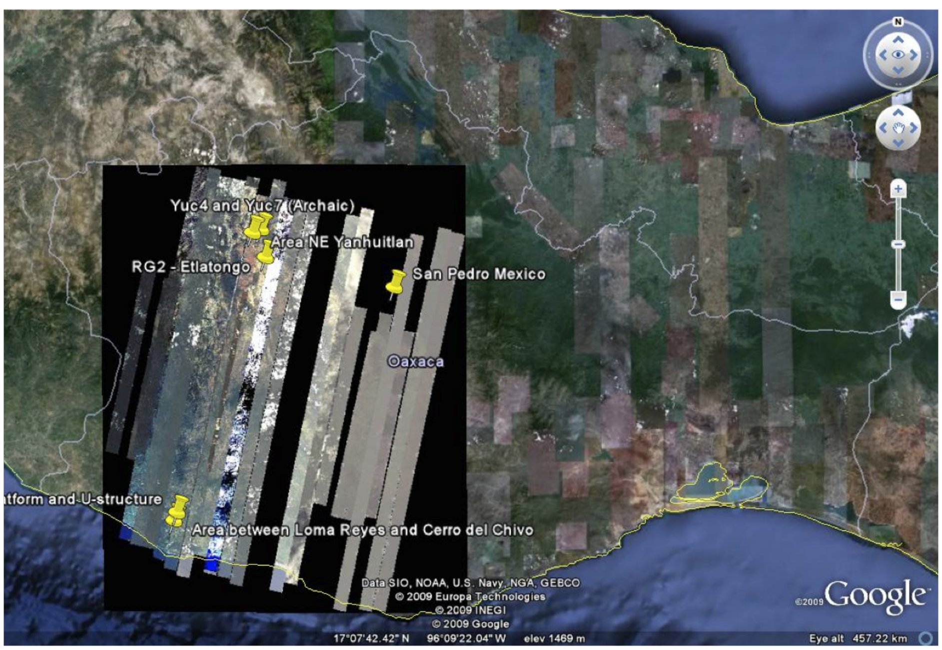
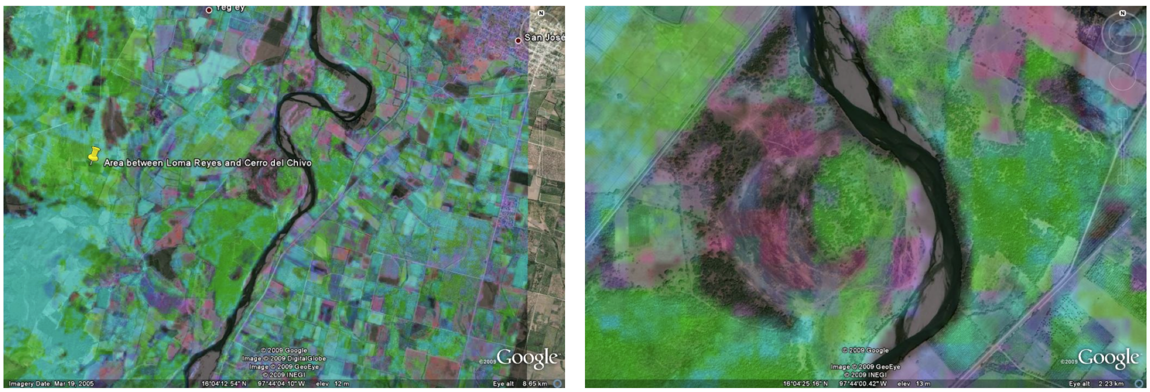


Figure 3.21-45: Imagery collected with the Hyperion sensor covering Oaxaca, Mexico as of 2009. The imagery has been geolocated and is shown in Google Earth for context.

been collected with the Quickbird commercial remote sensing system.

The hyperspectal imagery is analyzed primarily to understand vegetation states and changes during the dry season. Principal methods include the automatic calculation of several indicative features for each pixel in the scene. The include the Plant Senescence Reflectance Index (PSRI), the Normalized Difference

Vegetation Index (NDVI), and the Normalized Difference Water Index (NDWI). The PSRI shows regions where the vegetation is under stress. Similarly, the NDVI relates to the health of the vegetation and the NDWI is used to identify vegetated regions with high water content. The PSRI may be indicative of stressed plants due to submerged structures (causing variations in soil density and ground water) while the NDWI can be used to find growing plants due to hidden riverbeds or streams. The three indices can be visualized in RGB imagery, geolocated to high resolution imagery for spatial analysis. Figure 3.21-46 demonstrates this utility.



(a) (b)

Figure 3.21-46: RGB image based on derived vegetation indices from hyperspectral imagery overlaid onto high resolution imagery in Google Earth. (a) Region of interest. (b) Identification of likely historical oxbow in river. This site is of potential interest to archeologists due to the spatial proximity of settlements to rivers.

Figure 3.21-47 shows the use of the large area coverage to understand changes in the landscape between the rainy and dry seasons in Oaxaca. Note that while the overall land cover / land use changes between the dry and wet seasons, there are still regions of this area that can support vegetation during the dry season. Information like this allows archeologists to understand how much agricultural a landscape can support year round, which impacts the development of states.

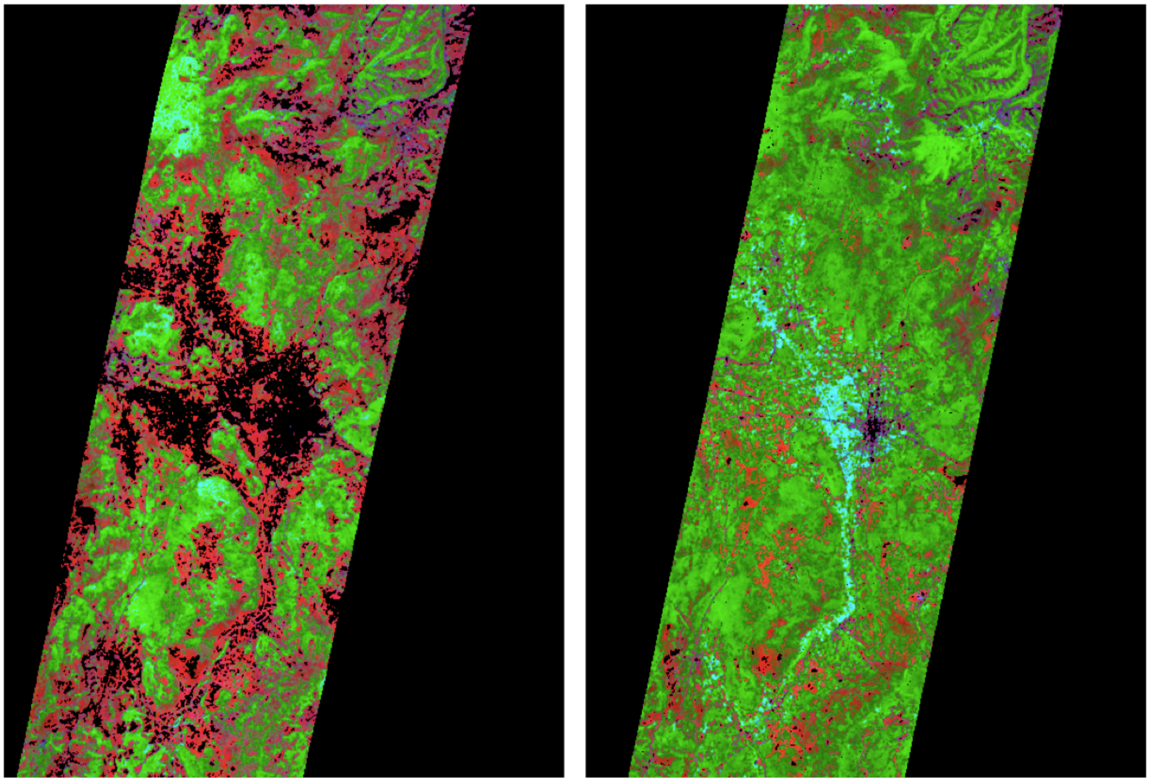
Project Status:
This project is ongoing. Additional work is now being conducted into understanding how the local landscapes can be classified into a meaningful taxonomy for archeological research. Also, a spatially adaptive spectral unmixing process is being developed to "map out" the landscape complexity across the very large area of Oaxaca, Mexico. This will allow researchers to understand spatial changes in the landscape and what sort of society each portion of the landscape can support.

3.22 Urban Traffic Video Scene

Sponsor: Lawrence Livermore National Laboratory

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

Project Description:



(a) (b)

Figure 3.21-47: RGB image based on derived vegetation indices from hyperspectral imagery of the Villa Hidalgo area. (a) Dry season. (b) Wet season.

The goal of this project was to explore new techniques in rapidly developing synthetic scenarios of urban environements that could be modeled with our in-house data simulation environment, DIRSIG. Specifically, this project focused the use of commercial and open-source software packages to automate a large portion of this labor intensive process (see Figure 3.22-48). The produced scene was then used to simulate the video products that would be produced by a low frame rate, large format system circling the site on an unmanned airborne vehicle (UAV).

Project Status:

Under this project, we produced a new DIRSIG scene that was based on a portion of Chicago, IL. The general layout of the scene was driven by a road network exported from OpenStreetMap (http://www.openstreetmap.org), which is a database of road data available under the Creative Commons Attribution-ShareAlike 2.0 (CC-BY-SA) licence. Unlike the restrictive licenese associated with other road map databases, the OSM license is very flexible. As a result, large portions of the commercial and open-source software community have embraced it. With a road network to define the basic fabric of the scene, the road network and existing scene geometry for buildings, trees, etc. were fed into a commercial, procedural city construction tool called "CityEngine" (http://www.procedural.com) to automate the placement of the these structures in the scene (see Figure 3.22-49).

The road network was also imported into the "Simulation of Urban MObility" (SUMO) (http://sourceforge.net/projects/sumo) traffic simulator. SUMO is a microscopic and continuous road traffic simulation

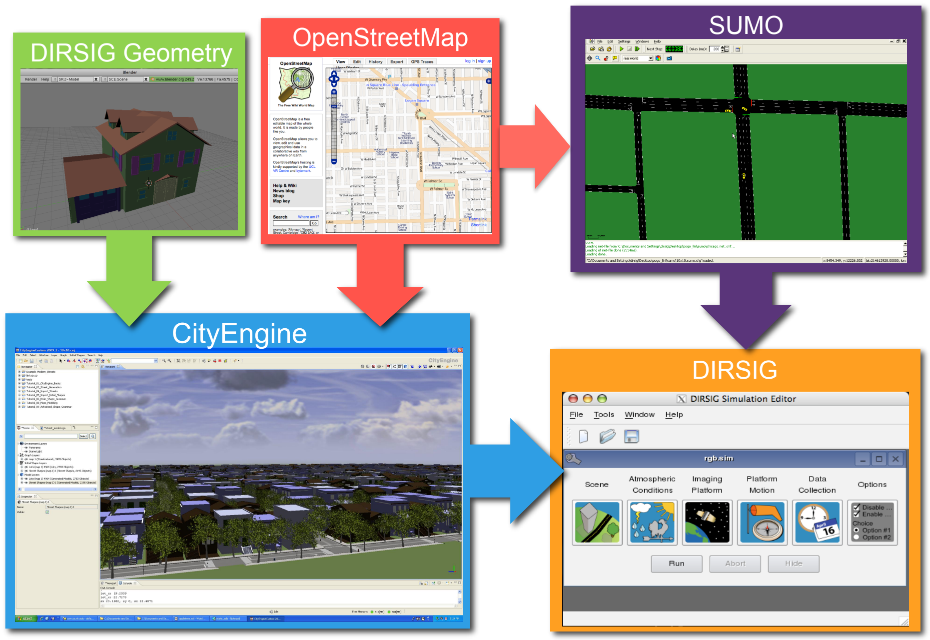


Figure 3.22-48: The flow chart of the heavily automated scene construction workflow explored in the creation of the new Chicago scene.

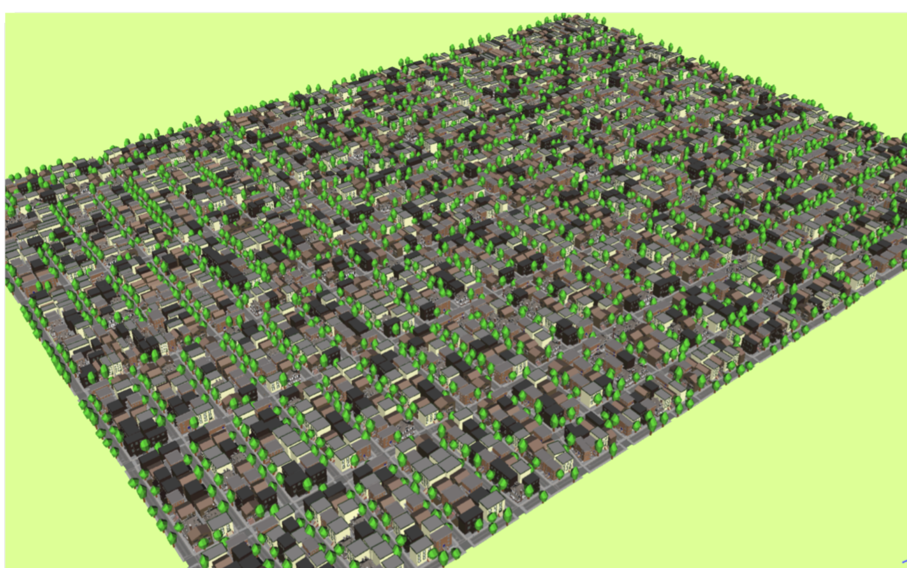


Figure 3.22-49: The screen shot of the CityEngine software with Chicago scene assembled.

software being developed mainly by the German Aerospace Center (DLR). It is an open-source model that uses an agent-based model (ABM) approach to predict how a large number of vehicles navigate a complex road network that includes traffic control devices such as speed limits, stop signs, traffic lights, etc. (all described in the OSM road network). The output of SUMO was translated into a format that could be used by DIRSIG to dynamically move vehicles throughout the scene in a realistic manner.

The completed scene was then rendered as a video using a simulated unmanned airborne vehicle (UAV) that was circling the scene.

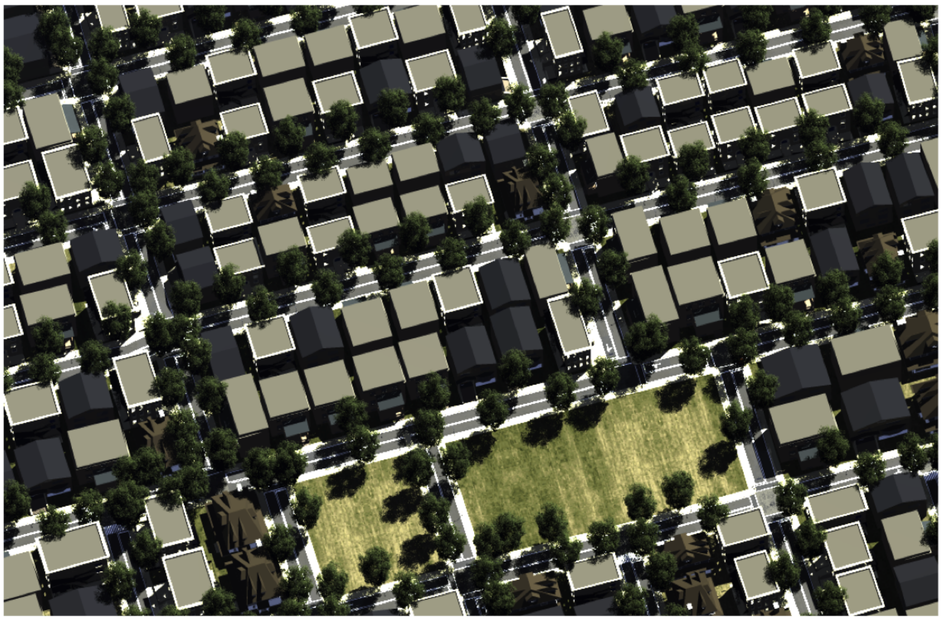


Figure 3.22-50: A zoom of the rapidly developed Chicago scene as rendered by DIRSIG.

3.23 Multiframe Simulation of MegaScene 1 in DIRSIG

Sponsor: Goodrich

Principal Investigator(s): Mr. Scott Brown
Research Team: David Pogorzala and Niek Sanders

Project Description:
The goal of this project was to generate a large-area, multi-modal (VIS, SWIR and MWIR) DIRSIG video simulation of a scene with dynamic content including vehicles and pedestrians. This was project leveraged the use of a new scene construction workflow that utilizes the commercial CityEngine (http://www.procedural.com) software and the open-source SUMO (http://sourceforge.net/projects/sumo) and OpenStreetMap (http://www.openstreetmap.org) software that had been experimented with earlier in the year.

Project Status:
After some discussion, it was decided that the best way to achieve the goals of the project was to rebuild the MegaScene1 area using the new scene construction workflow. By employing these new tools, the scene could be greatly expanded in area to meet the requirements for the project (see Figure 3.23-51 for a comparison of the original and new MegaScene1 site model).

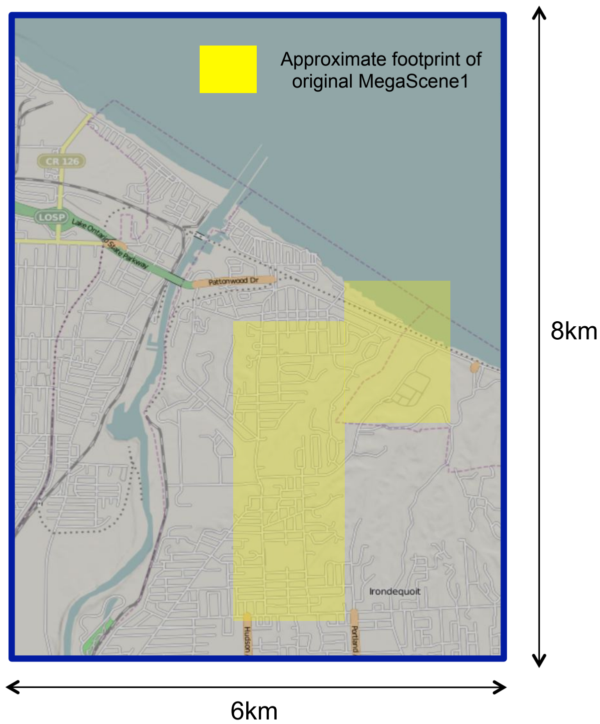
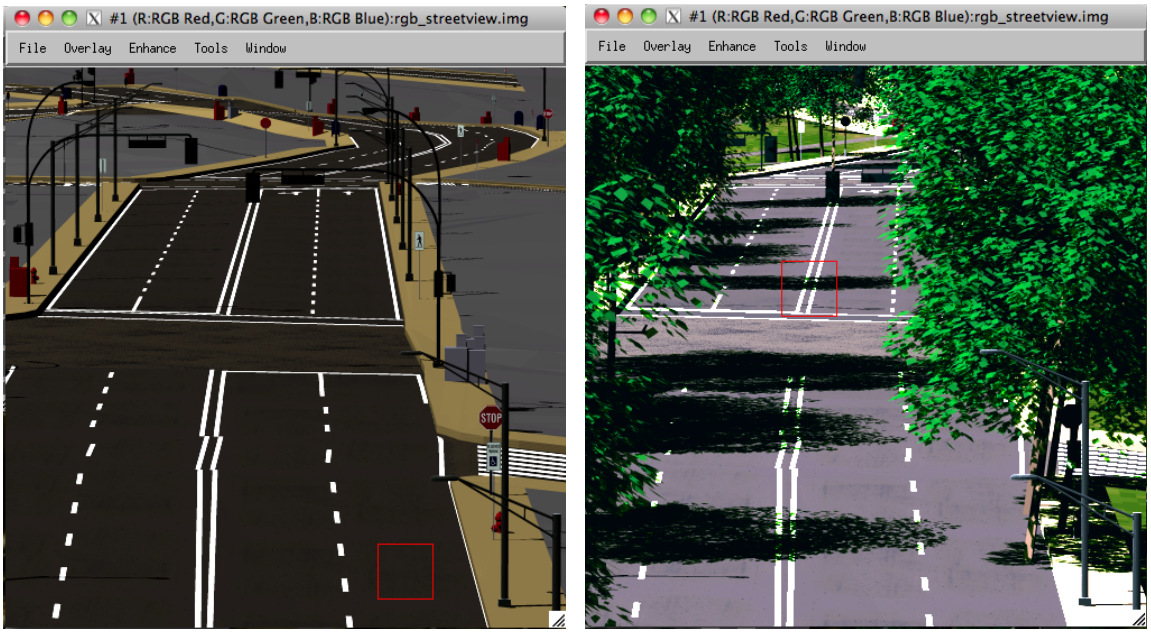


Figure 3.23-51: A map of the expanded MegaScene1 site model, including the footprint of the original scene.

The use of CityEngine to procedurally assemble the scene was found to be invaluable in this effort. The first version of MegaScene1 was hand assembled by undergraduate and graduate students over a period of 4-5 months. Including all of the data preparation and continued refinement of our new scene construction workflow, the new site model was completed in approximately 2-3 weeks. One of the advantages to using CityEngine is the ease that new objects can be added to the scene. For example, the images in Figure 3.23-52 show the vast amounts of "cultural clutter" (mailboxes, signs, fire hydrants, street lines, etc.) that was introduced in the rebuilt scene by introducing a few new procedural rules in CityEngine. Finally, the new scene model has a fully registered traffic model that integrates with SUMO. This allows the site to be populated with a large number of moving vehicles.

The image in Figure 3.23-53 is an early rendering of the site model produced by DIRSIG. Present in this preliminary image are some artifacts including road/terrain alignment issues, driveways not connecting to the street and the use of a single tree model. All of these issues will be addressed in the final version of the scene.



(a) (b)

Figure 3.23-52: Street level renderings of the new scene show the of "cultural clutter" in the rebuilt scene with the trees removed (a) and with the trees in place (b).

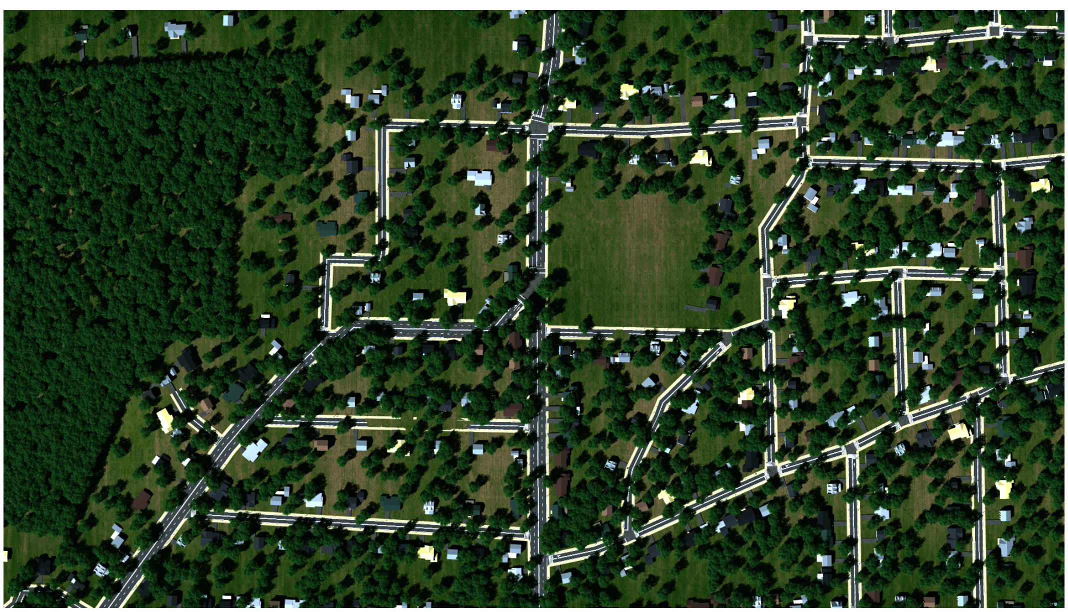


Figure 3.23-53: An early DIRSIG rendering of a portion of the rebuilt MegaScene1 site. The Y-shaped intersection near the middle of the image is the same intersection shown at the street level in Figure 3.23-52.

3.24 DIRSIG SAR Simulation Improvements

Sponsor: Lockheed Martin

Principal Investigator(s): Dr. Mike Gartley
Research Team: Dr. Adam Goodenough

Project Description:
The goal of this project is to continually advance the capability of the DIRSIG software tool to model collection of radio frequency (RF) signals, with an emphasis on (but not limited to) a Synthetic Aperture RADAR (SAR) scenario. The intention is to provide the user base with a full suite of simulation capabilities across the electromagnetic spectrum, leveraging a single material database and scene geometry. The science challenge of this project is to determine and implement the most computationally efficient and radiometrically accurate suite of radiative transfer tools permitting a historically particle based modeling tool to capture wave-based phenomenology (*i.e.*, diffraction and coherence effects).

Project Status:
During 2009 the team was able to implement a collection of RF specific scattering models, atmospheric radiative transfer models, and antenna gain patterns geared towards simulation of SAR collections. The user is capable of configuring a pulsed linear frequency modulated (LFM) waveform by specifying a pulse repetition rate, chirp rate, and pulse length. The waveform received by the antenna is then optionally mixed with a reference waveform to remove the carrier frequency and sampled by an analog to digital converter of a user specified sampling rate. IDL and compiled c++ tools are actively being developed to focus the DIRSIG output into visually interpretable imagery for both spotlight and stripmap type collection modes. Throughout the software development process, we continuously test the cases of moving objects in a scene (such as cars, and rotating blades on a helicopter etc.) as well as multiple bounce effects to ensure the expected phenomenology is maintained. Figure 3.24-54 below shows an example simulation of a spotlight SAR collection aimed at the Hubble Telescope moving through its orbit with various amounts of rotational velocity. The figure demonstrates the difficulty associated with exploiting SAR signatures of objects undergoing both translation and rotational motion.

3.25 DIRSIG MicroScene Development

Sponsor: MITRE

Principal Investigator(s): Dr. Mike Gartley
Research Team: Erin Ontiveros

Project Description:
The goal of this project was to extend the spatial extent of the synthetic DIRSIG scene called MicroScene. The original MicroScene spatial extent was on the order of a few hundred meters, with many fine spatial features rigorously modeled, such as pine needles on evergreen trees and screws holding the doorknobs onto doors. This work was meant to extend the spatial extent of the scene to a majority of the northern half of the Rochester Institute of Technology campus, with the nominal simulation ground sample distance being on the order of a few meters and a focus on full spectrum material properties (0.4 to 14.0 μm).

Project Status:
The extended MicroScene terrain was derived from a 2005 LIDAR collect over the campus. The raw LIDAR point cloud was bare earth processed and rasterized to a uniform spatial grid using the Merrick Advanced Remote Sensing (MARS) software tool. The resulting terrain was facetized and ingested into DIRSIG and

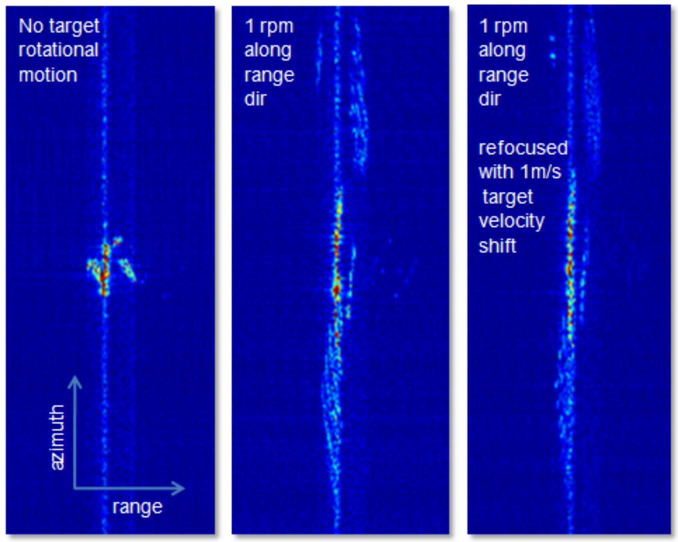


Figure 3.24-54: DIRSIG Spotlight SAR simulation of the Hubble Space Telescope as it moves through its orbit.

attributed with a material map and texture map for a realistic background. An on-campus pond, a portion of the Genessee River, and multiple calibration panels were also included in the scene as potential calibration sources. The final result was a spatially extended synthetic representation of the RIT campus suitable for visible, NIR, SWIR, MWIR and LWIR radiometric simulations enabling multi-modal sensor trades.

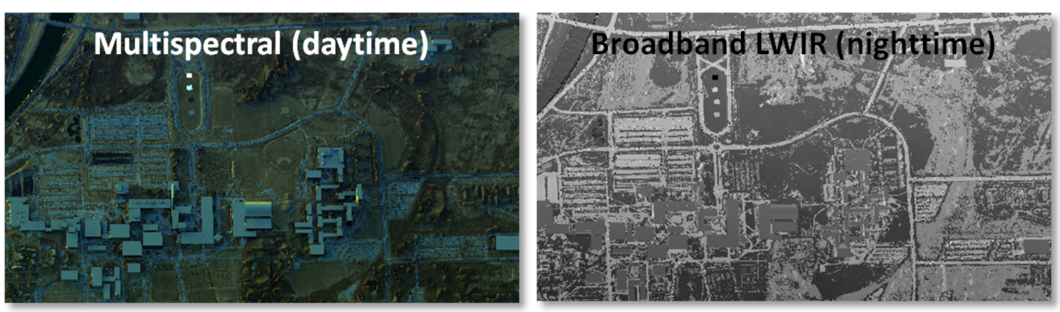


Figure 3.25-55: Expanded DIRSIG Microscene of RIT campus.

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

Sponsor: Air Force Research Laboratory Sensors Directorate, through subcontract from Gitam Technologies, Inc.

Principal Investigator(s): Dr. John Kerekes
Research Team: Danielle Simmons (CIS - MS), Nina Raqueño, David Pogorzala

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 algorithm developers at Gitam Technologies and biologists at Colorado State University who produced the genetically modified plants.

Sensor system design studies and scene simulations were 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. Figure 3.26-56 shows a portion of a simulated image of the biosensor plants attributed with exposed and unexposed reflectance spectra. This and similar images were used in the trade studies.

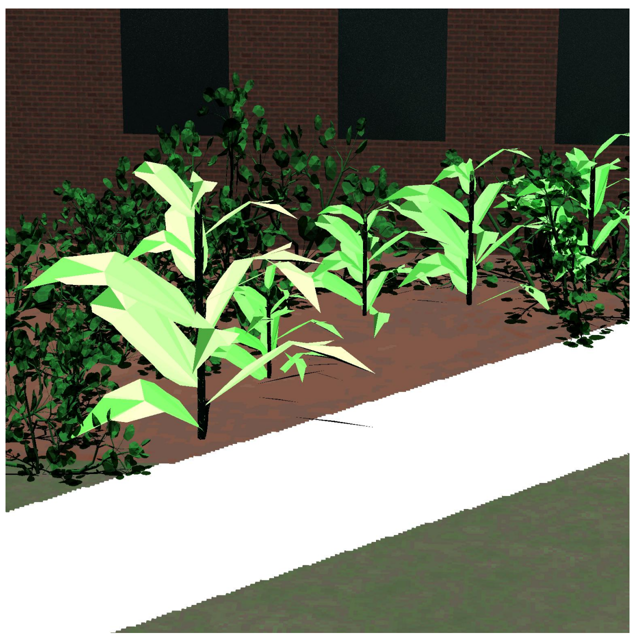


Figure 3.26-56: Simulated image of biosensor plants used for sensor design trade studies.

Project Status:
The project was completed in Fall 2009. The study found a spectral imaging system with modest spatial and spectral resolution could detect the exposure of the biosensors and discriminate the exposed plants from ones undergoing benign stresses such as lack of water or over fertilization. The results of the study were documented in a final report for the sponsor and a paper at the IEEE IGARSS 2010 conference.

3.27 Physically-Derived Signature Spaces for Spectral Unmixing

Sponsor: Naval Research Laboratory

Principal Investigator(s): Dr. Emmett Ientilucci
Research Team: Dr. David Gillis (NRL)

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. The work develops a generalized linear mixing model (GLMM) which incorporates an endmember grouping (EMG) technique as well as virtual endmembers generated through use of physics based modeling (PBM). In general, 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:
Work has been done on the concept of endmember grouping and endmember subspace projections (see Figure 3.27-57) where different subspace approaches (*e.g.*, linear and affine) have been taken. Additionally, the algorithm has been successfully tested on another data set (see Figure 3.27-58).

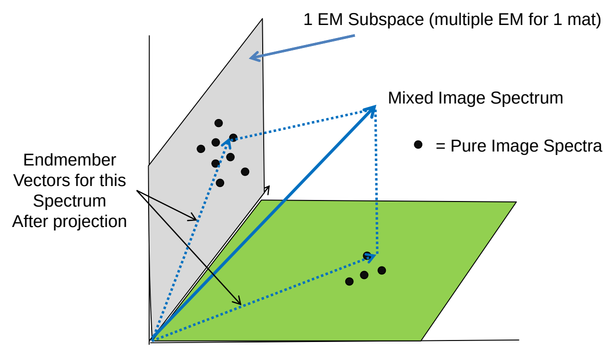


Figure 3.27-57: Projection of pixel spectrum into (grouped) EM subspaces.

3.28 Physics-based Target Detection in Hyperspectral Imagery

Sponsor: Intelligence Community Postdoctoral Fellowship

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

Project Description:
The overall goal of this effort is to develop improved physics-based modeling (PBM) 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:
We have developed the following *Max-type target space* detector to use with physics-based signatures spaces

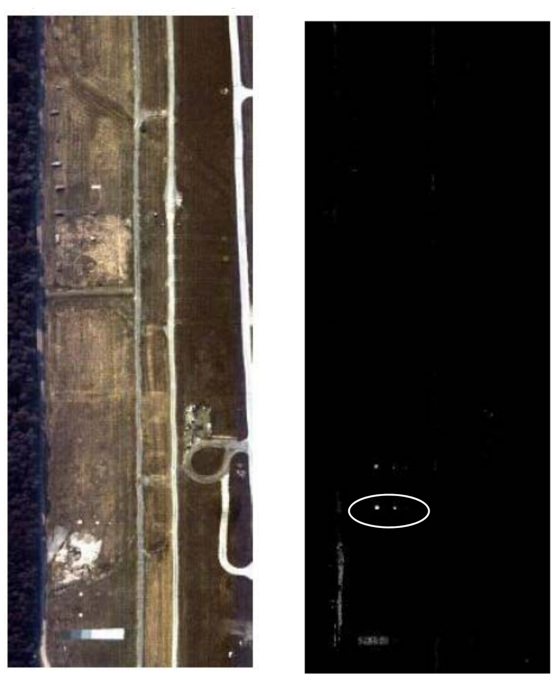


Figure 3.27-58: Results of using a virtual endmember subspace, for target detection, on the Forest Radiance data set. The targets of interest are circled in the detection image (left) with minimal false alarms.

of the form

$$M(\mathbf{x}) = \max_{1 \le j \le m} F_j(\mathbf{x}) \tag{1}$$

where $F_j(\mathbf{x}) = W(\mathbf{t}_j)^T W(\mathbf{x})$, and $\{\mathbf{t}_j\}_{j=1,\dots m}$ are all *m* spectra from the target space. The quantity $W(\mathbf{x}) = \mathbf{\Sigma}_B^{-1/2}(\mathbf{x} - \boldsymbol{\mu}_B)$. This is convenient in that we no longer need to adhere to the single vector input that the typical matched filter requires. That is to say, previously we only used a single vector to represent the entire target space. This single spectrum was the calculated *average* of the target space.

Large values of the matched filter $F_j(\mathbf{x})$ indicate presence of the target $\mathbf{t}_j$. By taking the maximum of those matched filters, we find the strongest evidence against $\mathbf{x}$ being the background pixel (see Figure 3.28-59). This is a form of discrete fusion. The target $\mathbf{t}_{j^*}$, such that $M(\mathbf{x}) = F_{j^*}(\mathbf{x})$, can be regarded as the most plausible approximation of the target present in the pixel $\mathbf{x}$.

In addition to the matched filter $F_j(\mathbf{x})$ discussed above, we also consider a truncated version

$$F_{j,k}(\mathbf{x}) = W_k(\mathbf{t}_j)^T W_k(\mathbf{x})) \tag{2}$$

where $W_k(\cdot)$ is a truncated version of $W(\cdot)$. More specifically, in the whitening process, the components of the whitened spectrum are ordered based on the eigenvalues of the $\mathbf{\Sigma}_B$ matrix, and only the top *k*-components are retained in $W_k(\cdot)$. A truncated version of the max-type detector is then defined as

$$M_k(\mathbf{x}) = \max_{1 \le j \le m} F_{j,k}(\mathbf{x}). \tag{3}$$

Results are shown in Figure 3.28-60 where we see the truncation in whitened space has drastically improved results. Additionally, we can see that the Max-type detectors further improve results.

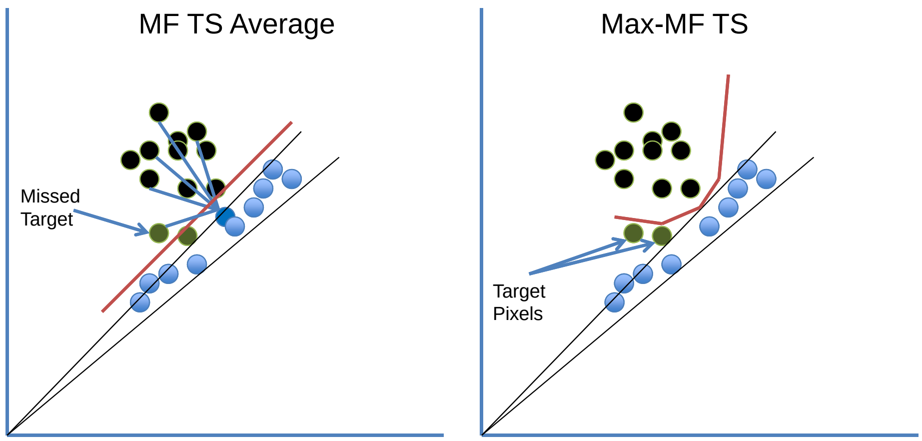


Figure 3.28-59: (Left) target space mean (dark blue dot) is computed and every image pixel (black dots) is tested against such an average using the standard matched filter. The decision boundary is a straight line. Here we have missed some image target pixels (green dots). (Right) these missed targets are located using the Max-detector because the decision surface is more selective and "wraps" around the background.

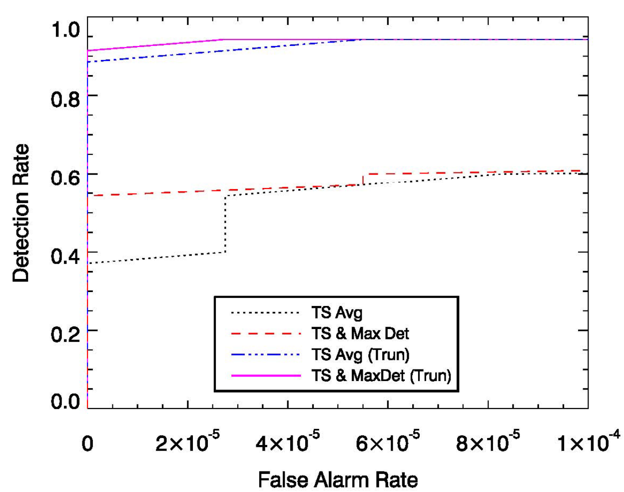


Figure 3.28-60: ROC curves showing improvement utilizing the Max-detector and Truncated Max-detector.

3.29 Adjoint Radiosity Phenomenology and Modeling Study

Sponsor: Ball Aerospace

Principal Investigator(s): Dr. Mike Gartley
Research Team: Dr. Emmett Ientilucci, Dr. Adam Goodenough, Caitlin Hart

Project Description:
The goal of this project was to support the sponsors development of a hyperspectral image exploitation tool geared towards retrieving target reflectance in complex environments. The sponsor has developed a novel Adjoint Radiosity approach for utilizing scene geometry knowledge, coupled with an adequate knowledge of solar and sky irradiance distributions, to extract spectral reflectance of target surfaces regardless of proximity to other objects (such as the sides of a building) and level of shadowing. RIT's role was to support the sponsor by providing a combination of DIRSIG simulated and experimentally measured spectral cubes of well characterized and simple geometric scenes. Additionally, RIT was tasked to explore an approach for incorporating an atmospheric adjacency point spread function as well as develop novel processing algorithms for facetizing complex scene geometries.

Project Status:
During 2009, RIT provided a series of experimentally measured and DIRSIG simulated spectral cubes of a simple scene known to exhibit severe multiple bounce radiance effects not captured by traditional spectral reflectance retrieval methods. Figure 3.29-61 demonstrates one such scene (where a panchromatic representation of the scene is displayed) consisting of a sphere and flat ground plate painted with a Krylon flat white paint that is known to be close to a Lambertian scattering surface.

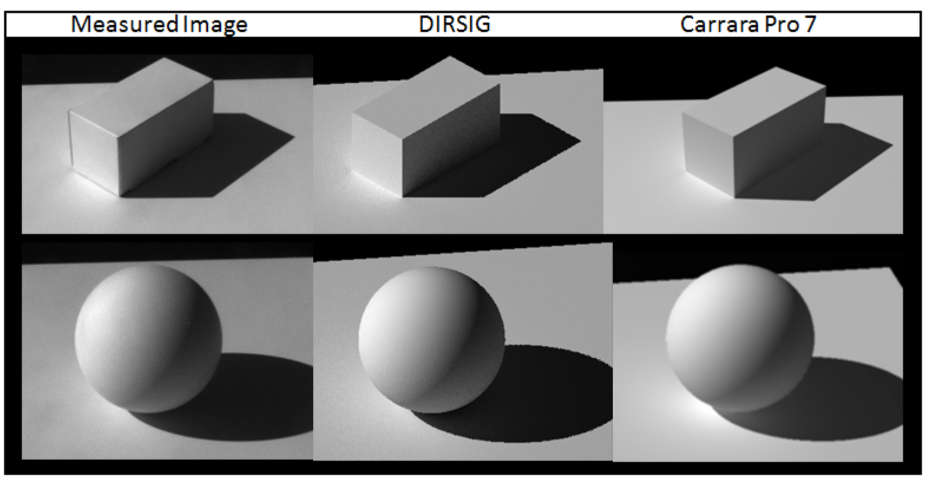


Figure 3.29-61: Panchromatic simulation of solid objects on a flat plate with a Lambertian surface.

The agreement between the experimentally measured, DIRSIG simulated, and image simulated by a commercial software product (Carrara Pro 7) was encouraging and provided a verification of the DIRSIG model for the project. Additionally, RIT was able to develop a theoretical framework based on MODTRAN atmospheric profiles to produce atmospheric adjacency point spread functions suitable for use within the sponsors exploitation toolset. Finally, an initial effort was also completed that examined efficient ways to best represent complex scene geometry with a limited number of facets in order to permit rapid exploitation within the sponsors suit of exploitation tools.

3.30 Extended Capability Wildland Fire Instrumentation Packages

Sponsor: USDA Forest Service through the University of Idaho - Boise

Principal Investigator(s):Dr. Bob Kremens
Research Team: Alistair Smith (University of Idaho), Timothy Miller, Alexander Yevstifeev, Nathan McCorkle

Project Description:
For this collaboration with the University of Idaho, we will provide 5 - 20′ field instrument towers and laboratory instrumentation. Most of this instrumentation has been developed for previous experiments, but the particular equipment for this project will be tailored to the needs of my collaborator Alistair Smith of the Univeristy of Idaho. The new instrumentation will include gas concentration monitoring and the ability to monitor photosynthetic activity (through the NIR/Red ratio NDVI) during post fire regrowth. We work on this project not as just instrument builders, but as a collaborator that understands the research and will use the facility in future cooperative efforts.

Each tower consists of a 20′ guyed metal pole with appropriate hardware to attach the required instrument packages. The towers disassemble into a man-portable package that weighs less than 25 lbs. The towers are guyed with steel cables, and can be set-up in under 15 minutes using a well-rehearsed 2-man crew. We have deployed similar equipment over 70 times on prescribed fires throughout the United States.

We will also be providing instrumentation for a wildland fuel combustion laboratory at the University of Idaho. This laboratory has been under construction for several years and will provide unique learning and research capabilities for outdoor, free-burning combustion research and teaching. The instruments for this laboratory include dual-band infrared radiometers (radiant flux), thermocouples (fire temperature and location), a multi-axis video recording system (fire position and extent), scales (mass loss rate) and a gas sampling system (combustion gas products, CO, CO_2, HC and NO_x). All of the data will be recorded synchronously using RIT-developed data logging equipment. Synchronous recording is especially important when observing transient phenomena like flaming combustion.

Figure 3.30-62: One of the many components of the UI laboratory fire instrumentation. This instrument housing contains a dual band IR radiometer, gas sensing video, relative humidity and air temperature sensors.

Project Status:

This equipment is currently being designed, tested and manufactured at RIT and will be delivered in Quarter 4 of 2010. We anticipate using the fire tower instruments on a classroom prescribed fire taught by Penny Morgan from the University of Idaho.

Figure 3.30-63: Alistair Smith (Univ. of Idaho) giving a lecture on combustion to a group of UI fire ecology/management students. UI has the only fire ecology program in the nation.

3.31 Development of Infrared Sensing Systems to Understand Radiant Hear Release for Wildland Fire Research

Sponsor: USDA Forest Service, Rocky Mountain Research Station (RMRS)

Principal Investigator(s):Dr. Bob Kremens

Research Team: Colin Hardy, Dan Jimenez, Bret Butler, Jason Forthoffer (USDA Forest Service), Timothy Miller, Christopher Tomkins-Tinch, Alexander Yevstifeev, Nathan McCorkle, Anna Higgins

Project Description:

The purpose of this collaboration is to explore, develop, and apply state-of-science thermal infrared (TIR) remote sensing hardware, algorithms, data acquisition methods, and integrated systems to quantify the processes and first-order effects of combustion in wildland fuel. In particular, we seek to understand the radiant heat release from wildland fire combustion at laboratory and field scale, including parameters such as emissivity, total energy release, radiant flux, and energy partition between radiative and non-radiative processes such as convection. We are involved in a series of experiments with the Rocky Mountain Research Centers Firelab, the premier wildland fire combustion laboratory in the world.

In our first series of experiments, to be conducted this December, we will perform optical radiation characterizations of wildland fuel material flames, including emissivity as a function of flame depth, radiant flux and energy release, and the energy partition between radiant and non-radiative energy release processes. These experiments will take place primarily at Firelab in Missoula, MT in the wind tunnel and free-burning test areas of that facility. RIT is developing several unique instruments for this study, including multi-band radiometers tuned to gaseous emission lines (CO, CO_2, HC) and dual-band narrow field-of-view radiometers. We will also use the RMRS mid-wave and long wave infrared camera systems and record flame extent and location with an RIT-built 3-axis videography system.

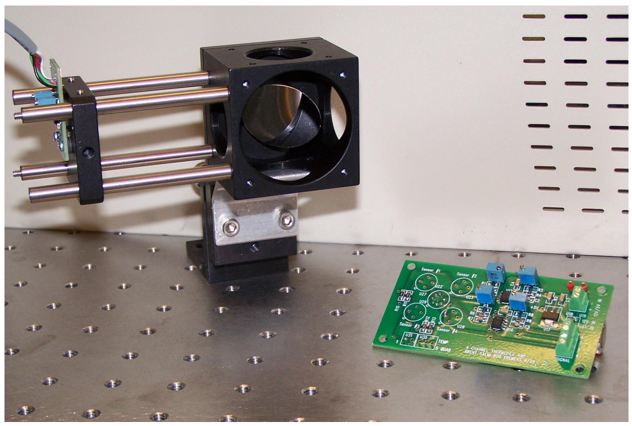


Figure 3.31-64: Narrow angle radiometer (left) and multi-band radiometer (right) used for fundamental physics measurements of wildland fires.

Project Status:
Based on our extensive experience in rapid-response wildland fire deployment and instrumentation (which began with field campaigns with RMRS in 2003 and continued to the present) we are redesigning the RMRS field instrumentation package. The present package, based on commercially available technology, has been plagued with reliability problems and weighs close to 7kg. Our redesigned package weighs less than 1.5 kg and has increased capabilities including longer recording time, three-axis flow recording (as opposed to two axis measured with the previous equipment) and increased time and signal resolution. Additionally the instruments are notebook-free in that they record GPS position information and compass heading along with the signal data. We have worked closely with RMRS personnel to engineer this solution. We have delivered five of these units for testing in the field by RMRS, before final delivery of a total of 10 units in late 2010. Our collaboration with RMRS has been a long and fruitful one, and we hope to continue this work with more experiments and field campaigns in 2011.

3.32 Validation of Fuel Consumption Models for Smoke Management Planning in the Easter Regions of the United States

Sponsor: Joint Fire Science Program (Forest Service, Park Service and Bureau of Land Management)

Principal Investigator(s):Dr. Bob Kremens
Research Team: Roger Ottmar, Elizabeth Reinhardt, Matthew Dickinson (USDA Forest Service), Timothy Miller, Christopher Tomkins-Tinch, Alexander Yevstifeev, Nathan McCorkle

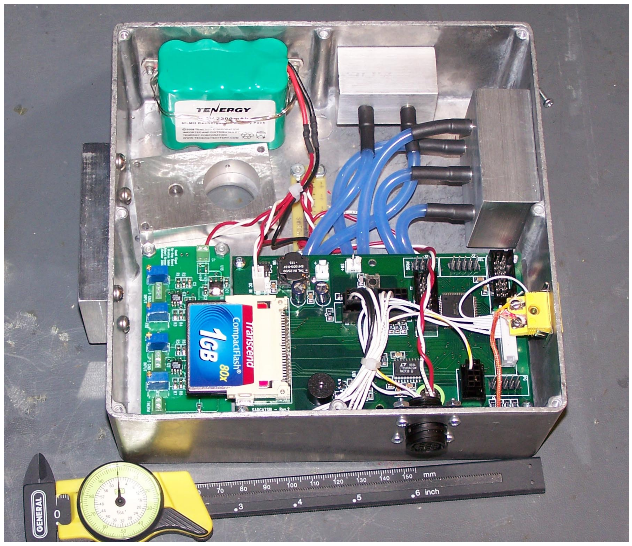


Figure 3.31-65: Interior of the new RMRS field data collection system. The unit measures total and radiant flux, narrow angle flux (to determine variability along the fire front), air temperature, and flow in three dimensions. The unit is synchronized with a GPS unit and has in internal compass so that the orientation of the instrument relative to the fire is always known.

Project Description:

Fuel consumption is one of the most critical variables in estimating smoke production for smoke management planning in the eastern United States. Although there are fuel consumption equations contained within the national fuel consumption and emissions production tools called Consume 3.0 and FOFEM, they have not been thoroughly validated except through anecdotal or non-scientific approaches since the majority of the consumption data available has been used to build and adjust equations internal to these software tools. Land managers have indicated the tools over-predict fuel consumption by 50% in the eastern regions of the country; however, these comments have not been validated with real fuel consumption data. The objective of this study is to collect a field dataset that will allow the determination of the uncertainties, biases, and application limits of the consumption equations within Consume 3.0 and the First Order Fire Effects Model (FOFEM) to wildland fire in the eastern regions (northeast, north central, southeast) of the United States. We propose to collect pre-fire fuel loading and fuel consumption data on a minimum of 20 prescribed burns located on U.S. Forest Service, NPS, USFWS, State, Private Lands, TNC, or Department of Defense lands of the eastern areas of the United States. We will also assemble any previously collected quality fuel consumption data for the regions to improve our validation set. Fixed-wing aircraft remote sensing will be used to estimate variability in consumption across burn units for comparison with averages from models. This data set will be provided to the Smoke and Emissions Model Intercomparison Project (SEMIP) repository by December, 31, 2010. If the data proves that current consumption models are inappropriate for these regions, modifications and adjustments will be undertaken by using the validation data. The validated or modified fuel consumption equations will be implemented in Consume 3.0 and FOFEM with an update to each tools user manual, scientific documentation, and tutorial. A training workshop will be conducted within these regions for land managers.

Project Status:

RIT is the primary instrumentation and data provider for this project. The WASP-LT and WASP camera systems were deployed on ten prescribed fires in Kentucky, Ohio, Georgia and Florida. We used previously developed ground instrumentation to provide ground truth for the overhead data collection (ground-leaving

Figure 3.32-66: Matthew Dickinson USFS, igniting a prescribed fire at Eglin AFB, Florida, in February 2010.

flux) and also to provide valuable data on in-fire weather (wind speed and direction at two vertical locations, relative humidity and air temperature) and gas concentrations (CO and CO_2). Our data collection method is unique in this field: we use ground based stations to calibrate the overhead sensors (eliminating the effects of smoke, particulates and gasses in the atmosphere above the fire) and fly continuously over the fire collecting a time-sequence of images. These images tell us the instantaneous power from the fire (fire radiated power, FRP) and by time integration, the total energy released from the fire (fire radiated energy, FRE). In a previous study we have shown that FRE is proportional to fuel consumed for scales of 1 m^2 to 100 m^2. Our collaborators have developed a model for smoke generation as a function of fuel consumed, so the radiant energy heat map (FRE) produced during this research allows estimation of smoke production which is an important large scale phenomena of great interest to environmental, public health and climate change researchers.

3.33 Multispectral - Multitemporal Image Exploitation

Sponsor: LASS Partners

Principal Investigator(s): Dr. David Messinger
Research Team: Alfredo Lugo (CIS - MS), Ryan Mercovich (CIS - Ph.D.), Dr. Tony Harkin (RIT School of Mathematical Science)

Project Description:
There are two efforts either underway or just concluded investigating the use of multispectral - multitemporal imagery to detection and characterize changes in scenes. The first (conducted by Alfredo Lugo) considers the question of what can be done with low spatial resolution multispectral imagery. Techniques from the hyperspectral image processing literature have been applied to two cases of interest: detecting

Figure 3.32-67: Removing an instrument tower from a prescribed fire at Mammoth Cave National Park in April 2010.

changes in a target location over time, and using the multitemporal nature of the data to better detection and characterize a stationary target.

For the first case, Landsat images were obtained over the Cape Canaveral area including the Kennedy Space Center. In one image, the space shuttle was being transported to the launch pad and is visible. This target was extracted and synthetically placed into other scenes at other locations collected over the span of 6 months. For the latter case, the target was injected into the same location and a “layer stacking” approach was used. In each case, it was demonstrated that using the temporal information, by either stacking the data or by using covariance-based methods (not typically applied to multispectral imagery), the target signatures could be located within the scene.

Another effort being conducted by Ryan Mercovich, and in collaboration with Dr. Tony Harkin in the RIT Math department, involves the use of a graph theory concept called “modularity” to cluster an image. The multispectral image is treated as a graph in spectral space, and modularity technique is used to divide the graph into distinct clusters. The method is iterative and hierarchical, providing information about the tree splitting history that a final cluster traversed. This information can then be used to identify changes in regions of the image based on changes in the iterative clustering process.

Figure 3.33-69 shows the RGB channels of a Worldview-2 image and the results from clustering using the modularity method. The result show here is after seven iterations. Note that even with only 8 spectral channels and with 3 m spatial resolution in this cluttered area, the method achieves a clean classification map. Figure 3.33-70 shows a similar example, this time for an area with no naturally occurring materials. The image is of a mall in Rochester, NY. Note that the method produces a generally clean map, extracting

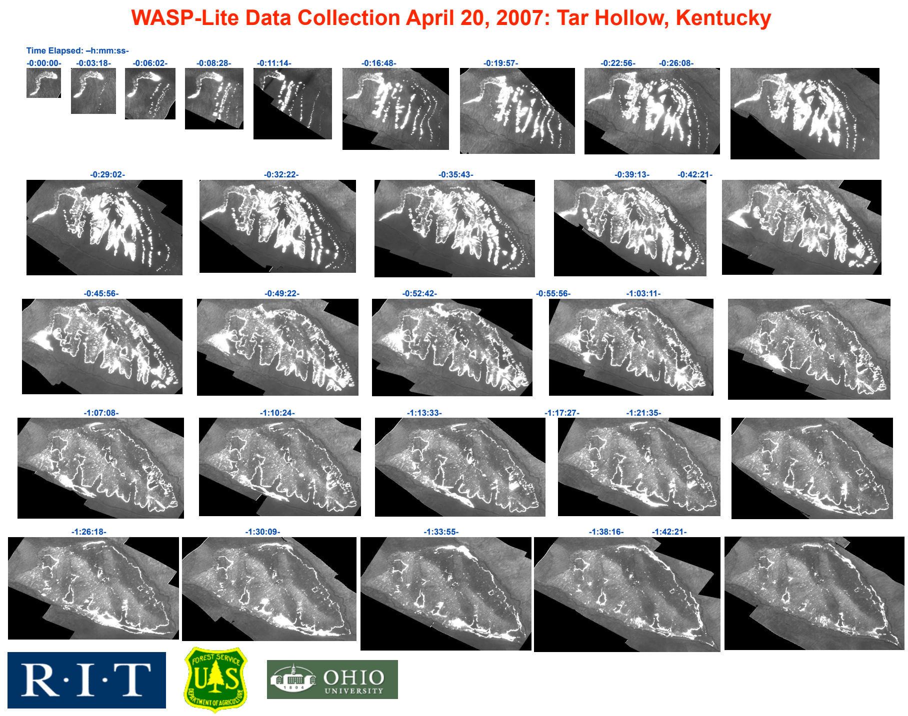


Figure 3.32-68: Time sequence overhead infrared images of a prescribed fire in Kentucky.

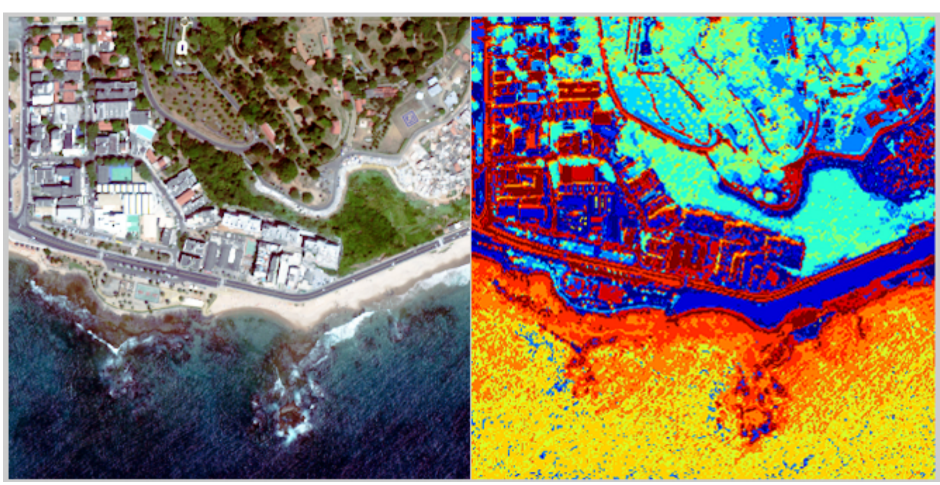


Figure 3.33-69: (Left) RGB image from the Worldview-2 sensor over an urban, coastal area. (Right) Color coded classification map after seven iterations of the modularity clustering method.

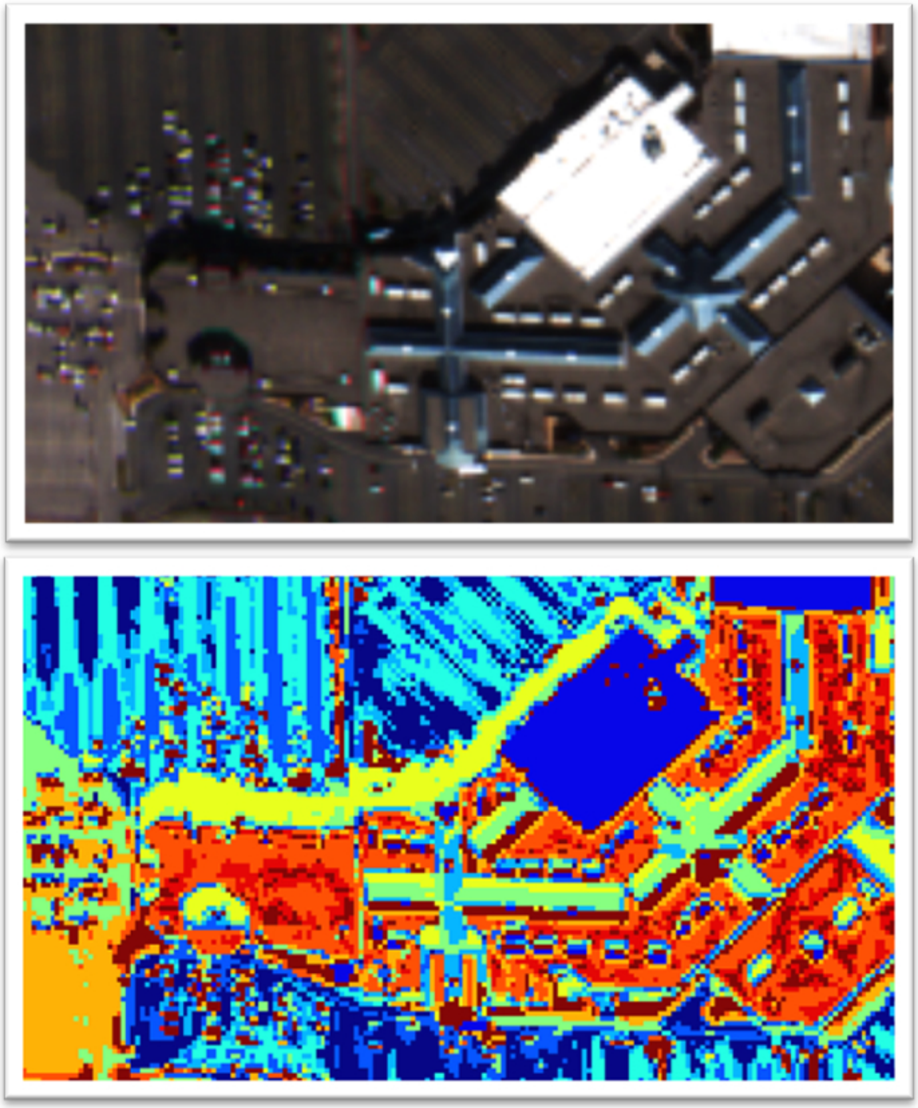


Figure 3.33-70: (Top) RGB image from the Worldview-2 sensor of a shopping mall in Rochester, NY. (Bottom) Clustering result produced with the modularity spectral clustering method.

details such as variations in the parking lots due to painted lines, visible at this spatial resolution.

Project Status:

The first effort was finished during the summer of 2010. The methods developed by Mr. Lugo will be further applied to change detection in regions such as Haiti before and after the earthquake in January, 2010. The second effort is ongoing and will continue into 2010-2011.

3.34 Feature Extraction Using Voxel Aggregation of Discrete LIDAR Data

Sponsor: LASS Partners

Principal Investigator(s): Dr. David Messinger
Research Team: Scott Brown, Shea Hagstrom (CIS - Ph.D.)

Project Description:
The introduction of lidar systems has given a new tool for remote sensing, one that is fundamentally different from previous imaging methods. Because of the ranging information provided by a lidar system we now have a means of determining precise 3-dimensional positions based on where scene objects have reflected the laser energy. This ability comes at the cost of multi-spectral information now available from many image scanners, but is invaluable in cases where the spatial structure of a scene is important to quantify.

Of the wide range of scanning lidar systems available, we are primarily interested in airborne lidar with a small imaging footprint. Our interest is in determining the scene structure down to 1-2m details, which can be provided by many current sub-meter footprint systems with a range of several kilometers. State of the art lidar systems also have the capability to record the entire reflected waveform, but in the interest of remaining compatible with many existing systems we will consider only discrete data with multiple returns.

Despite the ability to correctly register returns collected from any angle and position, most lidar is collected at near-nadir angles. This does in general give better penetration through canopies since it minimizes the total amount of occlusion the lidar beam must travel through. However, this is not true for all scenes and it may in fact be advantageous to collect lidar from multiple scan angles to increase the possibility of some canopy penetration, particularly if there is a specific region of interest.

In order to overcome this deficiency we require a metric to describe how voxels interact with the lidar beam which is constrained and consistent regardless of the system position and orientation, as well as handling differing amounts of data across the scene. One derivable measurement for a voxel is its overall transparency or, conversely, how much it occludes the lidar pulse. However, in order to know which voxels the lidar pulse has passed through we must know the point of its origin. This origin information is not typically recorded in the final point set, but is used with the system GPS/INS data during the processing from range to world coordinates. The purpose of this project is to show that recording the origin information for lidar pulses can be useful when mapping 3-dimensional structure of scenes, particularly under heavy occlusion by tree canopies where several passes by a lidar instrument from varying angles is possible. The transmission map generated by our technique has several desirable properties over the hit counting or occupied/unoccupied methods. First, the transmission values are constrained to the range [0, 1], which means it is not necessary to consider the errors that can occur when attempting to normalize the results of a hit counting method. This value is also continuous, unlike methods using an occupation metric. Second, the intensities of returns are taken into account to better estimate the energy distributions compared to many other methods.

To test the effectiveness of our technique under tree canopies we have created several scenes with varying levels of leaf density which will occlude several objects below. Our goal in creating these scenes is to include elements that incorporate features at the one meter level or smaller to determine if the resulting maps can extract these features. See Figure 3.34-71 below.

The transmission truth, visualized in three dimensions is shown in Figure 3.34-72(a) and the derived transmission is shown in Figure 3.34-72(b). Note that the use of multiple looks and the geometry of the collection in the methodology allows us to visualize the ground plane and other objects beneath the tree canopy.

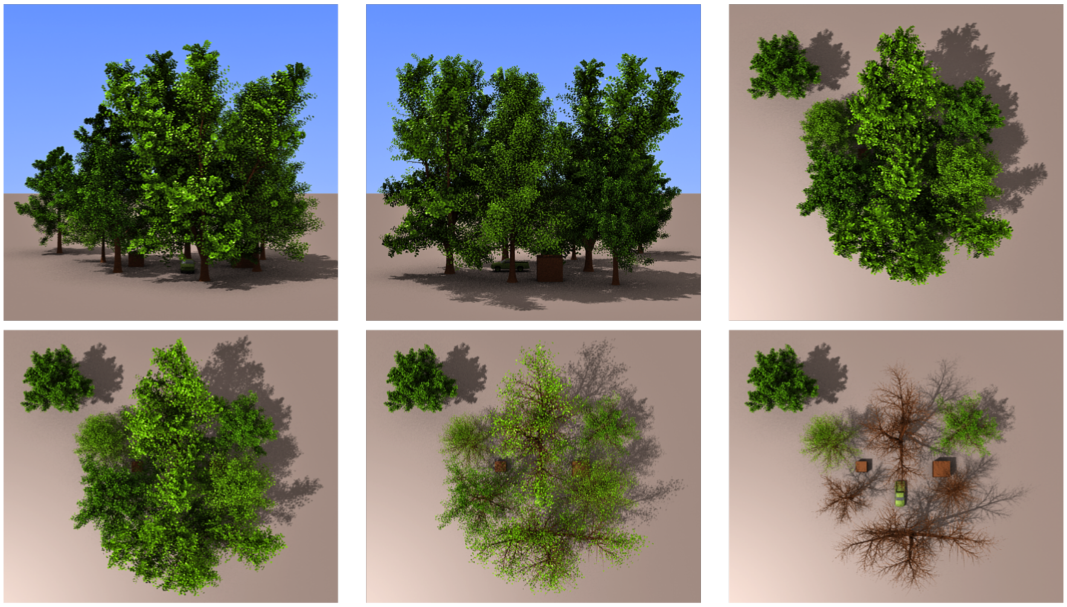
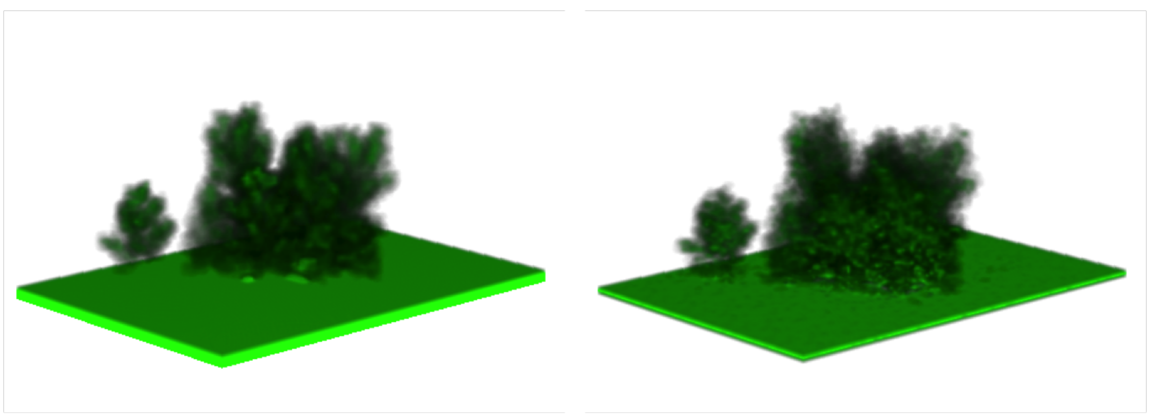


Figure 3.34-71: DIRSIG generated test scene of objects under trees of varying canopy coverage.



(a) (b)

Figure 3.34-72: (a) Transmission truth map from DIRSIG. (b) Derived transmission using the voxel aggregation method.

Project Status:

This project is ongoing. The technique is an example of how incorporating additional data sources, in this case origin information, into lidar processing can produce improved results. By recording pulse origin information instead of discarding it during the collection process we are able to derive an estimate of the light occlusion by structures in our scene. A by-product of this processing is also knowledge of areas the instrument is unable to penetrate, which is lacking from many current approaches.

By simulating several focused flights we have also showed that data collected from multiple angles can be incorporated into a single map and that the additional information can be used to increase the fidelity of the resulting map. This means that for a specific area of interest a more accurate structural map of its contents can be derived than is available from a single fly-by, and that its accuracy is relative to the amount of data collected. Further research is being conducted into the use of these techniques, combined with 3-D template matching methods, in detecting and identifying objects under tree canopies.

3.35 Airborne Imaging FTIR Trade Space Study

Sponsor: LASS Partners

Principal Investigator(s): Dr. David Messinger
Research Team: Aaron Weiner (CIS - Ph.D.)

Project Description:
Generally, one needs exceedingly narrow spectral sampling to accomplish identification of gases. When one is seeking to identify fugitive gases in particular, the lack of abundant CPL quantities and likely poor thermal contrast in the LWIR require significant sensitivity in the spectral measurement system. Further, due to the uncertainty in the location of the fugitive gas, one may need to cover a large area rapidly, suggesting the need for a mobile platform, likely an aircraft. Dispersive element spectrometer (DES) instruments require high levels of dispersion to achieve high levels of spectral resolution. The increased dispersion results in lower SNR at each spectral channel making it difficult to detect, let alone identify, fugitive gases in this manner. Another spectrometer type, known as Fourier Transform Spectrometers (FTS), generally do not suffer from reduced signal throughput at comparatively high spectral resolutions1. Through the process of optical interferogram formation, all passable wavelengths of light are used to form the interference pattern at varying optical path differences (OPD), bypassing the DES disadvantage of loss of signal due to high dispersion associated with high spectral resolution. In an FTS, longer maximum OPD (MOPD) is equivalent to higher spectral resolution.

There are multiple interrelations between performance factors in an FTS. This work is based on a basic Michelson Interferometer design under ideal optical conditions. Figure 3.35-73 shows the major contributing factors to FTS performance and their affect on SNR. In order to be able to explore the trades between the multitude of FTS performance parameters an end-to-end simulation was developed. A rudimentary airborne FTS instrument model was constructed and flown over a simulated scene and the output was subjected to a number of detection metrics to quantify differences in performance. Both the instrument model and simulated scene have multiple inputs that can be adjusted to isolate parameters of interest to accomplish a performance trade.

Figure 3.35-74 shows a plume simulated with the DIRSIG model based on the predicted plume depth and temperature from the Blackadar model. Colors in the image show the range in plume depth. While the plume does not "interact" with the trees, it is obscured by the geometry in the image.

This simulated image, along with others created both in DIRSIG and in a stand alone radiance simulation were used in the parameter trade study.

Project Status:
This project was completed during the summer of 2010. Major conclusions from the study indicated that dependent on target gas signature, platform jitter was not a limiting factor in the detection of fugitive gaseous plumes. However, atmospheric interference, from chemical constituents in the atmosphere, can impact the ability of a sensor to detect and identify the plume species depending on the location of the plume spectral signature with respect to the atmospheric signatures.

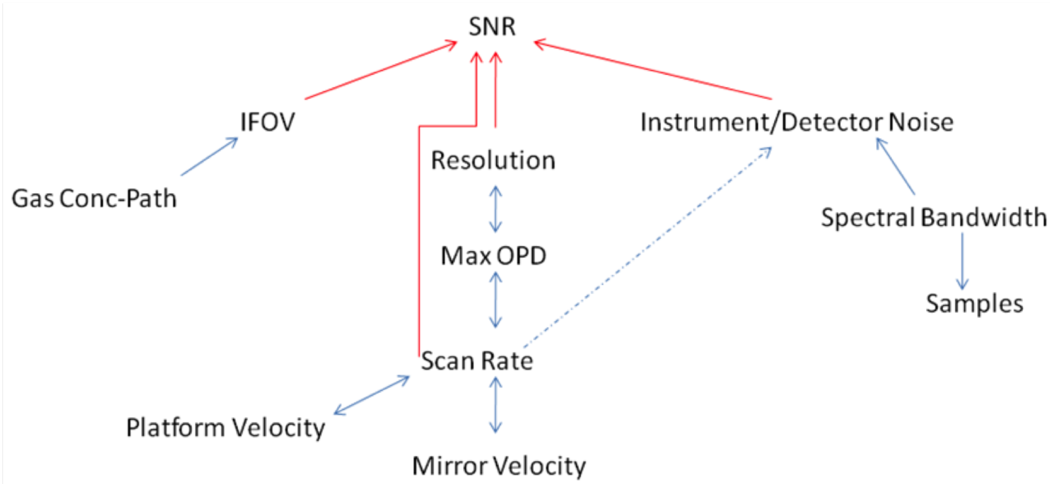


Figure 3.35-73: Parameters and their dependencies investigated in the analysis of an airborne FTIR system for gas detection and identification.

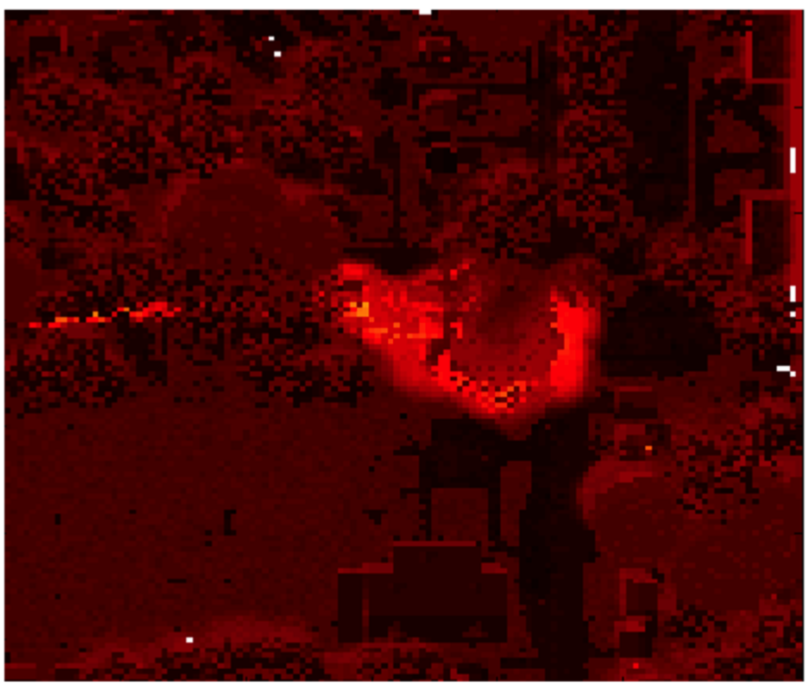


Figure 3.35-74: Simulated plume in DIRSIG inserted into tile #1 of MegaScene #1. Colors show plume depth truth.

3.36 Polarimetric / Hyperspectral Imaging Trade Space Study for Target Detection

Sponsor: LASS Partners

Principal Investigator(s): Dr. John Schott
Research Team: Brian Flusche (CIS - Ph.D.)

Project Description:
A process was developed to assess the effect of fusing polarimetric and spectral sensing modalities for an urban target detection scenario through simulation with the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model developed by the Rochester Institute of Technology. Two novel multimodal fusion algorithms were proposed - SPOT for the pixel level, and SPI for the decision level - and a series of trade-off studies were performed to analyze the performance of a variety of notional sensor configurations.

Project Status:
High value target location and tracking has been named one of the fundamental problems facing the intelligence community. Previous research efforts have attempted to address the problem by exploiting spectral information to detect targets hidden amidst a variety of backgrounds. However, the corresponding false alarm rates are often higher than desired, especially for small targets in areas with a large amount of man-made clutter such as urban environments. While spectral remote sensing has been exploited for a variety of uses, polarimetric remote sensing is a relatively new and largely undeveloped field. Anomaly detection algorithms have achieved some degree of success with polarimetric data in separating man-made materials from the natural background, but in an urban environment where a significant portion of the background is man-made, the utility of anomaly detection may be reduced. Further, polarimetric sensing has been shown to be highly sensitive to illumination conditions and viewing geometries. In an effort to overcome the limitations of each particular sensing modality, the complementary spectral and polarimetric data sets can be combined, or fused, to provide additional insight about a particular scene. DIRSIG was used to create a radiometrically accurate image of a synthetic urban scene for both spectral and polarimetric analysis, and the synthetic scene was validated quantitatively and qualitatively to ensure enough background clutter was present. Our novel spectral / polarimetric fusion algorithms performances were evaluated at 355 different sun-target-sensor viewing geometries, and a method to quantify the increase in performance was described. Tasking conditions where target detection performance was enhanced were identified and the decision fusion algorithm was shown to outperform the pixel fusion algorithm. The utility of polarimetric information varied with the sun-target-sensor geometry, but data fusion consistently enhanced spectral target detection performance when the sensor was located in the suns specular reflection lobe. Figure 3.36-75 shows that when the sensor was in the suns specular lobe, polarimetric information added significant value. Figure 3.36-76 demonstrates that when imaging from the same senor zenith angle as Figure 3.36-75, with the same solar zenith angle but a different relative azimuth to the sun, incorporating polarimetric information did not enhance performance because the upwelled radiance reduces polarimetric contrast between the target and background. Figure 3.36-77 highlights that when the sensor was placed azimuthally back in the suns specular lobe and the sensor zenith angle was changed to be near nadir, the reflected polarimetric signal weakened dramaticallyagain reducing the polarimetric contrast between the target and background.

One common approach to building new sensor systems is to recognize the reality of fiscal constraints and view cost as an independent variable. From this point of view, cost is treated as equally important as performance and schedule in program decisions. A series of trade studies were performed using the DIRSIG model to assess how varying the spectral signal-to-noise ratio (SNR), spectral ground sample distance (GSD), or target spectrum affected the impact of spectral and polarimetric data fusion via our novel decision fusion algorithm for a notional multimodal sensor.

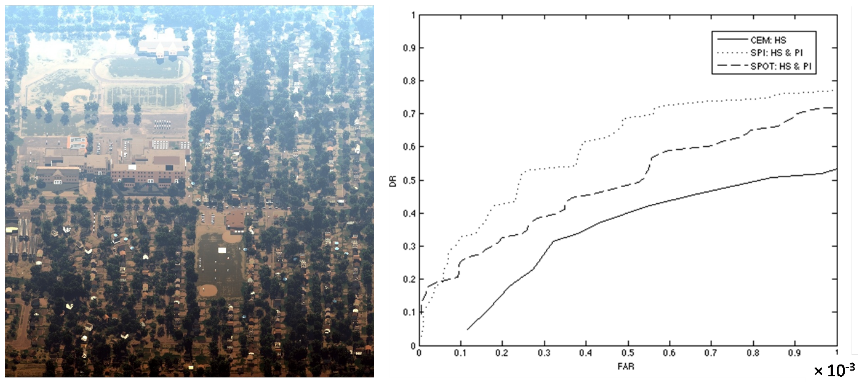


Figure 3.36-75: When the sensor is in the suns specular lobe, polarimetric information provided significant help. (Left) DIRSIG synthetic image (Right) ROC curves for SPOT pixel fusion algorithm (dashed line), SPI decision fusion algorithm (dotted line) and solely hyperspectral CEM algorithm (solid line).

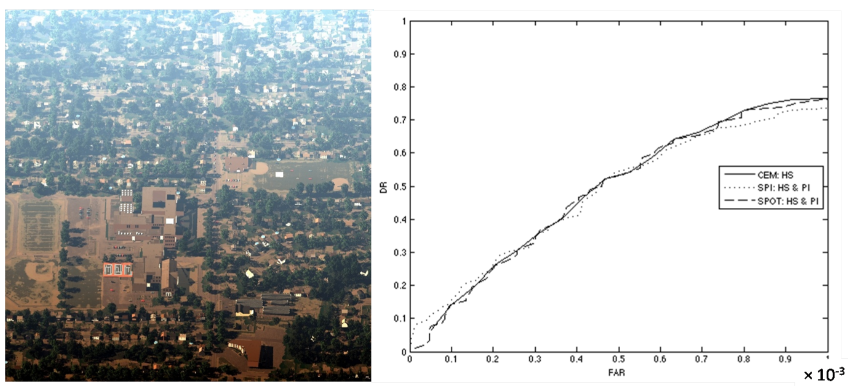


Figure 3.36-76: When the sensor is azimuthally away from the suns specular lobe, the atmosphere reduces polarimetric contrast between the target and background. (Left) DIRSIG synthetic image (Right) ROC curves for SPOT pixel fusion algorithm (dashed line), SPI decision fusion algorithm (dotted line) and solely hyperspectral CEM algorithm (solid line).

4 RIT Funded Core Research

4.1 DIRSIG Infrastructure

Principal Investigator(s): Mr. Scott Brown
Research Team: Niek Sanders, Mike Gartley and 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. We 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 fun-

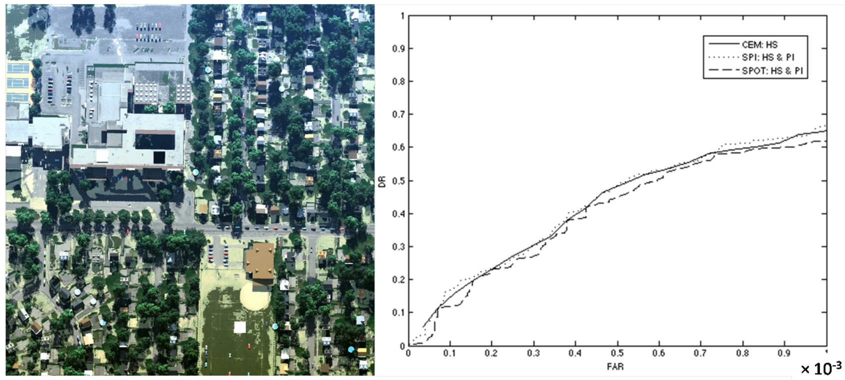


Figure 3.36-77: When the sensor is near nadir, the reflected polarimetric signal is weakened dramatically and the polarimetric contrast between the target and background is reduced. (Left) DIRSIG synthetic image (Right) ROC curves for SPOT pixel fusion algorithm (dashed line), SPI decision fusion algorithm (dotted line) and solely hyperspectral CEM algorithm (solid line).

damental funding streams for DIRSIG core development has been the DIRSIG Training Courses, which was offered on four (4) different occasions during the last year calendar, including off-site sessions in Livermore, CA and Dayton, OH.

The goal of this ongoing project is the continued improvement of the DIRSIG user experience. Specifically, to improve the utility of the tool and integration of the tool with other engineering tools commonly used alongside DIRSIG.

Project Status:
During most of the past year, the development team focused on Release 4.3. The important milestones of that effort was the continued improvements to the graphical user interface (GUI) in an effort to make the GUI an invaluable tool to new and old users. The following list highlights the new features introduced in the 4.3 release.

- Introduction of a graphical editor for mono-static LIDAR systems.
- A set of new spectrometer response import and creation wizards.
- Improvements to the channel response model which allow the user to assign linear polarizers.
- A new material database editor with interfaces to many of the advanced optical properties available in DIRSIG4.
- New platform jitter models which allow the user to model temporally uncorrelated and correlated jitter of the platform.
- The addition of new instrument mounts including the data-driven tabulated mount and the new scripted mount, which allow users to write simple programs to define periodic scan patterns.
- The ability to visualize dynamic (scanning) mounts in the user interface.
- The ability to use geo-located positions for both scene objects and the platform. This includes a new geo-location truth map that reports the latitude, longitude and altitude (WGS84) for each pixel.

- A set of new platform motion wizards that help the user quickly create specific types of collections. For example, the new ”race track” wizard allows the user to create a platform that circles around a given location.

The new polarization options in the channel response editor allow the user to include ideal, linear polarizers and to specify if the integrated radiance will be written out as either the total/unpolarized S0 Stokes Vector component of the entire 4-element Stokes Vector (see Figure 4.1-78).

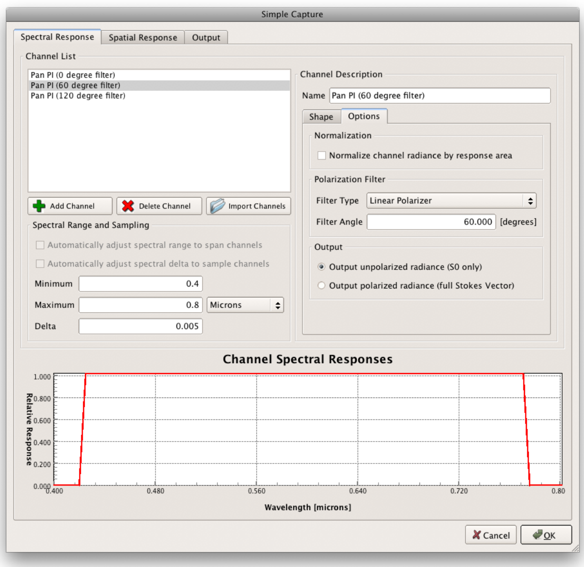


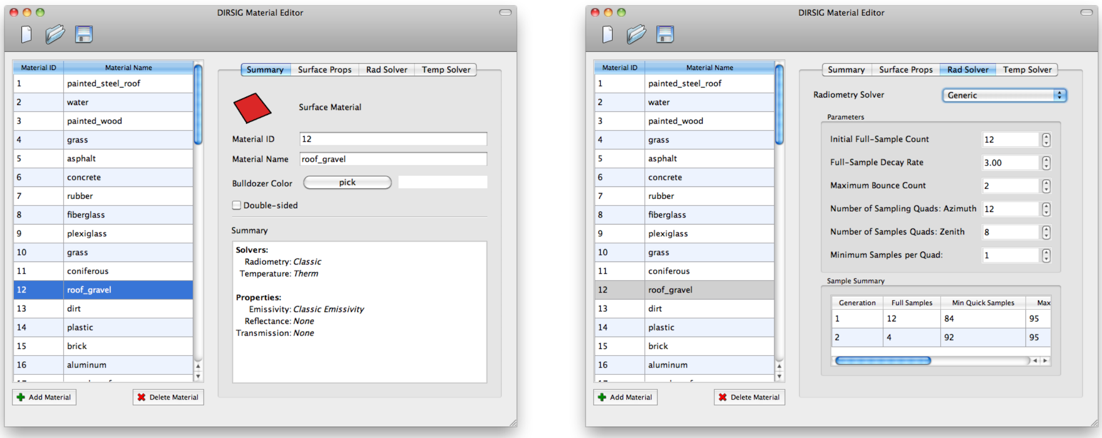
Figure 4.1-78: The spectral response editor showing the new options to add a linear polarizer to channel (see the upper right panel).

The 4.3 release also included the new material database editor which allows the user to manage a large database of materials and all of the radiometry engine options associated with them (see Figure 4.1-79).

4.2 Spatial - Spectral Classification of Environmental Change

Principal Investigator(s): Dr. Tony Vodacek
Research Team: Alvin Spivey (CIS - Ph.D.)

Project Description:
In this research project, the entire surface of the Earth is considered to be a living organism where a map of categorized landscape surfaces (*e.g.*, satellite derived Land Cover / Land Use (LCLU) classification maps, or census data) are a snapshot of biotic activity. Shape characteristics of an individual class patch and inter-relationships between class shapes along the landscape then become an indication of current and potential biotic health. As increased landscape activity alters hydrologic connectivity between landscapes, ground-water, and streams, more efficient delivery of contaminants to receiving waters is observed. Changes in LCLU are directly associated with nutrient retention capacity and soil erosion, contributing to nonpoint source contaminants; all of which are captured by observing the progressive shapes of LCLU.



(a) (b)

Figure 4.1-79: Screen shots of the new DIRSIG material database editor.

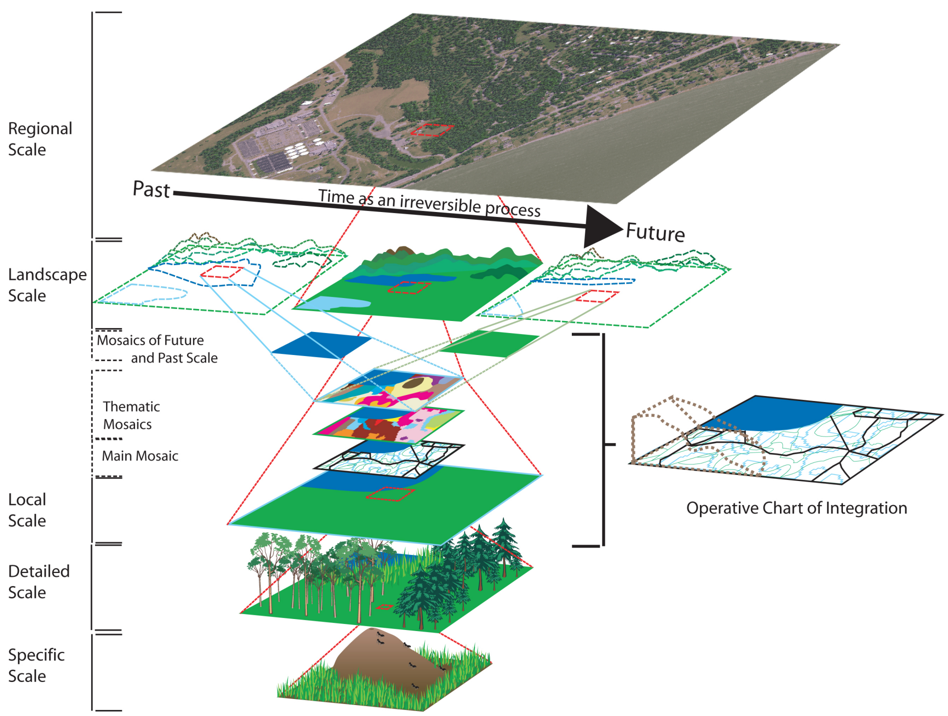


Figure 4.2-80: Structural model description showing evolution of land cover / land use (LCLU) over time and at several spatial scales.

Observing the changing shape of landscape LCLU through Fourier analysis, the relevance and reliability of this approach to monitoring water quality has been proven successful. Three independent metrics for interpreting landscape shape were developed in the Fourier domain, tested on synthetic data, and applied to the National Land Cover Database Landsat 30 [m] LCLU 1992 and 2001 data products. Performing with 98.62% accuracy when identifying fecal coliform compromised subwatersheds in South Carolina, the models and metrics developed contribute a 7.11% increase over commonly used detection methods.

Project Status:
This project will be completed in the Fall of 2010.

4.3 3D Multi-modal Registration

Principal Investigator(s): Dr. John Schott
Research Team: Lt. Col. Karl Walli (CIS - Ph.D.)

Project Description:
This research develops and improves the fundamental mathematical approaches and techniques required to relate imagery and imagery derived multimodal products in 3D. Image registration, in a 2D sense, will always be limited by the 3D effects of viewing geometry on the target. Therefore, effects such as occlusion, parallax, shadowing, and terrain/building elevation can often be mitigated with even a modest amounts of 3D target modeling. Additionally, the imaged scene may appear radically different based on the sensed modality of interest; this is evident from the differences in visible, infrared, polarimetric, and radar imagery of the same site.

To address these challenges robustly, a 'model-centric' approach to relating multimodal imagery in a 3D environment has been developed. By correctly modeling a site of interest, both geometrically and physically, it is possible to remove/mitigate some of the most difficult challenges associated with multimodal image registration. In order to accomplish this feat, the mathematical framework necessary to relate imagery to geometric models is thoroughly examined. Since geometric models may need to be generated to apply this 'model-centric' approach, this project also seeks to develop methods for deriving 3D models from imagery and LIDAR data. Of critical note, is the implementation of complimentary techniques for relating multimodal imagery that utilize the geometric model in concert with physics based modeling to simulate scene appearance under diverse imaging scenarios. Finally, the often neglected final phase of mapping localized image registration results back to the world coordinate system model for final data archival are being incorporated.

Once a target site is properly modeled, both geometrically and physically, it is possible to orient the 3D model to the same viewing perspective as a captured image to enable proper registration. If done accurately, the synthetic model's physical appearance can simulate the imaged modality of interest while simultaneously removing the 3-D ambiguity between the model and the captured image. Once registered, the captured image can then be archived as a texture map on the geometric site model. In this way, the 3D information that was lost when the image was acquired can be regained and properly related with other datasets for data fusion and analysis.

Project Status:
The challenges of multimodal 3D image registration have been addressed by using DIRSIG as a 3D physics based simulator, which is capable of generating imagery accurate enough to be registered with real dat. In order to provide nimble access to a variety of different modalities (VNIR, Infrared, SAR, Polarimetric, and LIDAR) DIRSIG was utilized to physically model a site of interest and register the resulting simulation with real Wildfire Airborne Sensor Program (WASP) imagery.

Automated multimodal registration of near-NADIR scenes has been demonstrated and oblique views should be possible when DIRSIG is used in concert with an accurate and properly oriented 3D scene model. The initial results provide good evidence that using DIRSIG as a physical modeling based "Rosetta Stone" to relate multimodal imagery is not only feasible, but, advantageous due to its extensibility into various regions of the EMS. The following provides a quick breakdown of the accomplishments that have been demonstrated:

DIRSIG as a Multimodal Rosetta Stone - Approach is Highly Extensible

- Case Studies have Demonstrated the Following for VNIR & SWIR
  - ”Multimodal Registration” is possible using DIRSIG
    - Panchromatic to RGB and SWIR
  - “Multitemporal Registration” is possible using DIRSIG
    - CITIPIX and WASP imagery taken 10yrs apart
  - “Multiplatform Registration” is possible using DIRSIG
    - CITIPIX: Film based, Color Sensor
    - WASP: Digital Focal Plane utilizing RGB/SWIR/MWIR/LWIR sensors
  - “Multidimensional (3D) Registration” is possible using DIRSIG
    - 3D influence of the terrain and buildings successfully mitigated
- Extensibility into other Spectral Regimes grows with DIRSIG
  - VNIR, SWIR, MWIR, LWIR, Polarimetric, UV, SAR, LIDAR

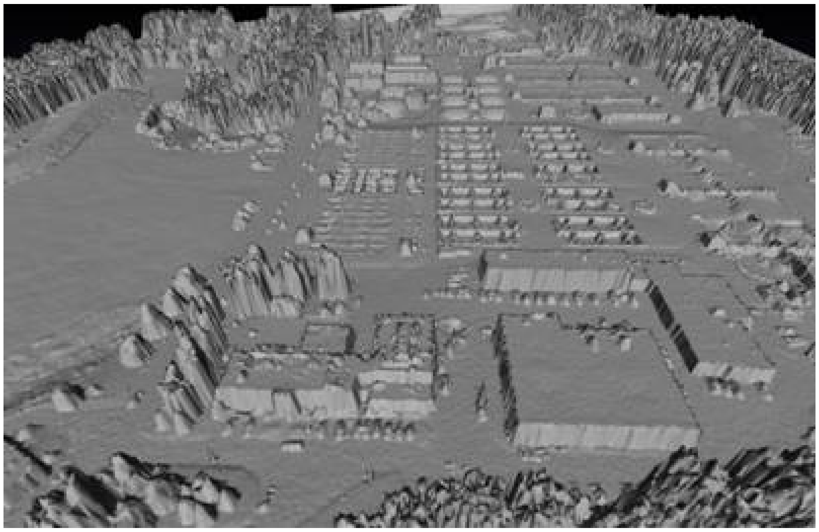
4.4 Advanced Analyst Exploitation Environment

Principal Investigator(s): Dr. John Schott
Research Team: Jake Clements (CIS - Ph.D.), Karl Walli (CIS - Ph.D.), Colin Doody

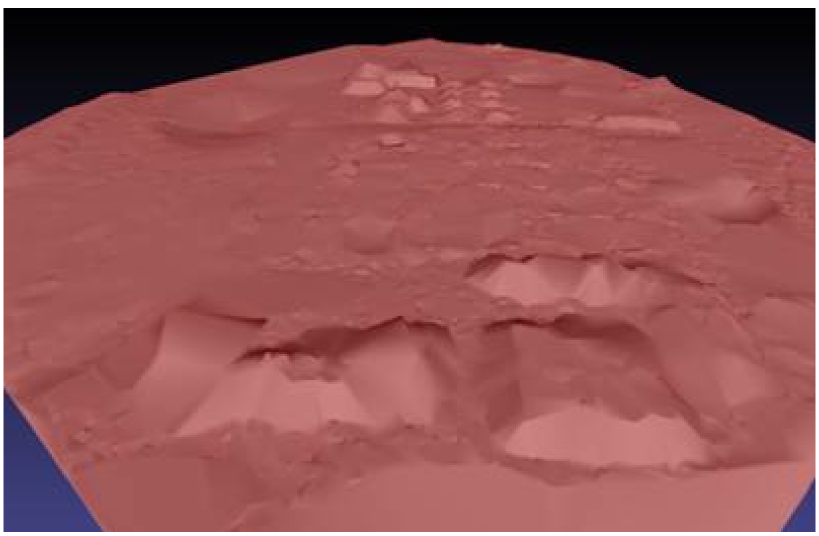
Project Description:
3-D Registration and Model Construction
The goal of this project is to design and test a new approach that can assist analysts so that they can more easily take in information, sift through historical data, and draw conclusions with higher confidence. The first step in this process is to build a model of the scene onto which all data can be registered. Scene creation in AANEE can be accomplished solely through the use of remotely sensed imagery from either multiple views from a calibrated camera or through the use of LIDAR range data. While LIDAR data can be directly used to create faceted models from a Dense Point Cloud (DPC) of the range returns (Figure 4.4-81(a)), it is also feasible to create a 3D model of the site from multi-view images (Figure 4.4-81(b)) that may initially provide an approximation of the site 3D structure.

Recovering 3D structure from 2D images requires only that the scene be imaged from two different viewing geometries and that the same features be accurately identified and related. More information on this can be found in section 4.3 on 3D multi-modal registration.

Data Visualization and Interpretation in an Interactive Environment
A 3D engine called Luster developed by Darkwind Media was utilized to build an interactive model of the site. The initial building models were provided by Pictometry, Inc. and placed on a the terrain. The environment is shown in Figure 4.4-83.



(a)



(b)

Figure 4.4-81: Demonstration of similarity of LIDAR and image derived terrains.

While using the environment an analyst may project new imagery onto the scene as seen in Figure 4.4-82. Each image can be tagged with a date so that the analyst may view the changes over time.

Exploitation Models and Results

Once we have placed the data into this environment we developed some advanced exploitation metrics. Instead of looking for anomalies in single images we used clues from all of the data to determine the processes taking place within the site. Small changes in site operations lead to small changes in the observables. These observables were then analyzed using three distinct methods of increasing complexity: template matching, cluster analysis, and statistical analysis.

Figure 4.4-82: An oblique screenshot of the Van Lare model in AANEE.

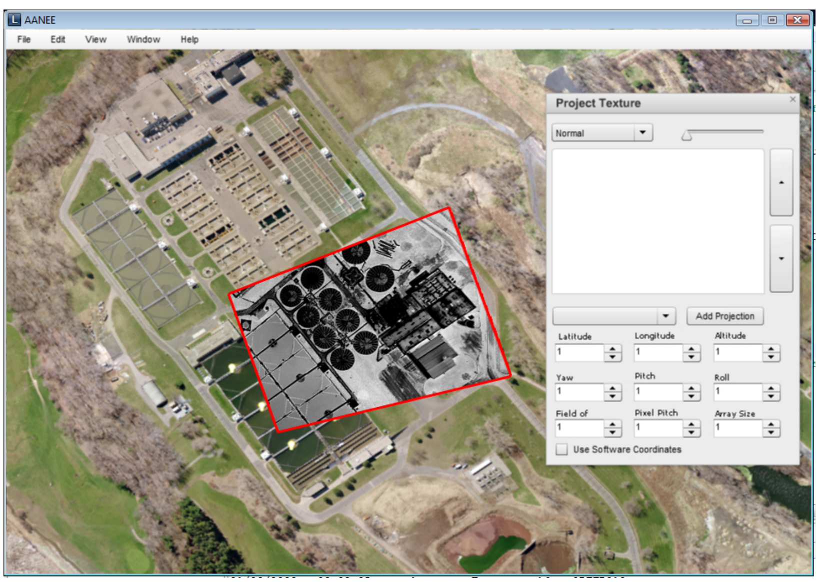


Figure 4.4-83: An image projected onto the scene in the AANEE environment.

Nailing down the manner in which the observables differentiate between operational modes at a site is a difficult task that is best left to a subject matter expert. For our site it was possible to breakdown the operational modes into low, medium, and high flow modes. At present there are seven observables that are used to differentiate these modes and more are likely to come to light as we continue to study this site.

Template matching involves creating a template for each of the three observational modes. Each template needs an acceptable value or range of values for each of the observables. Cluster analysis is done by first creating 10,000 simulated observation vectors. The vectors are then clustered using the entropy weighted k-means algorithm discussed in. The cluster centers found by the algorithm are representative of each of the three operational modes. Statistical analysis is done by taking the probability an operational mode is occurring given all of the observations. All of the observations have unknown amounts of statistical dependence. A subject matter expert was able to provide us with an initial guess as to how correlated each observation is with the mode of the plant. This allows us to sum the probability of each mode given the observation and weight it by how correlated that observable is with the operational mode.

These three metrics have been tested thus far on three real observation vectors. The results are shown in Figure 4.4-84. Given our current set of observables and our data set the statistical model appears to be the most accurate. Several more tests still need to be made, however, as three data sets are not a representative sample of the entire test space. Furthermore, the three data sets used here were all gathered while the plant was operating in its medium flow mode. Future work will center around gathering all of the observables as well as the truth information for newly acquired data sets.

	Template	Cluster	Statistical	Actual Flow (Mgal)
July 24, 2007	28.6 / 71.4 / 0.0	33.3 / 60.5 / 6.2	8.2 / 86.6 / 5.2	88.6 (low end Medium)
August 1, 2007	57.1 / 42.9 / 0.0	31.6 / 62.9 / 5.5	10.0 / 85.7 / 4.3	78.3 (low end Medium)
May 3, 2008	42.9 / 57.1 / 0.0	33.1 / 59.1 / 7.8	9.8 / 77.8 / 12.4	99.12 (Medium)

Figure 4.4-84: Probabilities of each flow rate on real data (Low/Medium/High).

Project Status:
This research is ongoing and focusing more on the multi-modal analysis portion of the project.

4.5 Polarimetric Imaging Trade Study

Principal Investigator(s): Dr. John Schott
Research Team: Chabitha Devaraj (CIS - Ph.D.), Dr. Mike Gartley

Project Description:
The vector directional property of radiation from a remotely sensed surface, indicated by polarization, varies with different scene related parameters such as illumination type, observation time, atmospheric condition and object geometry. This variability will influence the separability of materials in the scene and therefore it is important to identify the imaging configurations that maximize the material discriminability in polarimetric images. Moreover, sensor viewing geometry will introduce additional variability in the observed polarization information and therefore polarization physics needs to be incorporated in approaches that aim to maximize material discriminability in polarimetric images. A polarization physics based approach that utilizes the angular variation in the polarization response to infer the physical characteristics of the observed surface by imaging the scene in three different view directions was proposed. The usefulness of the proposed approach in improving detection performance in the absence of apriori knowledge about the target geometry was demonstrated for a scene shown in Figure 4.5-85. This cluttered scene includes different background materials such as grassland, tree canopy, soil, asphalt and man made objects like green, red, black and white glossy painted hemispherical targets. The color of the circle around the target indicates the color of the target, except blue circles correspond to glossy black targets. The solid circle corresponds to targets under direct solar illumination while the dashed circle corresponds to targets in shadow. Target discriminability analysis was performed by analysis of DIRSIG simulated data to identify the improvement in the image contrast using polarization information. Figure 4.5-86(a) presents the true color composite of

the intensity image and Figure 2 (b) presents the color composite image formed using orthorectified DOP images observed at different sensor zenith angles at 20°(red), 40°(green) and 60°(blue). In both cases the images were acquired at 6 am in the forward scattering direction, which can be further verified from the shadows in the scene. Also, the inverse relationship between the intensity and DOP images can be confirmed by comparing the white and black targets in 4.5-86 (a) and 4.5-86 (b). Different colors observed on the target illustrate that the observed polarization is a function of the scattering angle and therefore varies for different target surface orientation and sensor viewing angle. This demonstrates the usefulness of multi view polarimetric images in improving the target contrast when multiple targets with different surface orientations are present in the scene. In addition, the DOP images are independent of illumination type which makes them very valuable in cases of poorly illuminated scenes where the spectral sensors show poor target discriminability. Also, sensitivity analysis of the proposed system for different scene related parameters was performed to identify the imaging conditions under which the detection performance was maximized.

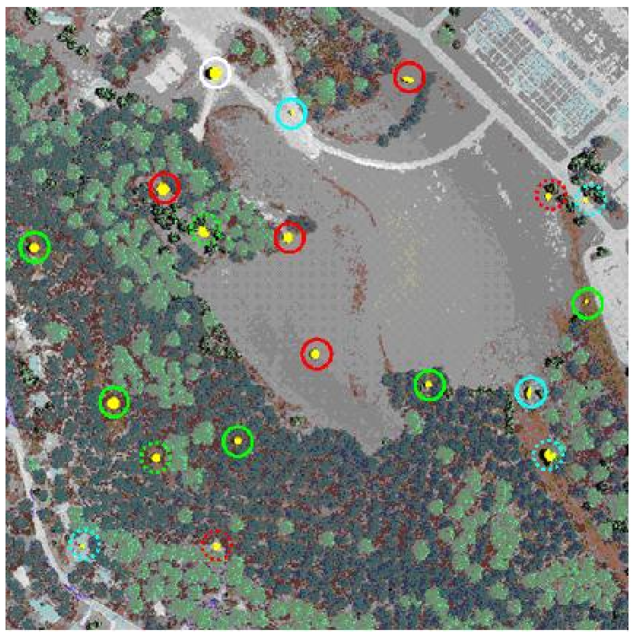


Figure 4.5-85: DIRSIGMegascene target layout used in polarimetric imaging trade study.

Project Status:
This project is scheduled to be completed in the Fall of 2010.

4.6 In-Water Radiative Transfer Modeling in DIRSIG

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

Project Description:
Sensor reaching radiance in coastal ocean-water environments contains contributions from the air-water interface, in-water objects, and the participating volume itself. In a synthetic image generation model, the

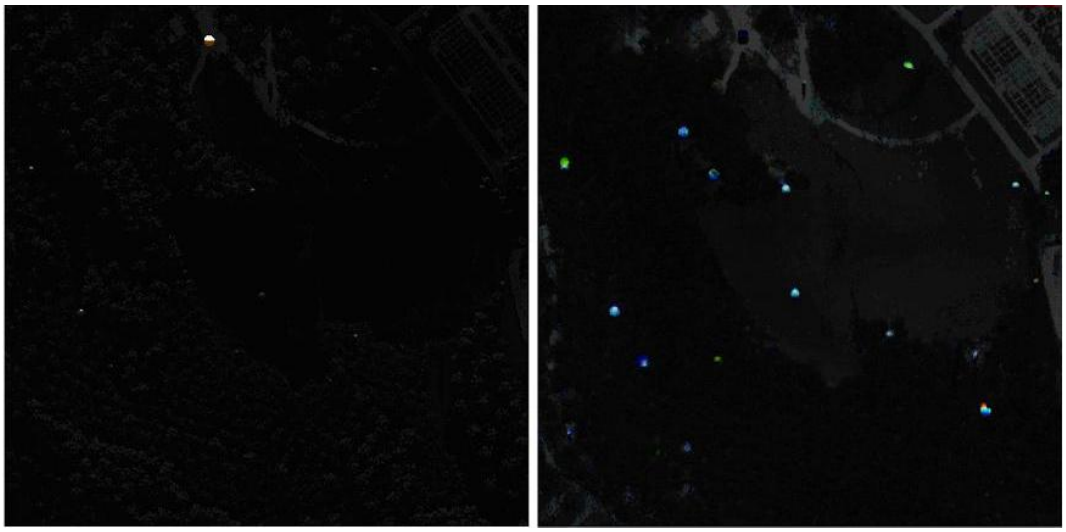


Figure 4.5-86: (a) True color composite image formed using red, green and blue bands, (b) Color composite image formed using DOP at different view angles (with 20°, 40°and 60°corresponding to red, green and blue respectively) acquired at 6 am with solar zenith of 80°in the forward scattering direction.

expected imagery must account for several interesting phenomenon, including, but not limited to; volumetric scattering, shadows, skyfraction, background reflections, and reflective and transmissive contributions that are a function of capillary and gravity waves (e.g caustics, solar glint, etc.). DIRSIG models the radiative transfer process in this complex environment using a combination of sophisticated raytracing and photon mapping techniques. This research validated the radiometric modeling process used by DIRSIG when rendering coastal environments with significant contributions from in-water objects.

The validation had three major phases. The first phase considered the absolute radiometric fidelity of DIRSIG modeled sensor reaching radiance. This fidelity was evaluated by comparing DIRSIG modeled results to those predicted analytically, by comparison with independent numerical models, and by comparison with observed field phenomenology. This is illustrated in Figures 4.6-87 and 4.6-88 which demonstrate DIRSIG's ability to model phenomenology that occur within a horizontally invariant water column[1], and one that is disrupted by the presence of a floating obstruction[2], respectively.

The second phase addressed image quality concerns that are a function of the computational mechanism and configuration used during image generation. The primary goal of this phase of the research was to provide the user with a first-order estimate of the variance and bias that can result as a function of the user-specified solution configuration. Results were based on the image transfer of slanted edges, fixed at various depths, and viewed through water columns with various degrees of turibidy. Spectral considerations also assessed the utility of generating single-band images sequentially, versus full multi-band simulations in parallel. An example is shown in Figure 4.6-89.

The final phase was to prepare visual demonstrates that highlight DIRSIG's ability to render complex coastal ocean-water scenes, proving that the full systems performs the way we expect it to based on the performance of individual parts. Collectively, all phases of the research indicate that DIRSIG can successfully

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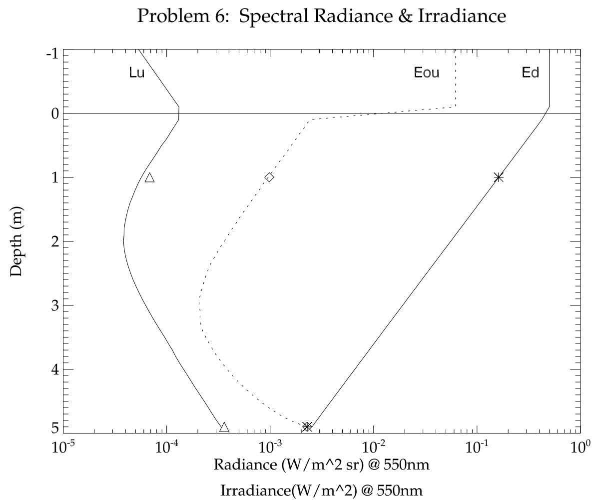

Figure 4.6-87: DIRSIG modeled results for canonical problem #6 after tracing 1 million photon histories. Each curve is labeled as either scalar upwelling irradiance [E_{ou}, dotted line], downwelling irradiance [E_d, solid line], or upwelling radiance [L_u, solid line]. The symbols (triangles, diamonds and asterisks) are the mean expected values at the full reference depth (5.0 m) and 1.0 m below the air-water interface.

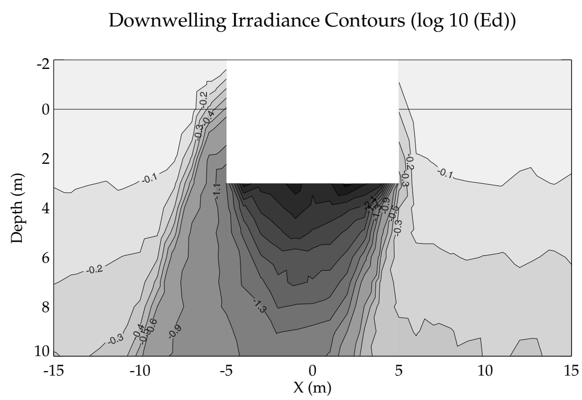

Figure 4.6-88: Normalized log_{10} downwelling irradiance at 532 nm as a function of depth and distance from a floating obstruction (centered at 0.0 m along the x-direction). The results are based on tracing more than 100,000 photons per cubic meter in the volume, and more than 240,000 photons per square meter on the ground surface. DIRSIG shows good agreement with independent numerical predictions.

recreate complex system-wide phenomenological events that include any number of spectrally variant parameters, generating radiometrically accurate hyperspectral imagery of participating media.

Project Status:
The validation work was completed August 2010.

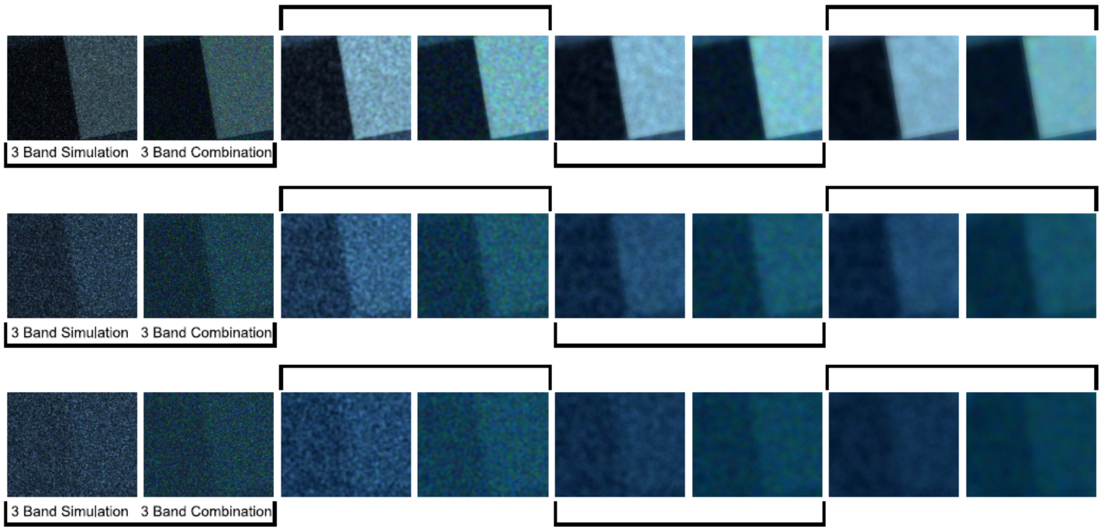

Figure 4.6-89: Each row represents a fixed target depth from the surface (*e.g.* 1.0, 2.5 and 3.5) (top to bottom). Columns are paired. In each pair, the left-most column depicts the multi-band simulation, and the right-most column depicts the combined single-band simulations. There are a total of 4 pairs, using photon mapping search radii that increase from left to right (from 0.25, 1.0, 2.0 and 3.0m). Results show that DIRSIG effectively utilizes variance and bias-reduction tools during simulation.

5 The DIRS Annual Research Symposium, June 8 - 9, 2010

The DIRS Annual Research Symposium was another successful event during which the DIRS laboratory presented the accomplishments to invited collaborators, sponsors, and other interested parties over the course of 2 days. Attendance at the symposium by outside visitors was approximately 35 persons across government, industry, and academia. The event started with an overview presentation on the "state" of the lab followed by 10 technical talks on Day 1. The second day continued with 14 shorter presentations. In all, there were 24 technical talks, of which 13 were contributed by graduate students in the DIRS laboratory.

The presentations were recorded and both the videos of the talks and the slides used are available on the DIRS web page at:

http://dirs.cis.rit.edu/special_events/annual_research_symposium/dars2010.

(a)

(b)

Figure 5.0-90: The DIRS Annual Research Symposium held on June 8-9, 2010.

6 Publications During This Period

[1] M. Montanaro, *Radiometric modeling of mechanical draft cooling towers to assist in the extraction of their absolute temperature from remote thermal imagery*. Ph.D. dissertation, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York, United States, May 2009.

[2] S. Higbee, *A Bayesian Approach to Identification of Gaseous Effluents in Passive LWIR Imagery*. Ph.D. dissertation, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York, United States, August 2009.

[3] A. Gerace, *Demonstrating Landsat's New Potential to Monitor Inland and Coastal Waters*. Ph.D. dissertation, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York, United States, April 2010.

[4] A. Schlamm, *Characterization of the Spectral Distribution of HSI for Improved Exploitation*. Ph.D. dissertation, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York, United States, April 2010.

[5] T. Rizzuto, "Low-SNR sensor framework incorporating improved nighttime capabilities in DIRSIG," MS dissertation, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York, United States, July 2009.

[6] M. Zelinski, "Space telescope image simulation tool," MS dissertation, Rochester Institute of Technology, College of Science, Center for Imaging Science, Rochester, New York, United States, July 2009.

[7] E. J. Ientilucci and P. Bajorski, "Hyperspectral target detection in a whitened space utilizing forward modeling concepts," *Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing* **1**, June 2010.

[8] S. Matteoli, E. J. Ientilucci, and J. P. Kerekes, "Operational and performance considerations of radiative transfer modeling in hyperspectral target detection, submitted to transaction in geoscience and remote sensing," *IEEE Transactions on Geoscience and Remote Sensing* **2**(1), 2010.

[9] D. W. Messinger, A. Ziemann, B. Basener, and A. Schlamm, "Spectral image complexity estimated through local convex hull volume," *IEEE Proceedings of 2nd WHISPERS Workshop* **2**(1), 2010.

[10] S. Matteoli, E. J. Ientilucci, and J. P. Kerekes, "of radiative transfer in physics-based models for an improved understanding of empirical hyperspectral data," *Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing* , August 2009.

[11] S. Matteoli, E. J. Ientilucci, and J. P. Kerekes, "Forward modeling and atmospheric compensation in hyperspectral data: Experimental analysis from a target detection perspective," *Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing* **1**, August 2009.

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[14] J. T. Casey and J. P. Kerekes, "Misregistration impacts on hyperspectral target detection," *Journal of Applied Remote Sensing* **3**, February 2009.

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