DIRS

Annual Report 2002

of the
Frederick & Anna B. Wiedman Professor
on the
Activities of the Digital Imaging and Remote Sensing (DIRS) Laboratory

prepared by
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1 FOREWARD

This year, like last, saw substantial growth and change in the DIRS Lab. This summer, as the academic year closed, we welcomed back Dr. Carl Salvaggio to a faculty role. Carl had been a member of the DIRS staff in the mid nineties and even earlier he was a student in the Center. After several years in industry, he was lured back by the exciting activities the Lab is engaged in and the opportunity to work with students. We also brought in Dr. David Messinger, Timothy Hattenberger and Paul Lee to augment the staff along with Ambrose Ononye as a Post Doctoral Researcher. A full listing of the faculty and staff is contained in the Personnel section. A major contribution to this year's growth has been the ramping up to support a Multidisciplinary University Research Initiative (MURI) grant the DIRS group was awarded at the start of the year. This large multiyear grant focuses on development of hyperspectral algorithms employing physics based models to augment or drive algorithm performance. It draws on the DIRS group's focus on imaging spectroscopy, that is embodied in the Laboratory for Advanced Spectral Sensing (LASS) initiative we announced last year and our long-term focus on modeling, most visibly embodied in the DIRSIG synthetic image generation model. This exciting new program will allow us to merge these RIT strengths with expertise from our collaborators at Cornell University and the University of California at Irvine to develop a new family of advanced hyperspectral imagery exploitation algorithms. The DIRS activities include major thrusts in instrumentation and measurement, modeling and simulation, advanced algorithms and applications. This report contains a brief description of many of the DIRS group technical activities this year along with a summary of our outreach efforts designed to share with K-12 students and the local community our excitement about the opportunities and scientific advances being made by remote sensing and imaging science. This report by its nature just touches the surface of most of our research activities. We invite the curious reader to consult the literature cited throughout the report and in the Publications summary or to contact us directly.

Change is always a source of stress within an organization and the last several years of growth have placed a substantial burden primarily on the research staff. These individuals have worked diligently to take on the extra burden of growth as we have struggled to add additional staff and students to support our expanding research commitments. Inevitably during this type of growth there is a lag between demand and our ability to meet that demand with increased personnel trained to respond to the advanced scientific challenges we ask of our staff and students to meet. I want to applaud and thank the DIRS staff for the efforts they have made to meet not only the technical challenges and the extra workload but at the same time to welcome and nurture the new staff and the always-new students into the group. The dedication of this group both to scientific integrity and discovery and to the ongoing nurturing of the next generation of scientists rest on the past success and the future possibilities of the DIRS Lab. I want to take this opportunity to thank these very talented scientists and educators and to dedicate this year's report to their efforts and success.

John R. Schott
December 2002

2 BACKGROUND

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 extraction of information from remotely sensed images of the earth and the education of students to continue this work for the government and industry.

The Lab includes 15 faculty and staff working with approximately 30 students from the Baccalaureate through the Doctoral level. Most of the students are degree candidates in Imaging Science but graduate Computer Science students are often part of the mix and this year, we had interns from local high schools and a number of undergraduate Physics and Engineering students.

This report summarizes the recent activities of the DIRS Lab as well as the activities of the Frederick and Anna B. Wiedman endowed professorship. The professorship was created by Frederick Wiedman Jr., to honor the memory of his parents and to promote excellence in scholarship and teaching in the field of Imaging Science. Dr. Schott had the honor of being appointed to the chair in January 1997.

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4 PROJECT DESCRIPTIONS

4.1 GENERAL

This section contains results of individual projects not specifically under the umbrella of the FIRES, MURI, or LASS programs.

4.1.1 Conesus Lake Project

A newly funded project in 2002 for DIRS is titled “Experimental Manipulation of Entire Watersheds through BMPs: Nutrient Fluxes, Fate, Transport and Biotic Responses.” This project is funded by the USDA through a subcontract to SUNY Brockport. The project co-PIs are Drs. Joe Makarewicz (SUNY Brockport) and Sid Bosch (SUNY Geneseo), who are studying how nutrients in farm runoff entering specific tributary streams effect the growth of algae and plants in Conesus Lake. DIRS is providing project direction related to remote sensing, aquatic optics and hydrodynamic modeling. The hydrodynamic modeling is intended to better our understanding of how sediments and nutrients that enter the lake via the study streams ultimately distribute within the lake.

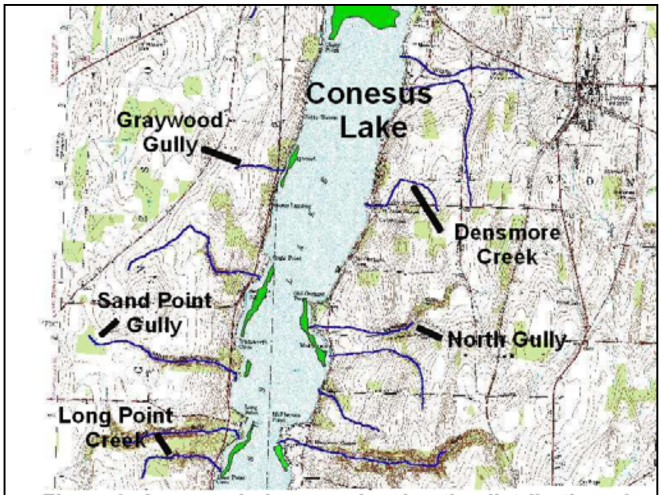


Figure 2. Conesus Lake map showing the distribution of macrophyte beds (in green) relative to selected creek mouths

RESEARCH TEAM

Yan Li, Nina Raqueño, Anthony Vodacek

4.1.2 Mapping nuisance algae along the western New York shore of Lake Ontario

The purpose of this research is to combine hyperspectral imagery with field collect data in order to map chladophora algae growing on the bottom of Lake Ontario along the shoreline of western New York. Monroe County, Finger Lakes – Lake Ontario Watershed Protection Alliance and the Great Lakes Protection Fund, has provided the funding for this project. Chladophora algae has increased in Lake Ontario as the lake has become more clear in recent years, apparently because zebra mussels are removing planktonic algae. The increased light penetration has allowed the bottom dwelling algae to thrive (Figure 1). Chladophora attaches itself to rocky bottom such as cobble or bedrock. In the summer months the algae dies off and becomes detached from the rocks and washes ashore where it decays. The rotting algae promotes the growth of bacteria, which not only makes the beaches aesthetically unpleasing but also hazardous to health. There have been numerous beach closings because of this nuisance algae. Our work is intended to provide images that will be useful in providing a large-scale view of the problem and potentially aiding in management decisions.

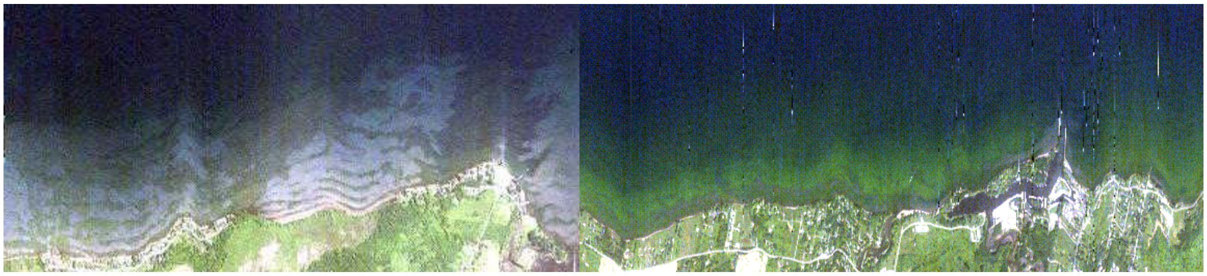


Figure 1: MISI images of Payne Beach (left) and Wilson, NY (right) showing detailed bottom features and abundant algal growth in the near shore area.

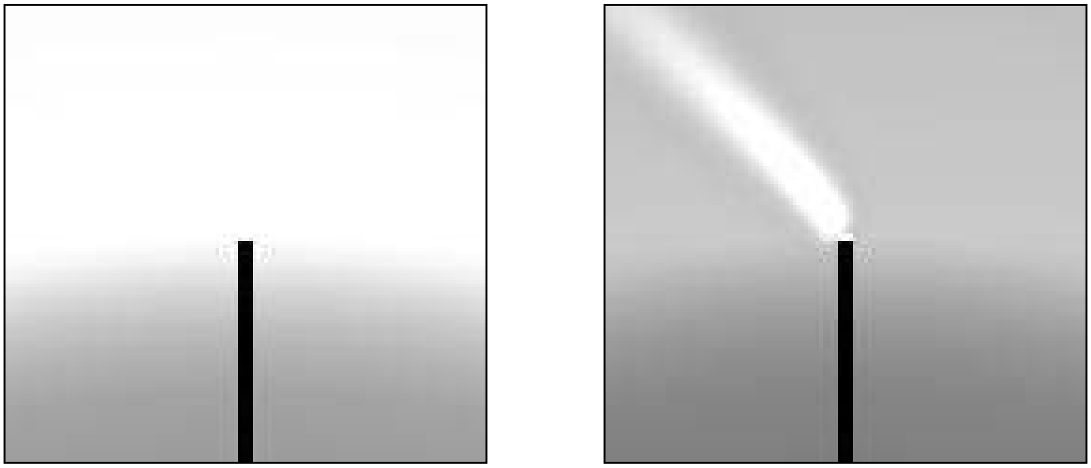
RESEARCH TEAM

Aleksey Tentler, Nina Raqueño, Anthony Vodacek

4.1.3 Factory Stack Modeling

Treaty enforcement and environmental regulations are two of the major driving forces behind this research. The goal is to support the design of sensors that can be deployed in the field to measure factory stacks and plumes. In addition, it is important to know the environmental conditions that will result in the greatest probability for success in measuring the stacks and plumes with the sensor. It is an interesting problem in the sense that rather than looking down through the atmosphere, at a ground target, as oftentimes is done in remote sensing, the idea is to have a portable sensor looking up at the stack, with the sky as the background. This makes some problems easier to handle, but also introduces others. The goal of this research is to develop a numerical model of a factory stack and an associated plume as viewed by the potential sensors.

There are many tools available to model plumes, two of which are currently available within the DIRS group. These two models are the JPL or Gaussian model and the slightly more sophisticated CALPUFF model. The JPL model is more robust to date, and is the model we are currently using to run the simulations. However, through the Generic Plume Interface (GPI) of DIRSIG, our synthetic image generation tool, the inputs are the same. These inputs include details of the stack geometry, stack effluent and several atmospheric parameters. The JPL plume model is integrated into DIRSIG, so we are able to create synthetic hyperspectral images of the stacks and plumes. A lot of time has been spent characterizing the JPL plume model. For the most part, we have a good understanding of the limitations of the JPL model. To date, we have been able to create synthetic imagery of a stack and plume in a DIRSIG scene. We have also begun to exercise the plume model by varying the input parameters. We are currently developing a figure of merit to quantify the detectability of the plume under different conditions. The next steps are to apply the metric to different images, and then create a database of imagery. Once we have the imagery, and stack characteristics of interest, we can introduce sensor characteristics, and compare the synthetic imagery to truth data.



These two figures are synthetic images of a stack with SO_2 as the effluent. The image on the left shows one band of the cube that is not centered on the absorption feature of SO_2. The image on the right is a band of the image cube centered on the main absorption feature of SO_2. It shows the plume in emission against the 'cold' sky background. It is observed that the plume emission decreases both as a function of downwind distance, and radial distance from the plume centerline.

REFERENCES

Kuo, S., Schott, J.R., and Chang, C., "Synthetic image generation of chemical plumes for hyperspectral applications," Optical Engineering 39(4), 1047-1056, 2000

RESEARCH TEAM

Timothy Hattenberger, David Messinger, Carl Salvaggio, Scott Brown, Erin O'Donnell

4.1.4 Landsat Radiometric Thermal Calibration: Towards a 20 Year Record of Calibrated Thematic Mapper Class Data

The research focus for the Landsat Radiometric Calibration project included continued monitoring of Landsat ETM+ thermal bands and further refinement of the Landsat TM calibration history. This calibration is essential to users of this thermal data since the Landsat system of instruments are intended for long-term studies of the earth.

4.1.4.1 Landsat TM

Landsat TM has been in use since 1984 and is still active. Until recently there has not been a rigorous study of the performance of its thermal band. The users of this thermal data had been using the data without knowing the status of the instrument. Over the years the instrument has had the potential to drift in calibration, especially since the instrument has surpassed its expected lifetime. In fact, when Landsat ETM+ was launched in 1999 there had not been a systematic check of thermal calibration of Landsat TM since shortly after its launch. Taking advantage of the fact that the two sensors, Landsat TM and ETM+, were simultaneously operational, a cross-calibration was possible. As Landsat ETM+ maneuvered into its orbit, it passed under Landsat TM's path resulting in both sensors having common spatial and temporal coverage. Using this common data the calibration of Landsat TM was shown to be within measurement error (i.e. better than ok). A historical calibration was also performed on Landsat TM's thermal band. This was done using various Landsat TM images of the Great Lakes from when it was launched in 1984 to 1999. Early spring images of the Great Lakes were used because of the thermal bar phenomena that occurs. The thermal bar creates a boundary of known temperature with-in the center of the lake. This known temperature boundary is used as a calibration reference. This historical calibration revealed that Landsat TM's thermal band has been operating nominally, within the uncertainties of this approach, over its lifetime (Figure1).

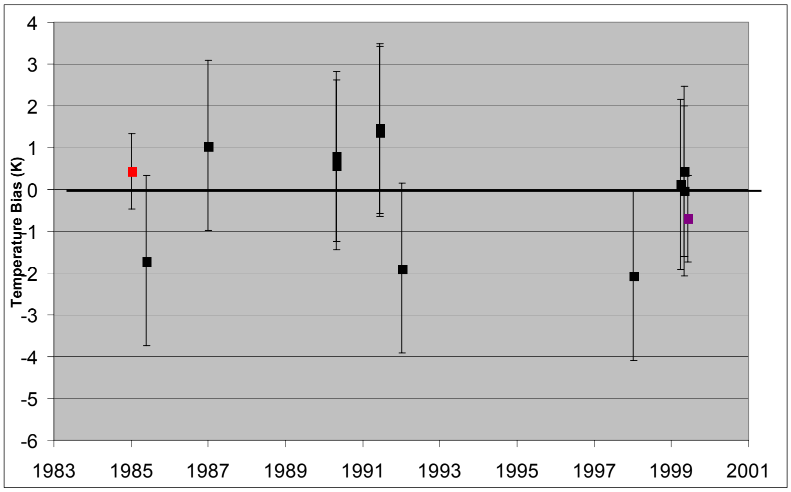


Figure 1:This graph represents the resulting TM calibration bias determined for specific years.

Currently two additional calibration techniques are being investigated to further refine the historical behavior of the thermal band and reduce the errors in the process. The first technique uses ship based temperature measurements taken within the Great Lakes over the years. The second technique takes advantage of the fact that Landsat TM and ETM+ are only offset by one day (Figure 2). The high thermal inertia of the massive Great Lakes will be used to cross calibrate TM to the well-calibrated ETM+.

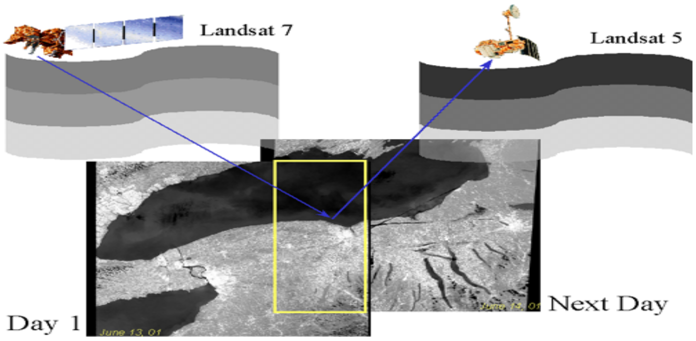


Figure 2: Landsat ETM+ & TM overlap region offset by one day

Current cross calibration results from the cross over studies suggest that Landsat 5's thermal band has remained in nominal specification since launch. After correcting for the shutter variation the residual difference between Landsat 7 and Landsat 5 shows up as a bias of 0.695 K. While the cross calibration period provided a snapshot view of Landsat 5's current status, a more thorough investigation of the historic behavior of Landsat 5 is ongoing.

4.1.4.2 Landsat ETM+

The fundamental goal of this project is to evaluate the thermal calibration of Landsat ETM+. Based on the 1999-2000 investigation it was determined by the RIT team that Landsat ETM+ image radiances were too high by $0.275\, W / m^2 sr \mu m$, or about 2K. During this phase of the project, additional ground truth was collected to further monitor Landsat ETM+. Table 1 summarizes the dates water temperatures were collected in the Rochester region.

The analysis of the 2001 season was based primarily on surface temperature measurements. Ground truth surface temperatures were converted to surface-leaving radiances and extrapolated to space using MODTRAN. The additional data collected in 2001 shows that the Landsat ETM+ instrument is still in thermal calibration. Combining the data collected in 2001 produces a bias of 0.23K shown in Figure 3. The compiled data from 1999-2001 is shown in Figure 4. The black line represents the Landsat predicted values after the bias correction was applied. The bias correction value of $0.283\, W / m^2 sr \mu m$ was applied by the Landsat Project Science Office based on the combined results of RIT and JPL calibration teams. The 2001 ground truth measurements indicate that this correction is still applicable.

The additional monitoring of Landsat 7 indicates that it remains stable and the initial bias calibration of $0.283\, W / m^2 sr \mu m$ is still applicable. DIRS is continuing its efforts to monitor and update the thermal calibration of the ETM+ sensor with additional ground truth observations. Thermal data from RIT's hyperspectral imager, MISI, will be used to augment ground truth observations.

Date	Sensor	Path/Row	MISI Imagery
19-Apr-01	Landsat 7	P16/R30 (D)	Lake Ontario
26-Apr-01	Landsat 7	P17/R30(D)	None
5-May-01	Landsat 7	P16/R30(D)	None
14-May-01	Landsat 7	P111(N)	None
30-May-01	Landsat 7	P111(N)	None
6-Jun-01	Landsat 7	P16/R30(D)	None
13-Jun-01	Landsat 7	P17/R30(D)	None
14-Jun-01	Landsat 5	P16/R30(D)	None
17-Sep-01	Landsat7, MTI, EO1	P17/R30(D)	None
7-Dec-01	Landsat 5	P16/R30(D)	None
28-Mar-02	Landsat 7	P17/R30(D)	None
15-May-02	Landsat 7	P17/R30(D)	None
11-Jul-02	Landsat 7	P17/R30(D)	None
3-Aug-02	Landsat 7	P17/R30(D)	None
12-Aug-02	Landsat 7	P16/R30(D)	Lake Ontario
28-Aug-02	Landsat 7	P16/R30(D)	Lake Ontario
4-Sep-02	Landsat 7	P17/R30(D)	Lake Ontario, Conesus

Table 1: Summary of Ground Truth Measurements for 2001-2002

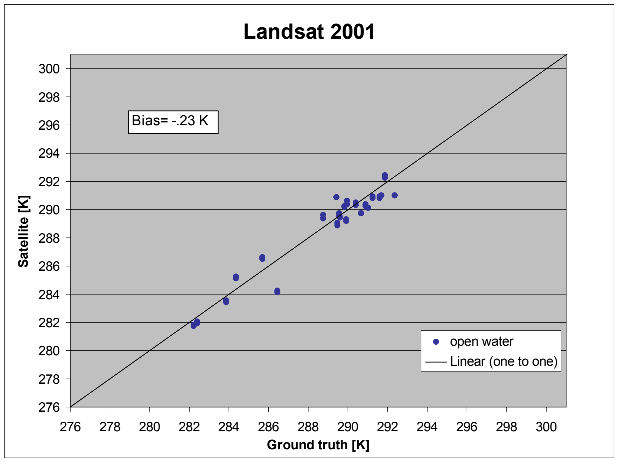


Figure 3: Results from combined 2001 ground truth

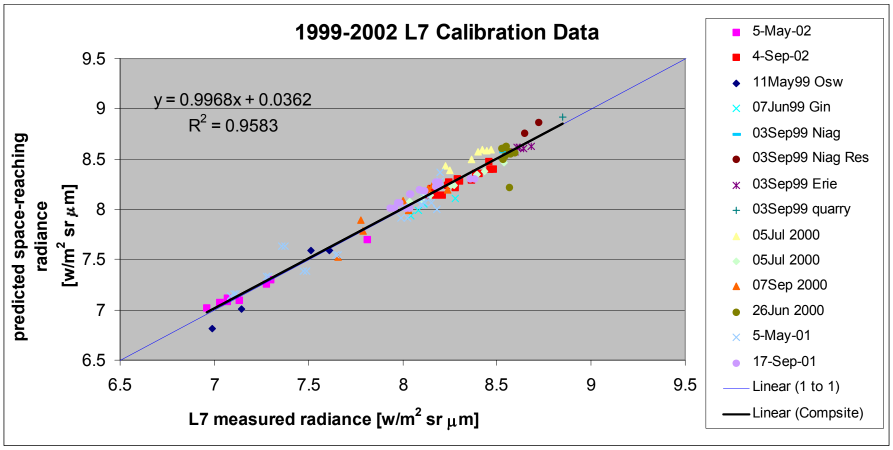


Figure 4: The combined results from the three years of Landsat ETM+

PUBLICATIONS

Barsi, J.A, Schott, J.R., Palluconi, F.D., Helder, D.L., Hook, S.J., Markham, B.L., Chander, G., O'Donnell, E.M. “Landsat TM and ETM+ Thermal Calibration”, Canadian Journal of Remote Sensing, 2002 in review.

Markham, B.L., Barker, J.L., Kaita, E., Barsi, J.A., Helder, D.L., Palluconi, F.D., Schott, J.R., Thome, K.J., Morfitt, R., Scaramuzza, P.,"Lansdat-7 ETM+ radiometric calibration: two years on-orbit," Proceedings of IGARSS, 2001

O'Donnell, E., Schott, J.R., Raqueño, N.G., "Calibration History of Landsat Thermal Data," Proceedings of IGARSS 2002, Toronto, Canada, IEEE Vol. 1, pp. 27-29

RESEARCH TEAM

Erin O’Donnell, Yan Li, Nina Raqueño

4.1.5 Synergistic Applications of EO-1 and Landsat ETM+ for Canopy Temperature Estimation

The overall objective of this research is to determine how effectively can the reflective data from one satellite be combined with the thermal infrared channels on a separate satellite. This combination will be used to develop brightness temperatures and normalized difference vegetation index relationships.

During the first phase of this project, DIRS role is to provide MISI data over a forested site that has been well characterized both spectrally and geometrically. An extensive field campaign was conducted at Camp Eastman Rochester, NY during August and September of 2001. ASD spectral measurements were taken of primarily tree leaves, tree bark, and background materials. DIRS Staff and students assisted the NASA team with a detailed survey of tree trunk locations, diameters, crown diameter, canopy type, species identification, and leaf area index. This survey was performed to provide geometric inputs for the model generation of the site. Additional weather related data was recorded throughout the two-month period. These surface temperature measurements included shaded and sunlit foliage and ground conditions.

MISI Imagery was acquired on September 9, 2001 in preparation for the September 17th E0-1, Landsat ETM+, and MTI satellite overpass (Figure 1). However MISI’s 2001 flight season was suspended on September 11, 2001. The ground truth and satellite campaign continued throughout September. Additional MISI imagery of this site was taken on August 12 and 28, 2002

Figure 1: MISI image of Camp Eastman and surrounding forest region (September 9, 2001)

PUBLICATIONS

Ballard, J.R. and Smith, J.A., "A Multi-Wavelength Thermal Infrared and Reflectance Scene Simulation Model", IEEE International Geoscience and Remote Sensing Symposium, Toronto 2002

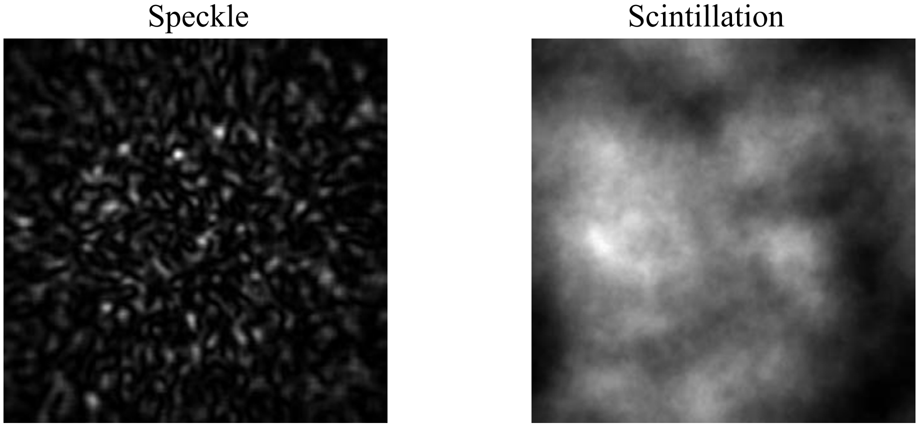
RESEARCH TEAM

Nina Raqueño

4.1.6 LIDAR Scene and Sensor Modeling

The capability to simulate laser imaging, or LIDAR (LIght Detection and Ranging), has been developed and integrated into DIRSIG. An initial study simulating the full wave propagation of the laser beam was completed to investigate the spatial and statistical effects of atmospheric turbulence (scintillation) and surface roughness (speckle). Once these effects were understood, a photon map approach was utilized to integrate the LIDAR imaging process into DIRSIG. Through photon mapping, the correct phase shifts in the laser beam, due to scintillation and speckle, can be incorporated into the beam at the detector. Figure 1 shows examples of speckle and scintillation patterns created in our LIDAR simulation.

In addition to the above-mentioned effects, the model incorporates other real-world phenomenology into the simulation. The geometrical form factor, a measure of the overlap between the laser beam and the receiver field of view is carefully computed. Multiple bounce photons from topographical targets are included as well as other noise sources such as beam wander and beam spread. Currently, only elastic scattering LIDAR is considered in the simulation.


Speckle

Scintillation

Figure 1: Speckle and scintillation patterns.

The LIDAR imaging capability in DIRSIG is being used to detect both concealed hard targets and gaseous effluent plumes through active imaging methods. The hard target detection uses a simple, time-gated detection scheme where the hard target itself is a source of the laser backscatter into the detector. For the gaseous effluent detection, a Differential Absorption LIDAR scheme (DIAL) is used. In this mode, two beams are sent through the gas, reflect off a topographic target behind the gas (or the gas itself), and return to the sensor along the same path. One of the laser beams has a wavelength equal to that of the absorption feature of the gas, and the other has a wavelength in a spectral region where the gas is transmissive. Comparison of the two returns provides information about the quantity of gas through which the beam passed.

PUBLICATIONS

Burton, Robin, “Elastic LADAR Modeling for Synthetic Imaging Applications”, Ph.D. Dissertation, Center for Imaging Science, Rochester Institute of Technology, 2002

Burton, R.R., Schott, J.R., Brown, S.D., “Elastic LADAR Modeling for Synthetic Imaging Applications”, SPIE Proceedings, Vol. 4816, pp. 144-155, July 2002

RESEARCH TEAM

Robin Burton, Scott Brown, David Messinger

4.2 FIRES

4.2.1 Forest fIRes imaging Experimental System (FIRES)

FIRES is a scientific research project focused on the detection and monitoring of wildfires. The scientific goals of this project are to study the phenomenology of wildfires, to accurately model the physical characteristics of wildfires, and to predict the performance of various approaches of detection and monitoring. The project also seeks to understand the needs of the ultimate user of the wildfire data in order to factor these needs into system requirements.
FIRES Web site: http://www.cis.rit.edu/research/dirs/research/fires.html

4.2.2 Emission line features and basic physical parameters of wildland fires

In order to correctly model wildland fires in scene simulators such as *DIRSIG*, optical characteristics such as emissivity, temperature, absorption and reflectance of the flaming fire must be known. It is also desirable to know the optical characteristics of the burn scar surrounding the area of flaming combustion so that a complete scene -active flaming front plus surrounding burn scar - can be generated accurately (see Figure 1).

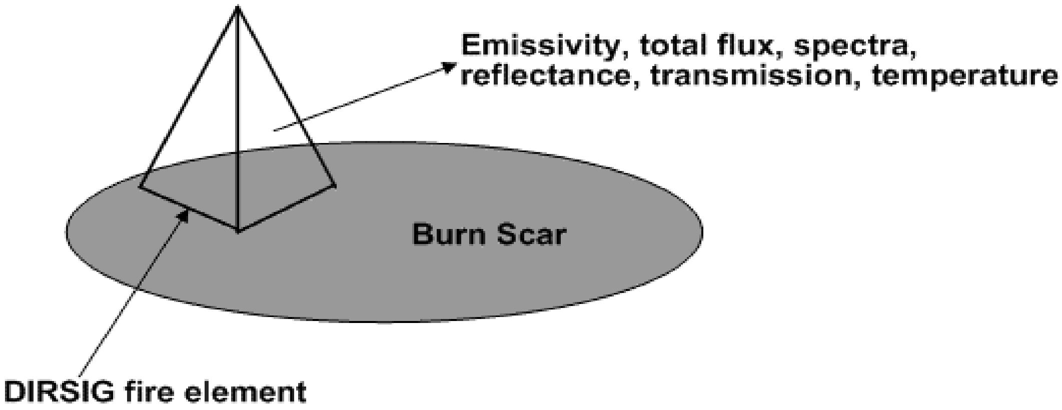


Figure 1: Required fire physical parameters for modeling and synthetic scene generation.

Efforts are underway to experimentally characterize the intensity of light emitted by a wildfire at all wavelengths applicable to remote sensing applications. Of particular interest is measurement of the flame emission from the resonance transitions ($^2P_{3/2}$ - $^2S_{1/2}$ and $^2P_{1/2}$ - $^2S_{1/2}$) of potassium (near 766 nm) and determination of the broadband emissivity of the flame as a function of wavelength. Potassium is abundant in wildland fire fuel materials (0.5 - 7 % by weight) and may be useful as an indicator of flaming combustion. We have reported on novel detection methods using potassium line emission analyzed with straightforward algorithms in the International Journal of Remote Sensing. Experiments have been performed locally and at the USDA Rocky Mountain Research Laboratory combustion chamber that use both emission-line imaging and non-imaging spectrometry to gather data to be used to model the process in test fires. A diagram of the potassium emission line camera is shown in Figure 2. We are analyzing this data in an attempt to more fully understand both the intensity of and the temperature dependence of the potassium emission.

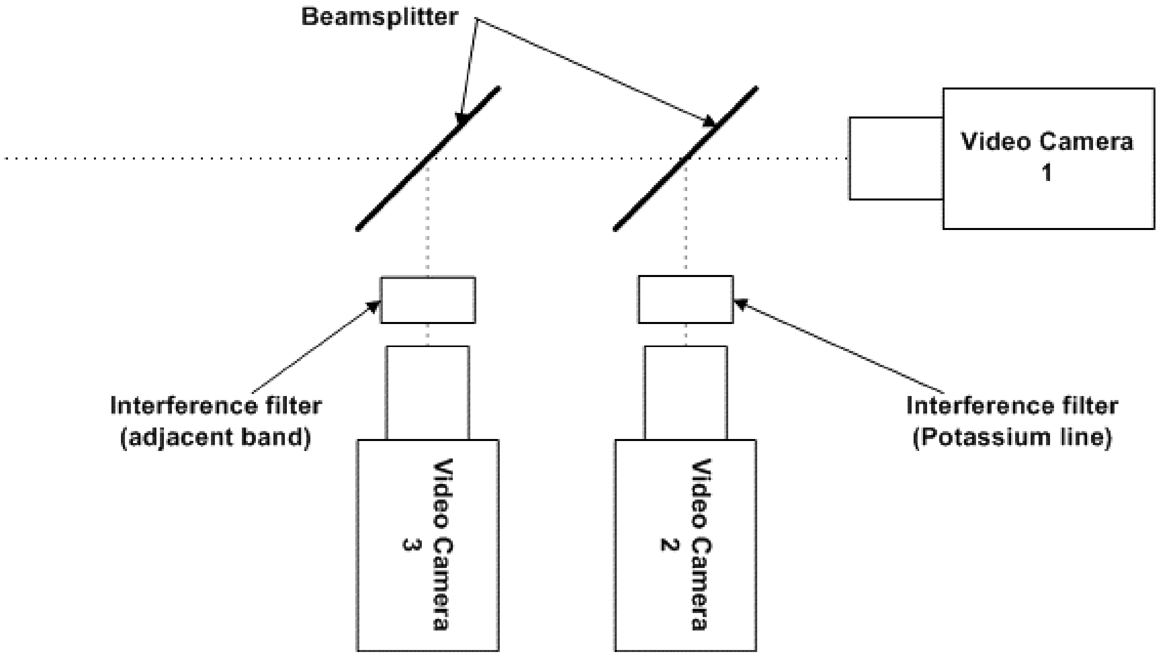


Figure 2: Three-band camera to image potassium emission lines and adjacent spectral regions. Video Camera 1 observes all wavelengths (400-700 nm) and is used for sighting, Video Camera 2 observes emission form the potassium line (766 nm), and Video Camera 3 observes emission form an adjacent narrowband region (780 nm)

These experiments were also designed to simultaneously determine the emissivity of wood flames in the 8-14 μm wavelength range. The depth of flame was varied and the kinetic temperature (as measured by thermocouples) and radiant flux (as measured by an IR radiometer) from the fire were measured spatially and temporally. The emissivity can be calculated from first principles using these measurements, and a plot of emissivity versus flame depth can be obtained. An outline of the experimental setup is shown in Figure 3. We are continuing to analyze the emissivity measurement data but initial data shows agreement with an exponential dependence of emissivity on flame length that is has been widely applied to fully mixed fuel-air combustion models. Similar experiments will be performed at the RMSC burn during the winter of 2002 to extend these measurements to other wavebands (visible, near IR and mid-wave IR).

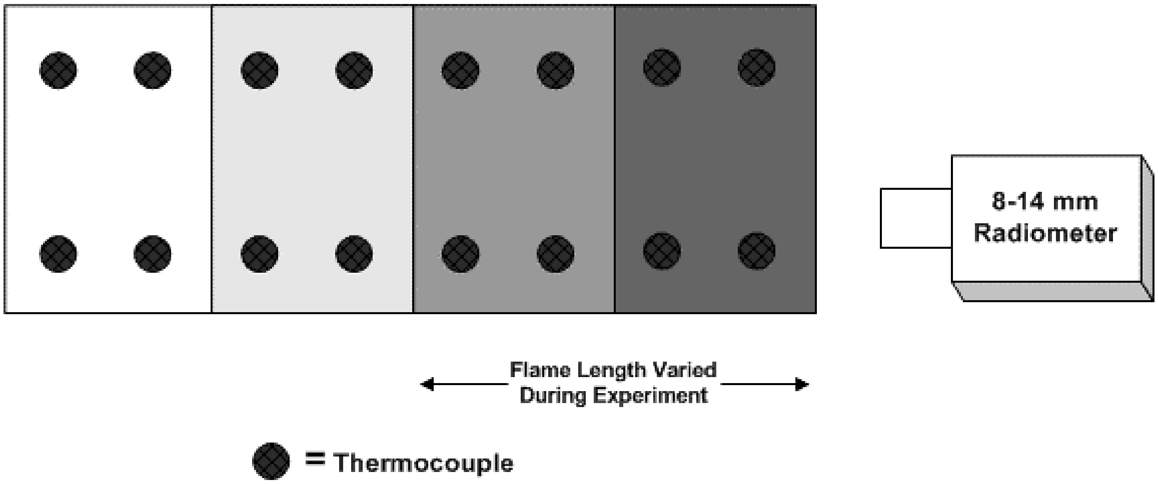


Figure 3: Experimental set up for measurement of flame emissivity and imaging of potassium emission

We are planning experiments for the spring of 2003 to optically characterize the burn scar from prescribed fires in the Rocky Mountains of Montana. The optical characterization will include measurement of emissivity and reflectance and measurement of the surface temperature of the burn scar as a function of time after passage of the fire front. Several different forest floor and fuel compositions will be measured to build a database usable in our *DIRSIG* simulations. We have developed specialized field instrumentation to measure the temperature field of the burn scar during passage of the flaming front.

Wildland fires emit copious quantities of carbon monoxide, carbon dioxide other gases and particulates into the atmosphere. Trees and understory growth in forested areas may contain trace radioactive materials (e.g. K^{40}) that are dispersed into the atmosphere during combustion. We are currently measuring the radioactivity in samples of wood from the northern Rocky Mountains obtained from the USFS to determine if radioactive releases from the combustion during large-scale wildland fire events pose a health risk to surrounding communities. These measurements are being conducted in collaboration with SUNY Geneseo in their special high sensitivity, low background radioassay laboratory.

PUBLICATIONS

Vodacek, A., Kremens, R.L., Fordham, A. J., VanGorden, S.C., Luisi, D., Schott, J.R., “Remote Optical Detection of Biomass Burning Using a Potassium Emission Signature”, International Journal Remote Sensing, Vol. 23, No. 13, pp. 2721-2726, 2002

RESEARCH TEAM

Adam Cisz, Peter Gee, Danielle Merritt, Robert Kremens, David Pogorzala, Anthony Vodacek

4.2.3 Distributed ground sensors for wildland fire detection and ground truth acquisition

A system of position-aware data acquisition units has been developed that provides a unique capability to record fire data on wildland fires. This miniature electronic package combines position location capability (using the Global Positioning System [GPS]), communications (digital data link or voice-synthesized radio), and fire detection capability (thermal, combustion gas, or smoke detector) into an inexpensive, deployable package. We call this system an autonomous fire detector (AFD). The AFD can report fire-related parameters via a radio link to firefighters located on the ground. These systems are designed to be placed in the fire by spotter planes at a fire site or positioned by firefighters already on the ground (see Figure 1). AFDs can also be used as permanent early warning devices near critical assets in the urban-wildland interface. AFDs can now be made with commercial off-the-shelf components. Using modern microelectronics, an AFD can operate for the duration of even the longest fire (weeks) using a simple dry battery pack, and can be designed to have a transmitting range of up to several kilometers with low power radio communication technology. A receiver to capture the data stream from the AFD can be made as light, inexpensive and portable as the AFD itself. Inexpensive portable repeaters can be used to extend the range of the AFD and to coordinate many probes into an autonomous fire-monitoring network. We have reported on this work at conferences, and published the results of the initial design process in refereed proceedings and journals. A diagram of the electronics configuration and a photograph of a completed AFD circuit board are shown in Figures 2 and 3, respectively.

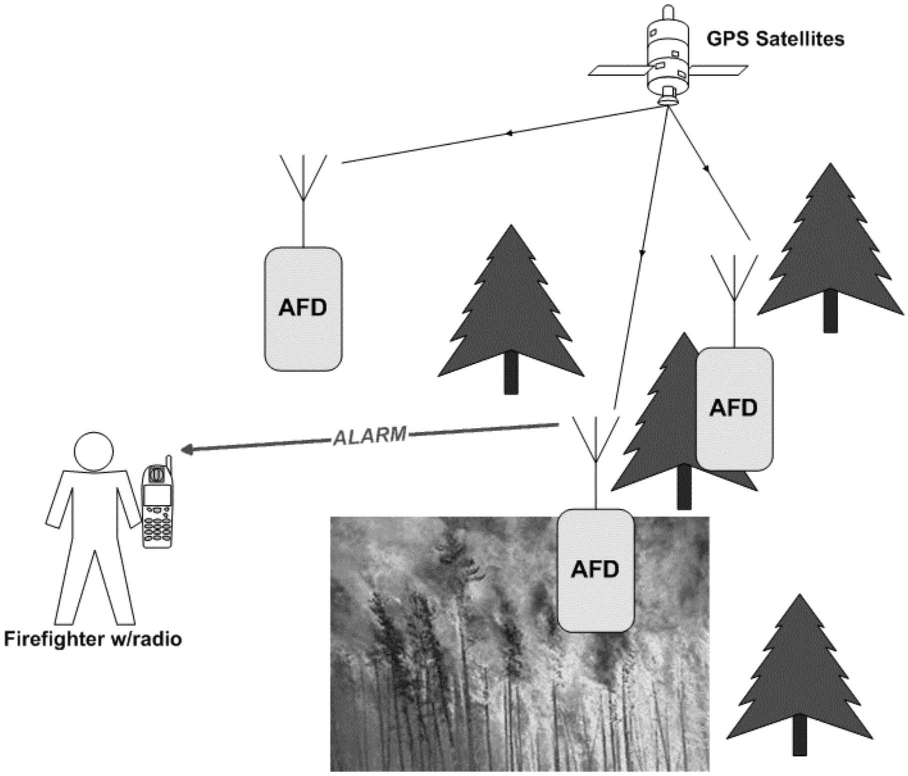


Figure 1: Implementation of an autonomous fire detector as a wildland fire sentry.

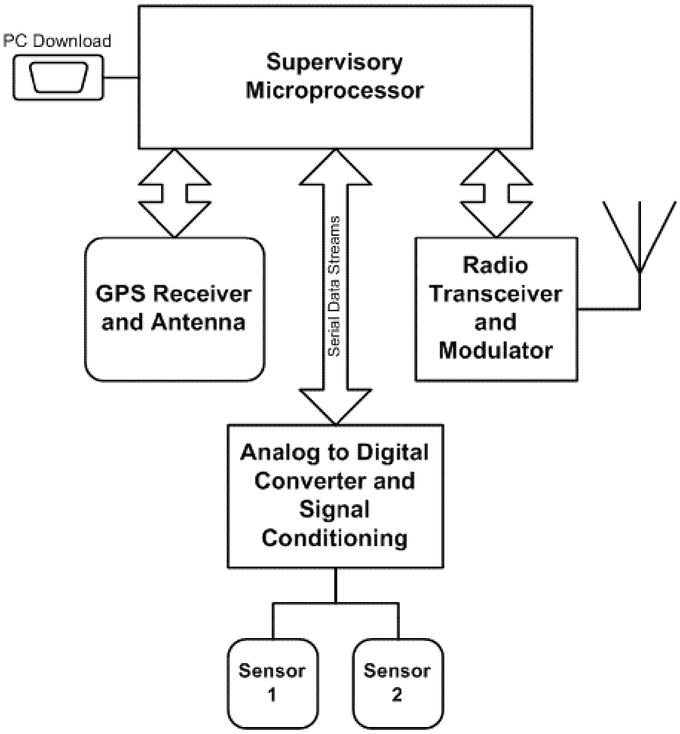


Figure 2: Electronic configuration of the autonomous fire detector.

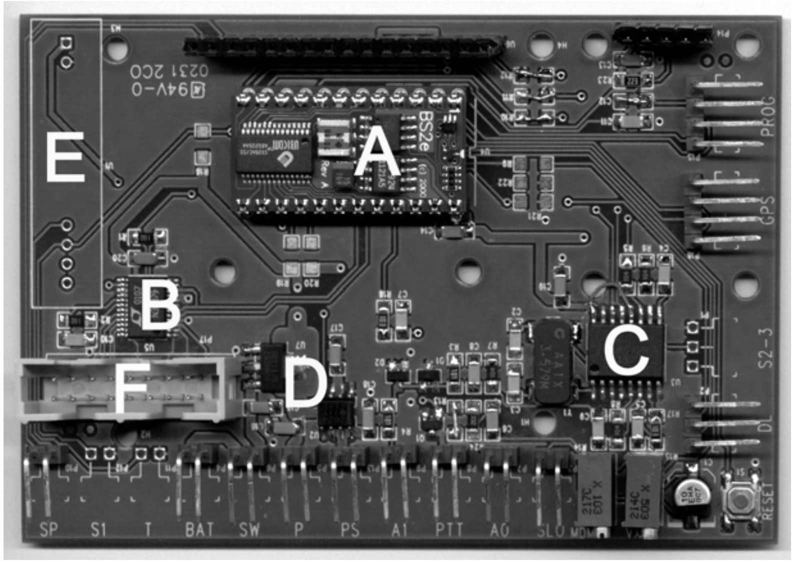


Figure 3: Photograph of a completed AFD circuit board. . A - Parallax Basic Stamp microprocessor; B - Linear Technology LTC1598 8-channel, 12-bit analog-to-digital converter; C - MX-Com MX 614 Modem IC; D - Power management circuitry; E - YSI 4800 LC precision thermistor module (not installed); F - 8-channel analog input connector.

PUBLICATIONS

Kremens, R.L., Gallagher, A.J., Seema, A., "Low Cost Autonomous Field-Deployable Environment Sensors", American Institute of Physics, Proceedings of the Unattended Radiation Sensor Systems for Remote Applications Symposium, Vol. 632, pp. 190-199, July 2002

Kremens, R., Seema, A., Fordham, A., Luisi, D., Nordgren, B., VanGorden, S., "Autonomous field-deployable fire sensors", presented at the 5th International Wildland Firefighter Safety Summit, Missoula Montana, November 2001

Kremens, R., Faulring, J., Gallagher, A., Seema, A., Vodacek, A., "Autonomous field-deployable wildland fire sensors", submitted to the International Journal of Wildland Fire, September 2002

RESEARCH TEAM

Jason Faulring, Andrew Gallagher, Robert Kremens

4.2.4 MISI hardware upgrades

We have completed upgrades to the MISI airborne scanner that extend the spectral range and provide increased performance in the existing bands. The added detector channels are in the SWIR - LWIR and were designed to accommodate a wide range of target temperatures to allow development and testing of wildland fire detection algorithms over highly characterized fire targets. We have added five new detectors in a separate detector focal plane assembly with the following characteristics:

a. InGaAs detector (photovoltaic mode) with passband of 1.21-1.32 mm, dual gain amplifier
b. InGaAs detector (photovoltaic mode) with passband of 1.46-1.84 mm, dual gain amplifier
c. InSb detector (photovoltaic mode) with passband of 1.9-2.35mm, dual gain amplifier
d. InSb detector (photovoltaic mode) with passband of 3.2-4.1 mm, dual gain amplifier
e.HgCdTe detector (photoconductive mode) with passband of 8.3 - 9.9 mm, low gain avoids saturation on high temperature objects.

The dual gain amplifiers on the NIR and MWIR channels allow the detectors to acquire unsaturated data over a wider dynamic range and so access temperatures from near Earth-ambient (~290 K) to fire temperatures (~ 1500 K) without saturation. The new LWIR channel has a gain setting adjusted to provide low-resolution (~1 - 2 K) detection of earth ambient temperatures and sufficient dynamic range to observe high temperature fires.

The MISI scanner now covers the region from 0.35 μm to 14 μm almost continuously in 80 desecrate bands. We flew several missions this summer over both experimental, well-controlled fires, and wildland fires. We are currently analyzing the data from these fires using both MWIR/LWIR and potassium line emission methods.

A complete electronics retrofit has been performed this year. The entire data acquisition system has been rebuilt with an eye toward reliability, repeatability, lowered power consumption and compactness. All electronics has been built using surface mount technology and multilayer printed wiring boards. Analog signal processing electronics have been designed and built for the silicon photovoltaic spectrometer detectors (70 channels), InGaS and InSb photovoltaic dual gain channels, and HgCdTe photoconductive auto-zeroing channels. In addition to the added detectors, new electronics has been designed and built for the control and timing system. The power supply and control system are now housed in electrically separate shielded enclosures and the analog electronics are mounted in several double shielded chassis near the detectors to minimize noise pickup and signal degradation from airplane systems. These modifications have resulted in a 100% success rate for recording data for the 2001-2002 flight season.

RESEARCH TEAM

Jason Faulring, Timothy Gallagher, Robert Kremens

4.2.5 FIRES Band Selection and Algorithm Development

A great deal of research involving thermal detection of fire exists in the published literature, so we have focused in part on non-traditional approaches. This research is examining several non-traditional detection strategies that have the promise of greater accuracy and lower susceptibility to false alarms than existing fire-detection algorithms. In collaboration with U.S. Forest Service personnel, we published a journal article that shows the feasibility for fire detection using a thermally excited potassium emission signature. This unique signature may be an important complement to thermal detection of fire while lowering false alarm rates.

Our approach to the overall goal of accurate fire detection has been to obtain spaceborne and airborne imagery (Figure 1), ground level spectral measurements, and field and laboratory data of controlled fires. Our postdoctoral researcher, Ambrose Ononye, has led the effort to obtain MISI data over a controlled site with various hotspot and flaming targets. These data are being analyzed to improve our understanding of viable approaches to fire detection and monitoring and the detection limits of various approaches. Working with MODIS satellite thermal data, we have been testing various thermal detection algorithms including one developed by Ying Li, one of the FIRES graduate students. Her approach is to apply a principal components type analysis with a minimum distance metric to isolate fires with fewer false alarms than produced by existing algorithms. This work will be continued with an emphasis on obtaining field data so that better estimates of algorithm accuracy and limitations can be calculated from overhead imagery.

Figure 1: MISI color (left), zoomed color (middle), and thermal (right) images of a fire in the Adirondack Mountains of New York in August 2002.

PUBLICATIONS

Vodacek, A., Kremens, R., Fordham, A., VanGorden, S., Luisi, D., Schott, J.R., and Latham, D., “Remote optical detection of biomass burning using a potassium emission signature,” International Journal of Remote Sensing, 23:2721-2726, 2002

RESEARCH TEAM

Ying Li, Ambrose Ononye, Anthony Vodacek

4.2.6 FIRES Flame Modeling in DIRSIG

The purpose of this research is to create a physics-based flame model in DIRSIG. This model is intended for use in evaluating detection algorithms, sensors, and for interfacing with fire propagation models. The main objectives are to utilize data outputs from current models as well as research on fire physics to create a 3D view of wildfires. For example, FARSITE is a flame propagation model used by the U.S. Forest Service. The outputs of FARSITE can provide critical information on fuel consumption, smoke generation, flame intensity, etc., all of which can be used to drive models which produce the flame structure. Some applications of flame modeling may require quite highly detailed spatial characteristics of flames while others can afford to relax the spatial resolution. This work will incorporate the laboratory and field measurements of fire we are undertaking to so that we may better characterize wildland fire physics.

Figure 1: A true color DIRSIG scene containing a simulated grass fire. The fire pixels are the brighter pixels in the center of the trees. Spectral measurements of fire obtained at the Fire Sciences Laboratory were used to create the scene.

RESEARCH TEAM

Zhen Wang and Anthony Vodacek

4.3 MURI

Hyperspectral imagery exploitation algorithms incorporating physics based models

This section contains descriptions of research projects initiated under a Multidisciplinary University Research Initiative (MURI) grant. This program is targeted at development of a new generation of algorithms to extract information from imaging spectrometer data. The program includes four exploitation areas:

- Study of the Littoral Zone
- Detection and identification of gaseous effluents
- Atmospheric compensation
- Target and material mapping

4.3.1 Atmospheric Parameter Retrieval

Of interest to many in the remote sensing community, is the make-up of our atmosphere. When airborne or satellite based imaging sensors capture spectrographic information about a piece of real-estate below, it is usually of prime importance for the remote sensor (scientist) to estimate what the ground leaving parameters were (reflectance or radiance). This task can only be achieved if there is adequate knowledge about the atmosphere, for example. When this information is known, algorithms can be applied to “back-out” the effects of the atmosphere thus leaving spectroscopic corrected imagery as though is was measured from the ground itself.

There are many approaches to solving the above-mentioned problem. One such approach is to use the multivariate statistical technique known as canonical correlation analysis (CCA). When we have the situation where observed values (*e.g.,* spectral radiance) are a function of *multiple* unconstrained physics based model input parameters (*e.g*., target temperature, atmospheric temperature profile, etc.), we need to generate a multi-parameter statistical model that relates predicted observed vectors, to model input parameter vectors. The multi-parameter model we will use is the use of canonical correlation analysis in a *regression* scheme (CCRA).

Initially, this research effort has the task of estimating atmospheric profiles, such as temperature or water vapor as a function of altitude, from observed sensor reaching radiance in thermal infrared spectral images. The tool used for this analysis, which has its origins in multivariate statistics, is called canonical correlation analysis (CCA). Canonical correlation analysis seeks to identify and quantify the associations between two sets of variables (i.e., inputs and output). It focuses on the correlation between a linear combination of the variables in one set (inputs) and a linear combination of the variables in another set (outputs). The idea is first to determine the pair of linear combinations having the largest correlation. Next, we determine the pair of linear combinations having the largest correlation among all pairs uncorrelated with the initially selected pair, and so on. We then put these pairs, or canonical variables, in a regression scheme (CCRA) to ultimately invert the model process (i.e., estimate what the input might have been given the output). The feasibility of this physics based model inversion was then tested on synthetically generated observed radiance spectra (see Figure 1) with very encouraging results. To date, the algorithm has been used on real data to estimate similar atmospheric profiles as well as ground temperatures and surface emissivity.

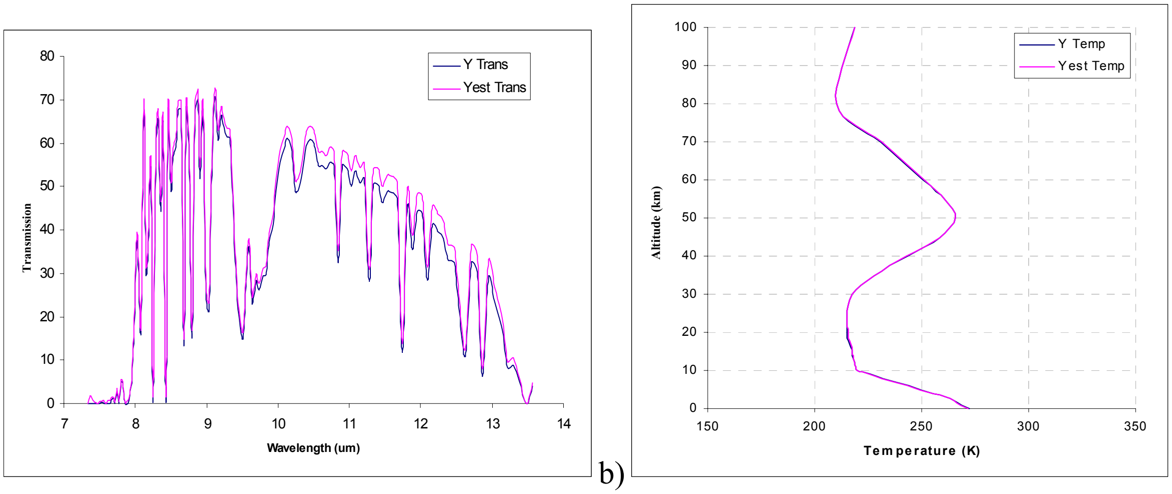

a)
b)

Figure 1: a)CCRA used to estimate atmospheric transmission and b)temperature profile from synthetic data

RESEARCH TEAM

Marvin Boonmee and Emmett Ientilucci

4.3.2 Gaseous Effluent Studies

We are continuing to develop the capability to spatially and spectrally simulate imagery of factory stack emission plumes. In addition, we are initiating an effort to develop an algorithm set to detect and characterize plumes in simulated and real images. The goal of these algorithms is to produce, at the pixel level, an identification of the presence of a gaseous effluent, a determination of all gaseous species present, both relative and absolute concentration levels for all species present, as well as estimates of the gas plume source characteristics. Areas such as atmospheric correction, plume detection, and plume constituent identification and quantification will be addressed.

To this end, we have integrated a plume model, originally developed by the EPA, into DIRSIG. Given a description of the gas release properties and the spatial and spectral description of a scene, DIRSIG performs the simulated image generation of the scene with the plume. The radiative transfer through the plume accounts for spatial variations in temperature and concentration of the gas constituents. The spectral characteristics of the plume are specified in species-dependent absorption spectra.

An example of a synthetic scene containing a plume is shown in Figure 1. Here, a scene containing a building, some trees, a vehicle, and an SF_6 plume has been created and an image taken at a wavelength of 10.6 μm (LWIR) is shown. Sample spectra taken from this scene over a wavelength range of 10-11 μm are presented in Figure 2. Spectra from a variety of locations in the scene are shown. The black curves are from pixels without a plume between the surface and the sensor. Red curves are from the same background material, but with the plume effects included. The plume can be seen in both emission and absorption, depending on the relative temperature between the plume and the background material.

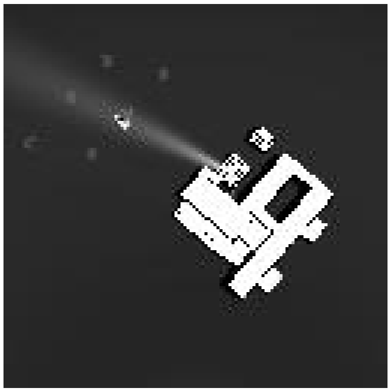


Figure 1: On-absorption image of SF_6 plume

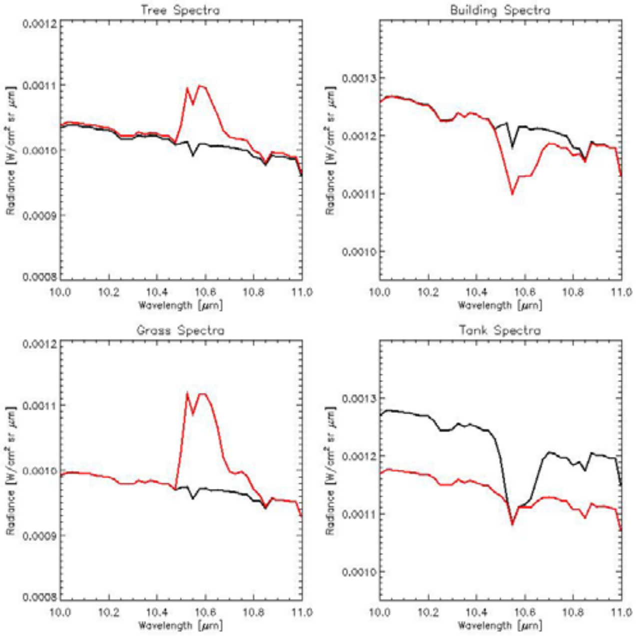


Figure 2: Example scene spectra against various backgrounds. Black curves represent "non-plume" pixels, and red curves are from pixels that contain the plume. The plume is seen in both emission and absorption at various points in the scene.

RESEARCH TEAM

Erin O'Donnell, Timothy Hattenberger, David Messinger, Carl Salvaggio

4.3.3 Material Identification

This effort is directed at development of hyperspectral detection algorithms capable of detecting sub pixel targets when the only input to the algorithm is an estimate of the spectral reflectivity of the target of interest. The approach builds on the Invariant Algorithm introduced by Glenn Healey's team at UC Irvine one of the MURI collaborators (c.f. Healy and Slater 1999). The RIT effort was aimed at developing a sub pixel extension of the fully resolved invariant approach that could deal with images that might contain significant numbers of target contaminated pixels. The invariant approach attempts to compensate for atmospheric and illumination variation by modeling (using MODTRAN in this case) all the ways a target might appear in radiance space (i.e. in the image). These possible manifestations of the target are described geometrically by the algorithm as a subspace of the entire spectral space possibly spanned by the image. In a similar fashion the actual image data under analysis can be characterized as spanning some geometrical subspace of the entire spectral space accessible by the imaging system. This image subspace can be thought of as being made up of background (i.e. non target) pixels and target or mixed target/background pixels. Since we know what portion of image space the pixels occupy from the initial steps it is possible to separate out just the background subspace. The detection algorithm operates by comparing the likelihood that a pixel is background to the likelihood that it is target or mixed target/background.

Figure 1 illustrates the inputs to the algorithm in the form of a target spectra (reddish brown point on a basketball court) a portion of an AVIRIS image of northern Rochester. Also shown are the algorithm results displayed as brightness values and a high-resolution air photo blow up of the tow detection areas. One is the tennis court where the spectra was measured by RIT's measurement team (see the LASS write up)) and the other is a tennis court surround painted with what appears to be the same paint. Also shown on these high-resolution images is the footprint for a single AVIRIS pixel to illustrate the sub pixel nature of these detections. These initial results are very encouraging and refinement and further testing of this algorithm are underway.

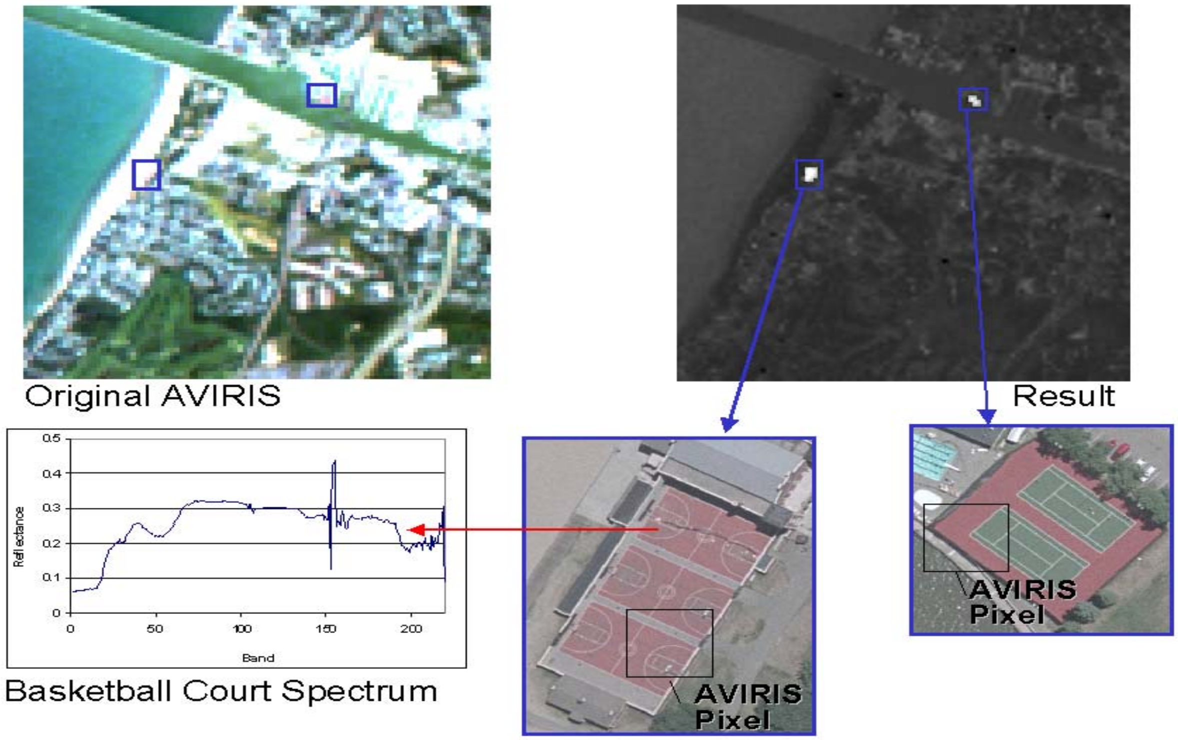


Figure 1: Target Detection for the Basketball Court Spectrum

PUBLICATIONS
Lee, Kyungsuk, “A Subpixel Scale Target Detection Algorithm for Hyperspectral Imagery”, Ph.D. Dissertation, Center for Imaging Science, Rochester Institute of Technology 2002

Schott, J.R., “Use of Physics-Based Models in Hyperspectral Image Exploitation” presented at AIPR Workshop, Washington, DC, October 2002

RESEARCH TEAM
Kyungsuk Lee, Rolando Raqueño, Gary Hoffmann

4.3.4 Light Propagation Through an Arbitrary Air/Water Interface and Multiple Scattering Techniques for Inhomogeneous Media

The primary goal of this project has been to consider the implications of a natural wave surface on parameter retrieval algorithms in littoral zones (c.f. Figure 1a). Specifically, a wind-blown wave surface that has been modeled spatially as well as statistically can produce unique phenomenology such as wave focusing, glint patterns, foam distributions, etc…. While the basic techniques for creating wave surfaces with spatial characteristics that are consistent with natural environments are fairly well understood, the modeling of light propagation in such an environment has been severely limited by the capabilities of existing water models. These limitations stem from the fact that (known) existing models are ill suited for handling the three dimensional data produced by a wave covered surface. In an attempt to alleviate some of these restrictions, light propagation has been generalized as Monte Carlo procedures that are based on the ray tracing capabilities of DIRSIG. The main difficulty with implementing Monte Carlo ray tracing in the past has been the efficiency of such methods. With this in mind, we have borrowed a process known as “photon mapping” from the computer graphics community (c.f. Figure 1b) which approximates the multiple scattering component of the Monte Carlo equations using a density estimate (H. W. Jensen Realistic Image Synthesis Using Photon Mapping [A K Peters, 2001]). This decision was motivated by extremely realistic underwater images generated by the technique that demonstrate the types of phenomenology that we wish to model. By adapting these methods and using spectral parameters based on natural waters, we hope to retrieve scientifically accurate images. Once the model is in place, it will be possible to generate scenes based on arbitrary three-dimensional structure with minimal effort.

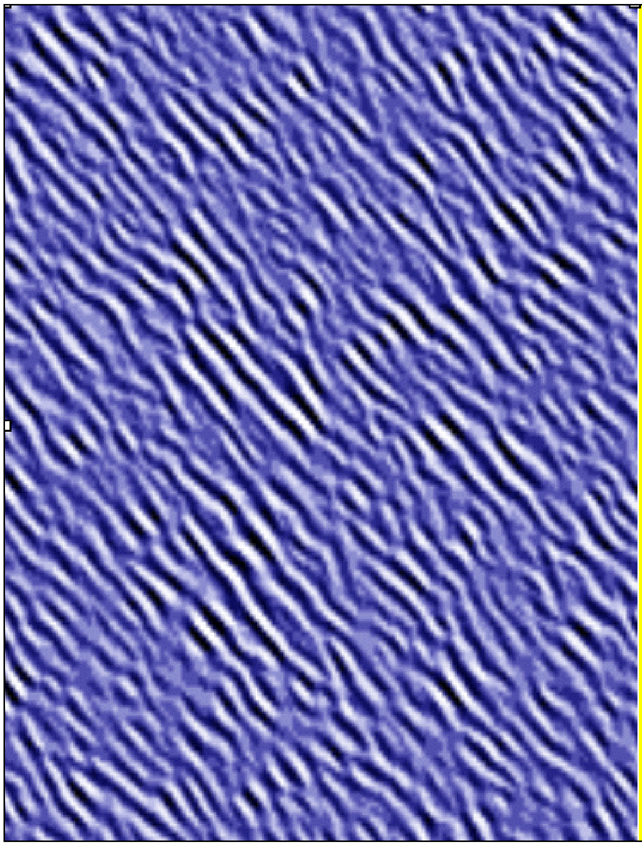


Figure 1a

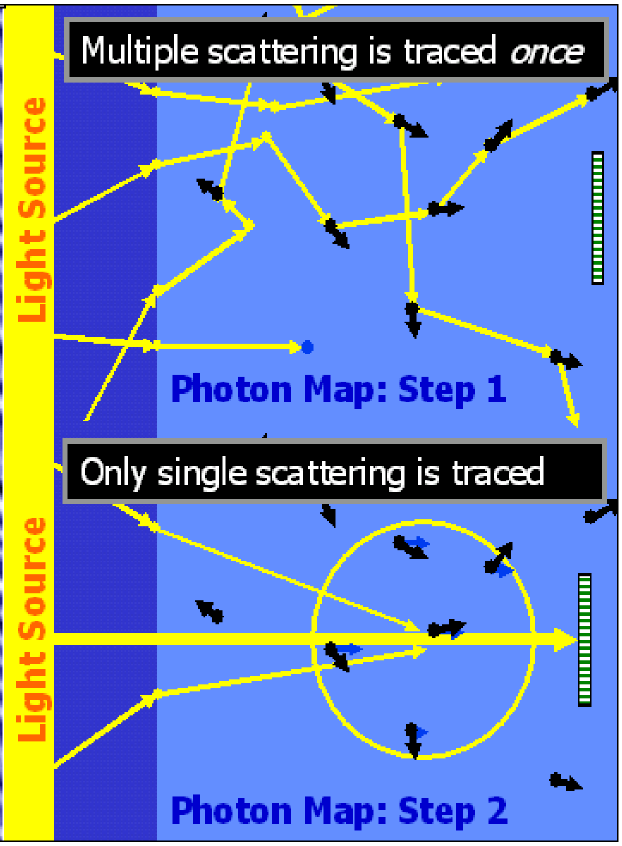


Figure 1b

1a: Sample height field of a wave surface generated from a spectral model.

1b: General overview of Photon Mapping using stored photons to calculate multiple scattering contribution to measured radiance

RESEARCH TEAM

Rolando Raqueño, Jason Hamel, Adam Goodenough

4.4 LASS

This section contains descriptions of projects being conducted as part of the Laboratory for Advanced Spectral Sensing (LASS) a DIRS initiative begun last year. LASS is a collection of joint government industry sponsored research initiatives designed to advance the field of imaging spectroscopy. Most of the research projects pool resources from multiple sources to leverage the productivity available to each sponsor. The objective is to provide insights and fundamental scientific advances to all participants to support broader advances in this rapidly evolving field.

4.4.1 DIRSIG Megascene

With the increased interest in and use of the DIRSIG model, there has been an increased demand for wide-area, high fidelity scenes that can be used in conducting system performance predictions. Historically, smaller synthetic scenes (0.25 square miles) were built and attributed manually using a combination of computer-aided design (CAD) tools and custom built programs. This process was very time consuming and did not scale well for building significantly larger "mega-scenes" (6 miles square). For this task, a new set of well designed and well implemented scene creation tools have been constructed that streamline and simplify the building process thereby allowing users to create large-scale scenes quickly and more often.

Under the LASS effort, we have set a goal of periodically constructing megascenes for general use by the user community. The target area for this first scene is the northeast side of Rochester, NY that includes urban residential, urban commercial, rural and coastal regions. Figure 1a below shows the first tile of the megascene. This tile is about 0.6 square miles. Figure 1b is a zoom of this tile. What sets these renderings apart from previous ones is the order of magnitude increase in objects, materials, and spectra. Some 5,000 objects exist in the scene including houses, buildings, pools, trees, etc. Additionally, there are over 140 materials encompassing some 2,500 unique spectra. The large number of spectra is required in order to produce accurate textures of materials such as grass and concrete. The creation of the texture itself is driven by the statistics of the original imagery. This in turn, yields a high correlation between synthetic and real imagery in textured regions.

Figure 1: a) Nadar view of tile one from the first Rochester megascene. b) Zoom of the tile showing a high school with a textured roof.

PUBLICATIONS

Kennedy, Carolyn, Senior Project, "The Testing and Assessment of Texturing Tools Used to Build Scenes in DIRSIG", Center for Imaging Science, Rochester Institute of Technology, 2002

RESEARCH TEAM

Carolyn Kennedy, Ken Ewald, Alvin Spivey, Bryan Shaw, Lomax Escarmant, Emmett Ientilucci

4.4.2 DIRSIG Atmospherics

The goals of this research can be grouped into two main categories, the clear-sky goals, and the incorporation of atmospheric inhomogeneities. The clear-sky goals include the overall improvement of DIRSIG's treatment of the atmosphere. Currently, DIRSIG only sees the atmosphere as homogeneous slabs, varying only vertically, in discrete sections. Enabling DIRSIG to handle horizontally varying atmospheric inhomogeneities will allow us to include such features as horizontally varying water vapor and aerosol concentrations, and possibly clouds, in the synthetic atmosphere.

In order to accomplish these goals, the code, which handles and creates the atmospheric database LUT (henceforth, referred to as the ADB), will have to be changed significantly.

4.4.2.1 Current Desired Changes

When encountering an object at a non-zero altitude, DIRSIG simply scales the atmosphere to the corresponding height. The result is a "compressed" atmosphere along the line of sight. (Figures 1 and 2.) The ray from DIRSIG, therefore, incorporates the lower layers of the atmosphere, even though the object may not be in these layers. This leads to an exaggeration of atmospheric effects, especially in objects with high altitudes.

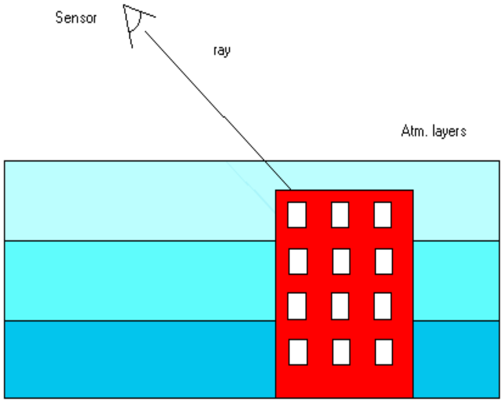


Figure 1: Illustration of the altitude problem. This is how we want a non-zero altitude to be handled.

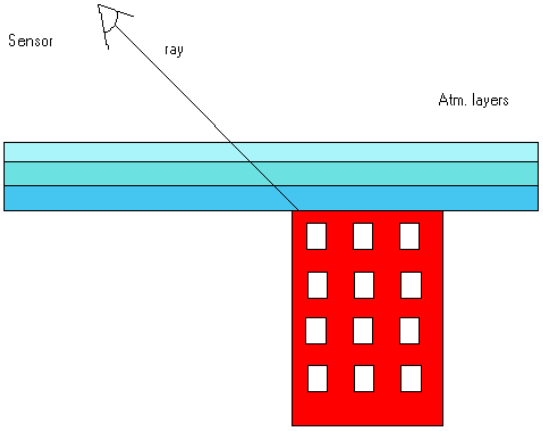


Figure 2: Illustration for altitude problem. This is what DIRSIG actually does when encountering a non-zero altitude object. It scales the atmosphere to the lower range, passing the ray through, the lower, optically thicker atmosphere.

Currently, the ADB incorporates only zenith angles in the sensor (upwelled) section of the LUT (Figure 3). This results in an azimuthally symmetric upwelled radiance. This is not normally the case in the real world. This will be fixed by incorporating azimuthal angles as well as zenith angles within the sensor paths section of the ADB. This is illustrated in Figure 4. To combat the previously mentioned altitude problem, multiple altitudes will be in the ADB as well. This will give us a more accurate and thorough sampling of the atmosphere (Figure 4). Experiments have been carried out to find the ideal number of zeniths, azimuths, and altitudes to use in the new ADB. The experiments were designed to find an acceptable balance between accuracy and processing time; the more look angles involved, the higher the accuracy, but the longer the processing time.

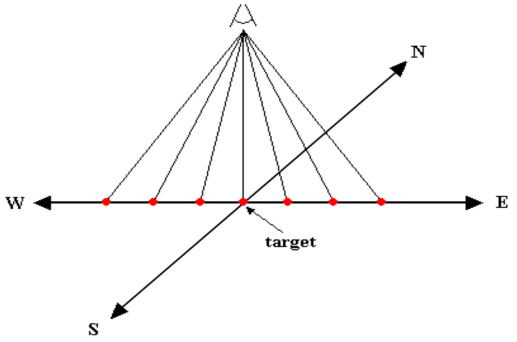


Figure 3: Current method for the upwelling section of the ADB, where the red dot presents MODTRAN runs

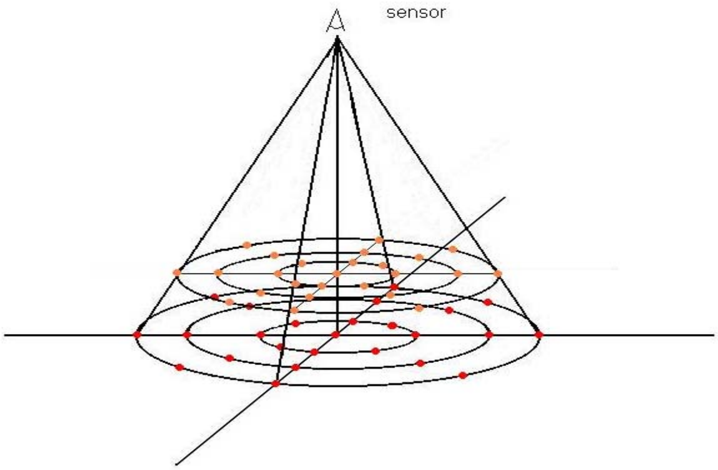


Figure 4: Proposed method for the upwelling section of the ADB, where the red dots represent MODTRAN runs on the ground level, and orange dots are at the first altitude.

4.4.2.2 Inhomogeneities

All the previous steps are essential in order for us to have the ability to move on to inhomogeneities. Actually incorporating them in the atmosphere will require a few additions to DIRSIG. These include multiple atmospheric databases, and "map" objects. The maps will be 2-d representations of inhomogeneities, each with a number of varying optical "thicknesses". To generate this, each inhomogeneity will have an ADB for each level of "thickness". This way, during image rendering, the ray will encounter an object in a given part of the sky, retrieve it's type and concentration of inhomogeneities, and reference the correct ADB. The geometry will already be taken care of within the ADB.

RESEARCH TEAM

Rolando Raqueño and Brian Dobbs

4.4.3 Modeling Polarimetric Imaging using DIRSIG

Background:

Traditional remote sensing techniques rely on the total intensity of light that reaches a detector, with little regard for other factors. Physics tells us that many manmade objects and some natural materials, such as water, tend to polarize reflected light. Solar illumination angles and scattered skylight can lead to significant level of polarization. Recently, researchers have been trying to determine the effectiveness of polarimetric imaging for use as a tool for the detection of manmade objects in a highly cluttered, natural environment.

Research Project:
To aid researchers in their effectiveness studies, RIT has chosen the modeling of a polarimetric imaging system in DIRSIG as his Ph.D. thesis topic. Current simulation environments do not have the ability to model polarimetric phenomenology. Captain Meyers has been investigating the intricacies of modeling hyperspectral polarimetric phenomenology in order to establish the technical foundation for including polarimetric properties into RIT's DIRSIG simulation software.

Status:
A substantial portion of this work has been completed. BRDF models have been studied and a candidate model, Torrance-Sparrow, has been identified for use in DIRSIG. Atmospheric modeling techniques that include polarization information have been worked with some of the leading researchers in this area. The radiative transfer functions within DIRSIG have been modified to allow for the transport of polarized data. A polarization sensitive sensor model has been developed that allows a number of system configurations, such as a line scanner or framing system, to be evaluated against a common target and background. With the final integration of these models almost complete, final validation of the simulation performance is being evaluated against several test cases.

PUBLICATIONS

Meyers, Jason, "Incorporation of polarization into the DIRSIG synthetic image generation model", Ph.D. Dissertation, Center for Imaging Science, Rochester Institute of Technology, 2002

Meyers, J.P., Schott, J.R., Brown, S.D., "Incorporation of polarization into the DIRSIG synthetic image generation model", SPIE Vol. 4816, pp. 132-143, July 2002

RESEARCH TEAM

Scott Brown, Rose of Sharon Daly, Jason Meyers

4.4.4 Next Generation DIRSIG

In the last year, the DIRS group embarked on a series of new research initiatives that included modeling and simulation as a component. These included the modeling of factory stack plume radiance signatures, water leaving radiance signatures, polarization dependent radiance signatures and basic radiation propagation of LASER light in an active image mode (LADAR and LIDAR). Our core simulation and modeling effort is largely encompassed in a whole scene model called the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model. Many of these demands on the DIRSIG were not feasible using the existing software architecture that had been developed and enhanced over the last 15 years. Due to the size and complexity of the model, it had become almost impossible for students without anything short of a MS in Computer Science and several years of experience to contribute to the model development. In addition to the new capabilities slated for addition to the model, the features and capabilities that had been added over the last 5 years had become very difficult to upgrade and maintain.

To address these many needs and issues, an effort was begun to redesign and rewrite the model in a heavily modularized approach that would break the model up into logical elements that could be enhanced, modified and replaced with ease. This design allows the staff and student developers to modify, test and evaluate the components of the model with limited or no impact on the rest of the model. The code rewrite effort includes the user of a software documentation model that mixes code and supporting documentation so that detailed explanations and illustrations are literally attached to the source code. This allows new people joining the project to learn about the model and how it works on their own.

The modular design of the model allows people working on the model to learn and understand the specific subsystem they are working on rather then the entire model. This modular design also allows algorithm developers to utilize a piece of the DIRSIG model where, in the past, the entire model would have to be run to extract a single calculation of interest. This design also allows for the basic components of the model to be easily assembled in a different fashion so that different "versions" of the model can be created to perform different tasks or to serve a different user community.

This version of DIRSIG will be released in the spring of 2003.

RESEARCH TEAM
Scott Brown, Paul Lee, Niek Sanders

4.4.5 DIRSIG Sensor Modeling Efforts

One of the major improvements in the next generation of DIRSIG is with respect to the sensor modeling capabilities provided by the model. The DIRSIG model was started as an effort to simulate radiation propagation in complex environments. The model accounts for a myriad of first principles radiation transfer processes including propagation through the atmosphere. The existing sensor model in DIRSIG accounts for focal plane geometry effects including scanning mechanisms associated with line scanners and platform motion. The model could also model basic image spectrometer instruments using user defined spectral calibration data. A basic ability to model the detector point-spread function (PSF) was added in 2001. The model did not provide any mechanism to introduce sensor noise into the system. However, for the effects that were modeled, the behavior was assumed to be constant over the entire focal plane. In push broom systems the spectral calibration varies across the focal plane due to an effect called "spectral smile or frown". The PSF may also vary as a function of position on the focal plane. More importantly, all of these properties may vary as a function of time.

Many of the DIRSIG users utilize the model to produce high spatial and high spectral resolution radiance images simulating the radiance field at the front of the sensor. These large images where then processed down through in-house sensor models to produce final system images. In an effort to streamline this capability for organizations with these in-house capabilities and to provide a basic capability to organizations without these features the sensor model was significantly redesigned.

The new DIRSIG sensor model allows the user to specify the spectral response, spectral PSF and spectral noise on a *pixel-by-pixel* basis. This feature allows system modelers to provide this information at run-time rather then force a post processing procedure. In addition, the creation and distribution of basic system models for community accessible imaging assets such as AVIRIS, HYDICE, etc. will allow uses without these modeling capabilities to produce more realistic image data. The flow diagram in Figure 1 illustrates the basic flow of the model and how the spectral response, spectral PSF and spectral noise are introduced during a single pixel calculation.

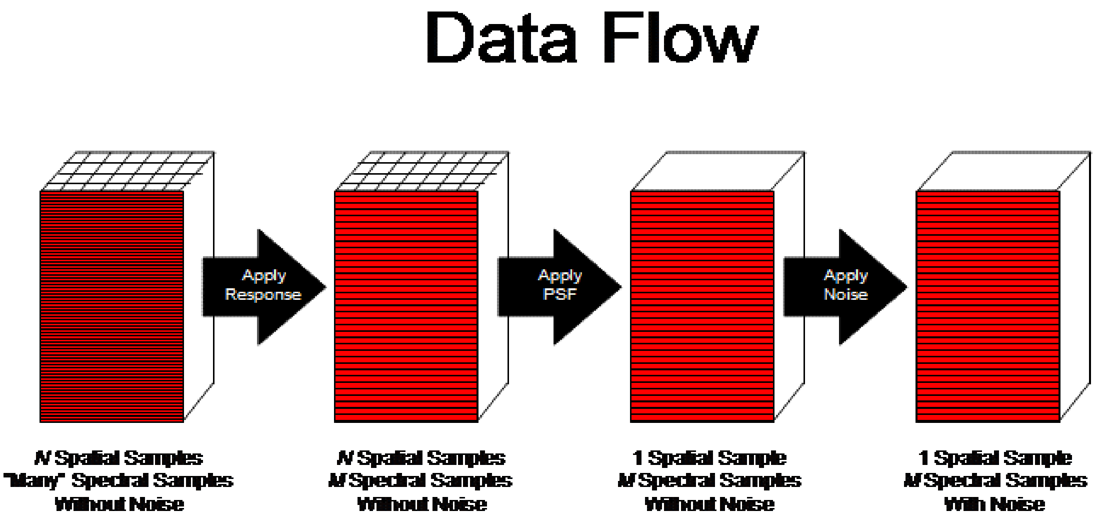


Figure 1

RESEARCH TEAM

Paul Lee, Cindy Scigaj, Scott Brown

4.4.6 Scene Construction Tools

Coincidental with the MegaScene effort, DIRS began an effort aimed at improving the ability to construct new scenes and modify existing scene databases used by DIRSIG. Under this effort, we expanded the scope of a planned tool that would allow the user community to attribute individual scene objects and then assemble multiple objects into a scene database.

The result was a tool that has become known as “bulldozer”. This OpenGL and Qt based application allows the user to import geometry models from common computer aided design (CAD) packages and attribute them with DIRSIG specific thermodynamic and optical properties. These objects can then be saved in the DIRSIG native geometry format. The user can then insert this object into an existing scene or into a new scene using the interactive interface to position the object where they please. Several “helper” features were added to the application that allows the user to streamline repetitive tasks and decrease scene construction time. Figure 1 contains a screen shot of the “bulldozer” tool being used to edit a scene.

The tool has an integrated and interactive help system that includes the user manual for the tool and tutorials. This effort also marks the first time we have used DocBook to create documentation that can be easily formatted into a variety of hard and soft copy formats. This allows us to create and maintain one document that produces LaTeX formatted, conventional index style manuals fit for hard or soft copy viewing *and* dynamically linked HTML and XML for interactive browsing.

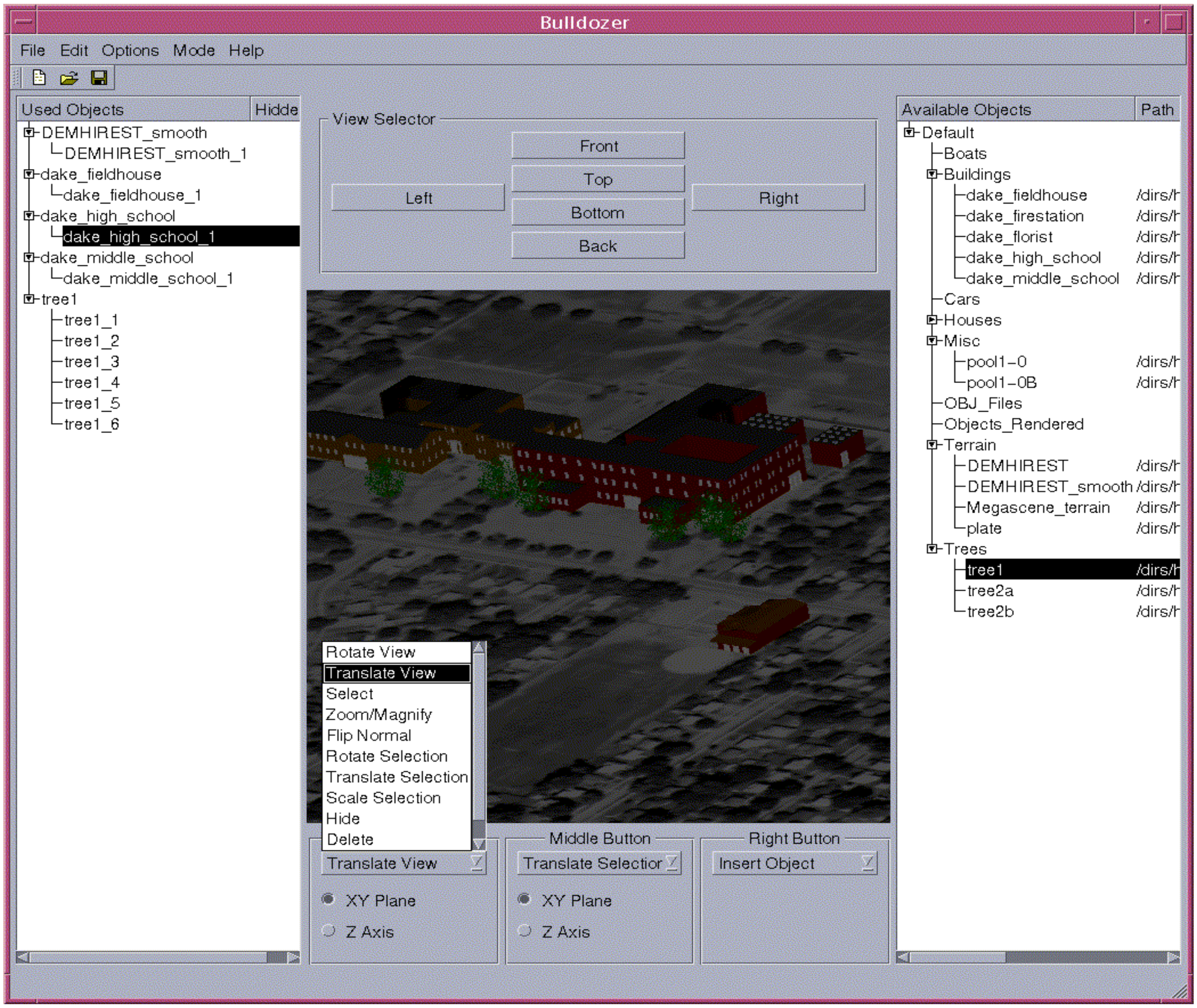


Figure 1

RESEARCH TEAM

Paul Lee, Robert Doran, Scott Brown

4.4.7 Materials Measurement Laboratory

2002 saw the further development and equipping of the new Materials Measurement Laboratory. The prime focus of this lab is the collection of reflectance spectra from background materials found in remotely sensed images. The spectral data is populating a database for use in synthetic image generation and image interrogation activities. Besides collecting material spectra, the lab is also involved with collector training, and monitoring the calibration and health of the other instruments used within DIRS.

This past year the lab took delivery of two major pieces of equipment. In April 2002, a Cary 500 Spectrophotometer with a 150 mm integrating sphere was installed. This instrument has a spectral range of 175 nm to 3,300 nm in transmission mode, and 200 to 2,500 nm in reflection mode. The majority of the measurements made this past collection season have been of vegetation. Of particular interest were tree leaves of different species during different phases of the growing season (Figure 1). The exceptional capabilities of the Cary 500 allowed us to accurately characterize the transmissive and reflective properties of tree leaves used for synthetic image generation. The stability of the instrument has also allowed us to characterization the change in leaf spectra as leaves wilt once removed from a tree.

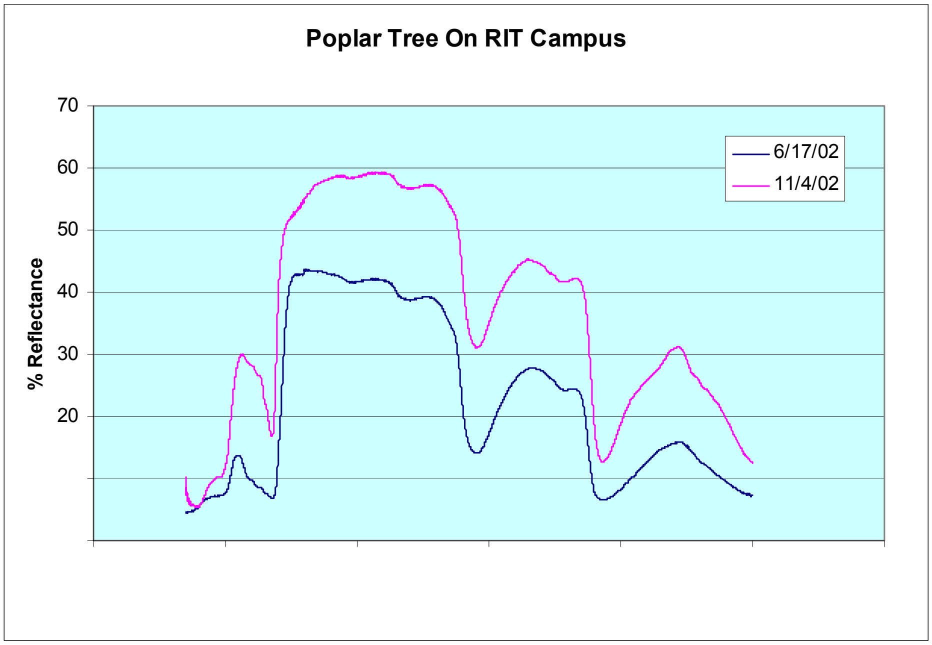


Figure 1

In July 2002, a Surface Optics Corporation (SOC) 400T IR Reflectometer was delivered. This is a portable reflectometer with a spectral range of 2.0 to 25.0 microns. It uses a miniature FTIR, internal gray body source, and internal references to measure the spectral reflectance of materials independent of surface temperature. The measurement team is working to learn the instrument operation, and how to incorporate the instrument with ASD measurements for near concurrent material measurements. These measurements will allow the lab to characterize the spectral reflectance of materials from 0.35 to 20.0 microns in one collection while in the field.

This past collect season we had the use of an ASD FieldSpec Pro Spectrometer to complement our own ASD unit. The FieldSpec Pro is on loan to us, and is an updated version of the ASD unit we have used for the past 3 years. Having the newer unit available to us has benefited the lab greatly in that there is a second unit available for major collect campaigns. The portability of the ASD has made it the workhorse of the lab. In addition to collecting material reflectance data (.350 to 2.50 microns), it also acquires radiance measurements during major field collections with MISI and the FIRES Program.

The lab is anxiously awaiting the delivery of a SOC-100 IR Reflectometer. Similar to the way the Cary 500 and the ASD complement each other, the SOC-100 will be the laboratory complement of the SOC-400T. It will have a similar spectral range, but will have the added capability of measuring directional reflectance. Delivery and installation is anticipated in the fall of 2002.

Materials that were measured this year reflect the lab's effort to provide greater detail for synthetic image generation activities. Previous measurements were successful at obtaining representative samples of various background materials. While the range of materials measured continues to expand, the major focus this year also included measuring the variability within a material. Examples include the spectral texture found in grassy areas, the transition between road materials and neighboring vegetation, and the variation in road materials due to composition, wear, and weathering. To accomplish this level of detail, thousands of spectral files were collected in the field and in the lab.

Managing vast amounts of spectral data in the past required a lengthy and manual process that often resulted in a long time lag between collection and data availability. Through the efforts of various team members, software was developed that greatly automated the data quality control process. Associated with each spectral measurement is a complete description of the material, digital images, and measurement conditions. Currently this information is manually entered into the database. To reduce this time consuming step, Palm technology is being developed that will allow direct downloading of Metadata.

RESEARCH TEAM

Gary DiFrancesco, Nina Raqueño, Carolyn Kennedy, Jim Uplinger, Jessica D'Amico, Danielle Merritt, Pete Gee, Jared Clock, Adam Cisz, Jeff Dank

4.5 DIRS OUTREACH

During this year DIRS continued to support the recruitment efforts of the Center for Imaging Science. DIRS recognizes the need to recruit at many different levels. This outreach section will review some of our recruitment efforts that were targeted at the general public, graduate students, high school students and teachers.

4.5.1 Public

This year DIRS continued its outreach activities to the public. DIRS faculty and research staff formed a relationship with the Rochester Museum and Science Center to educate the public about Rochester based imaging science research. From the initial discussions it was determined that the one of the ways we could become more involved with RMSC was to host one of their Science Saturday Programs. Practically all CIS and DIRS faculty, staff and students assisted with this huge effort. Overall CIS had sixteen different hands-on activity booths manned by over 40 CIS volunteers. DIRS organized the overall event and had four hands-on activities: Great Lakes Water Quality, Fun with Optics, Thermal Imaging, and Rochester in 3D. Some of the activities may be found at http://www.cis.rit.edu/RMSC/. This was a very successful event and CIS hopes to repeat it and other RMSC activities in the future.

DIRS also responded to a request to present current Remote Sensing Research at the New York State Association of Transportation Engineers Conference: The Image of Transportation.

4.5.2 K-12 Students and Teachers

For the third year DIRS continued to support the CIS high school student internship program. Based on the experiences of the previous year, CIS decided to expand the program to include eight local students. CIS improved the intern experience by adding a few career exploration activities. The interns visited both Xerox and Kodak and assisted in the RIT College and Career Day. During the summer of 2002, DIRS mentored three students: Mike Simson, Matt Meyer, and Jesse Schott. Mike expanded some of our 3D outreach materials, Matt worked with the DIRSIG Megascene team to produce new scene objects, Jesse assisted the NASA Landsat calibration project, and all of our interns assisted in DIRS field measurements. At the conclusion of the internship each student summarized their experience with a presentation to CIS. (http://www.cis.rit.edu/~dirs/presentations/interns). An exciting outcome of this internship was that one of the DIRS 2001 interns returned as an Imaging Science Freshman.

DIRS scientists provided workshops and an information booth at the regional Science Teachers Association of NYS Science Exploration Days. Workshops included thermal imaging experiments and demonstration of the drop tower. Remote Sensing overviews were presented at Canisius High School and Hartford Central High School. A keynote address on Remote Sensing was presented at the Hoosic Valley Research Symposium. The History and Applications of Remote Sensing was presented at Victor's Mission Geography teacher training workshops. DIRS assisted CIS in the Dake Middle School hands-on activities and the CIS Imaging Science Day for high school students. DIRS responded to a request from Hartford Central School's Kindergarten to teach them about 3D image viewing.

4.5.3 Graduate Students

In an ongoing attempt to increase CIS graduate enrollment, the DIRS group recruited at RIT and regional universities. Fire Physics Phenomena presentations were made at the University of Rochester S & T Symposium, SUNY Geneseo, SUNY Binghamton, SUNY Potsdam, Clarkson Institute of Technology and St. Lawrence University. DIRS continues to utilize the excellent RIT resource of computer science and physics students in many of the research projects.

RIT NEW AND EVENTS: March 28, 2002

IMAGING SCIENCE SATURDAY… RIT's imaging scientists hit the road March 16th for Science Saturday at the Rochester Museum and Science Center where students, faculty and staff from the Chester F. Carlson Center for Imaging Science helped introduce children to a new world of light. The overview included hands-on activities for children to discover such concepts as color contrast and separation, remote sensing and remote learning, microgravity, eye tracking, optics, astronomy, and medical imaging. Here Dr. Maria Helguera, Coordinator of the Distance-Learning program at CIS uses a slinky to demonstrate a concept of ultrasound for a curious visitor.

Scenes from the CIS's Science Saturday at the Rochester Museum and Science Center

5 PUBLICATIONS

Books and Journal Articles

Barsi, J.A, Schott, J.R., Palluconi, F.D., Helder, D.L., Hook, S.J., Markham, B.L., Chander, G., O'Donnell, E.M. "Landsat TM and ETM+ Thermal Calibration", Canadian Journal of Remote Sensing, 2002 in review.

Goward, S.N., Goetz, A.F., Thome, K.J., Ustin, S.L., Koger, T., Schott, J.R., Townshend, J.J., Woodcock, C.E., Pearlman, J., Turner, R.W., "The Resource21 Science Advisory Board: Recommendations for a Global Observatory to Continue the Landsat Mission Heritage," (submitted to American Society of Photogrammetry and Remote Sensing)

Kremens, R.L., Gallagher, A.J., Seema, A., "Low Cost Autonomous Field-Deployable Environment Sensors", American Institute of Physics, Proceedings of the Unattended Radiation Sensor Systems for Remote Applications Symposium, Vol. 632, pp. 190-199, July 2002

Kremens, R., Faulring, J., Gallagher, A., Seema, A., Vodacek, A., "Autonomous field-deployable wildland fire sensors", submitted to the International Journal of Wildland Fire, September 2002

Markham, B.L., Barker, J.L., Kaita, E., Barsi, J.A., Helder, D.L., Palluconi, F.D., Schott, J.R., Thome, K.J., Morfitt, R., Scaramuzza, P.,"Lansdat-7 ETM+ radiometric calibration: two years on-orbit," Proceedings of IGARSS, 2001

Simmons, R.E., Vermillion, S., Coss, J., Schott, J.R., Raqueno, R., Raqueno, N.G., Vodacek, A., Fairbanks, R., Goodenough, A., "Water Quality Monitoring with Hyperspectral Imaging," (submitted to Photogrammetric Engineering and Remote Sensing)

Schott, J.R., Brown, S.D., and Barsi, J.A., (in press). "Calibration of Thermal Infrared (TIR) Sensors". In J. Luvall & D. Quattrochi (Eds). *Thermal Remote Sensing in Land Surface Processes*. United Kingdom: Taylor & Francis.

Schott, J.R., and Barsi, J.A., (in press). "Radiometry for Remote Sensing". In R. Diggers and E. Lichtenstein (Eds). *Encyclopedia of Optical Engineering.* United States: Marcel Dekker, Inc.

Vodacek, A., Kremens, R., Fordham, A., VanGorden, S., Luisi, D., Schott, J.R., and Latham, D., "Remote optical detection of biomass burning using a potassium emission signature," International Journal of Remote Sensing, Vol. 23, No. 13, pp. 2721-2726, 2002

Published Proceedings

Burton, R.R., Schott, J.R., Brown, S.D., "Elastic ladar synthetic image generation model," Proceedings of SPIE, Vol. 4816, pp. 144-155, Seattle 2002

Meyers, J.P., Schott, J.R., Brown, S.D., “Incorporation of polarization in DIRSIG synthetic image generation model”, Proceedings of SPIE, Vol. 4816, pp. 132-143, Seattle 2002

O’Donnell, E.M., Schott, J.R., Raqueno, N.G., “Calibration History of Landsat Thermal Data”, Proceedings at IGARSS 2002, Toronto, Canada, IEEE Vol. 1, pp. 27-29

Schott, J.R., “Use of Physics-Based Models in Hyperspectral Image Exploitation” presented at AIPR Workshop, Washington, DC, October 2002

Presentations

Schott, J.R., “Remote Sensing of the Great Lakes: What We Can See, What We Can’t See, What We May See in the Near Future,” presented at the 15th Annual Great lakes Research Consortium, Syracuse, NY, January 2002

Schott, J.R., “Civil and Reconnaissance Applications of Remote Sensing: Yesterday, Today and Tomorrow” presented at Roberts Wesleyan College Fall Lecture Series, Rochester, NY, November 2002

Schott, J.R., “Remote Sensing of the Great Lakes”, presented to the RIT Women’s Council, Rochester, NY, November 2002

6. CAPSTONE PROJECTS COMPLETED BY DIRS STUDENTS

In this section we list the completed work of students from Ph.D. dissertations to senior projects. We list not only the recent work but also the past students projects to recognize student contributions to DIRS continued success.

Ph.D. Dissertations

Snyder, W., *An in-scene parameter estimation method for quantitative image analysis.* Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 1994.

Feng, X., *Design and performance evaluation of a modular imaging spectrometer instrument*. Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 1995.

Gross, H., *An image fusion algorithm for spatially enhancing spectral mixture maps*. Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York, 1996.

Kuo, D., *Synthetic image generation of factory stack and cooling tower plumes*. Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York,1997.

Fairbanks, R., *A characterization of the impact of clouds on remotely sensed water quality.* Unpublished doctoral dissertation, U.S. Air Force, Rochester Institute of Technology, New York ,1999.

Sanders, L., *An Atmospheric Correction Technique for Hyperspectral Imagery.* Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 1999.

Hernandez-Baquero, E., *Characterization of the Earth's surface and atmosphere from multispectral and hyperspectral thermal imagery*. Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2000.

Bishop, J., *Modeling of Plume Dispersion and Interaction with the Surround of Synthetic Imaging Applications*. Unpublished doctoral dissertation, Rochester Institute of Technology, New York, 2001.

M.S. Theses
A.J. Sydlik, 1981, "A technique for calculating atmospheric scattering and attenuation effects of aerial photographic imagery from totally airborne acquired data" Canadian Forces
Lawrence Maver, 1983, "The effects of shadow visibility on image interpretability"
George Grogan, 1983, "A model to predict the reflectance from a concrete surface as a function of the sun-object-image angular relationship"
A.E. Byrnes, 1983, "A comparison study of atmospheric radiometric calibration methods for aerial thermograms" Canadian Forces
I.D. Macleod, 1984, "An airborne thermal remote sensing calibration technique" Canadian Forces
William Volchok, 1985, "A study of multispectral temporal scene normalization using pseudo-invariant features, applied to Landsat TM imagery"
Joseph Biegel, 1986, "Evaluation of quantitative aerial thermography"
Tim Hawes, 1987, "Land cover classification of Landsat thematic mapper images using pseudoinvariant feature normalization applied to change detection" U.S. Air Force
Carl Salvaggio, 1987, "Automated segmentation of urban features from Landsat thematic mapper imagery for use in pseudoinvariant feature temporal image normalization"
Myra Bennett Pelz, 1989, "A robotic vision system for identifying and grasping objects" (M.S. Computer Science)

John Francis, 1989, "Pixel-by-pixel reduction of atmospheric haze effects in multispectral digital imagery"
Denis Robert, 1989, "Textural features for classification of images" Canadian Forces
Jan North, 1989, "Fourier image synthesis and slope spectrum analysis"
Michael Davis, 1990, "Bidirectional spectral reflectance field instrument"
Wendy Rosenblum, 1990, "Optimal selection of textural and spectral features for scene segmentation"
Eric Shor, 1990, "Longwave infrared synthetic scene simulation"
James Warnick, 1990, "A quantitative analysis of a self-emitting thermal IR scene simulation system"
Curtis Munechika, 1990, "Merging panchromatic and multispectral images for enhanced image analysis" U.S. Air Force
Xiaofan Feng, 1990, "Comparison of methods for generation of absolute reflectance factor measurements for BRDF studies"
Rolando Raqueño, 1990, "Automated boundary detection of echocardiograms" (M.S. Computer Science)
Jonathan Wright, 1991, "Evaluation of LOWTRAN and MOTRAN for use over high zenith angle/long path length viewing" U.S. Air Force
Eubanks, Craig, 1991, "Comparison of ellipso-polarimetry and dark field methods for determining of thickness variations in thin films"
Robert Mericsko, 1992, "Enhancements to atmospheric correction techniques for multiple thermal images"
Gustav Braun, 1992, "Quantitative evaluation of six multi-spectral, multi-resolution image merger routines"
Sharon Cady, 1992, "Multi-scene atmospheric normalization of airborne imagery: application to the remote measurement of lake acidification"
David Ehrhard, 1992, "Application of Fourier-based features for classification of synthetic aperture radar imagery" U.S. Air Force
Bernard Brower, 1992, "Evaluation of digital image compression algorithms for use on lap top computers"
Donna Rankin, 1992, "Validation of DIRSIG an infrared synthetic scene generation model"
Craig Laben, 1993, "A comparison of methods for forming multitemporal composites from NOAA advanced very high resolution radiometer data"
Tom Servoss, 1993, "Infrared symbolic scene comparator"
Richard Stark, 1993, "Synthetic image generator model: application of specular and diffuse reflectivity components and performance evaluation in the visible region" U.S. Air Force
Eleni Paliouras, 1994, "Characterization of spatial texture for use in segmentation of synthetic aperture radar imagery"
Robert Rose, 1994, "The generation and comparison of multispectral synthetic textures"
Joseph Sirianni, 1994, "Heat transfer in DIRSIG an infrared synthetic scene generation model"
Gary Ralph, 1994, "Characterization of the radiometric performance of an IR scene projector" Canadian Forces
Jim Salicain, 1995, "Simulation of camera model sensor geometry effects"
Steven Nessmiller, 1995, "A comparison of the performance of non-parametric classifiers with gaussian maximum likelihood for the classification of multispectral remotely sensed data" U.S. Air Force
Serge Dutremble, 1995, "Temporal sampling of forward looking infrared imagery for subresolution enhancement post processing" Canadian Forces
Alexander J. Granica, 1996, "Modeling of the radiometric characteristics of a simulated flourescent imager"
Todd A. Kraska, 1996, "Digital Imaging and Remote Sensing Image Generation Model: infrared airborne validation & input parameter analysis" U.S. Air Force
Frank J. Tantalo, 1996, "Modeling the MTF and noise characteristics of an image chain for a synthetic image generation system"
Russell A. White, 1996, "Validation of Rochester Institute of Technology's (RIT's) Digital Image and Remote Sensing Image Generation (DIRSIG) model-reflective region" U.S. Air Force
Jeffrey Allen, 1997, "Methods of digital classification accuracy assessment"
Paul Llewellyn Barnes, 1997, "In-scene atmospheric correction for multispectral imagery"
Todd Birdsall, 1997, "The development of an analytical model for the Kodak digital science color infrared cameras and its aerial imaging applications"
Phil Edwards, 1997, "A Canadian Resource Guide for a Water Quality Study of Lake Ontario" Canadian Forces
Gary Robinson, 1997, "Evaluation of two applications of spectral mixing models to image fusion" U.S. Air Force
David Schlingmeier, 1997, "Resolution enhancement of thermal infrared images via high resolution class-map and statistical methods" Canadian Forces
Tom Haake, 1998, "Modeling Topography Effects with DIRSIG

David Joseph, 1998, "DIRSIG: A broadband validation and evaluation of potential for infrared imaging spectroscopy"
Julia Laurenzano, 1998, "A comparative analysis of spectral band selection techniques" U.S. Air Force
Francois Alain, 1999, “Simulation of Imaging Fourier Transform Spectrometers Using DIRSIG” Canadian Air Force
Dilkushi Anuja de Alwis, 1999, “Simulation of the formation and propagation of the thermal bar on Lake Ontario”
Daisei Konno, 1999, “Development and Testing of Improved Spectral Unmixing Techniques”
Emmett Ientilucci, 1999, “Synthetic simulation and modeling of image intensified CCDs (IICCD)”
Pete Arnold, 2000, “Modeling and Simulating Chemical Weapon Dispersal Patterns in DIRSIG”
Julia Barsi, 2000, “MISI and Landsat ETM+ : thermal calibration and atmospheric correction”
Robert Gray, 2000, “Modeling Forests for Synthetic Image Generation” Computer Science
Mary Ellen Miller, 2000, "An approach for assessment of Great Lakes Water Quality using Remote Sensing”
John Klatt, 2001, “Error Characterization of Spectral Products using a Factorial Designed Experiment”
Andrew Fordham, 2002, “Band Selection and Algorithm Development for Remote Sensing of Wildfires”
Hyeun-Gu Choi, 2002, “Spectral Misregistration Correction and Simulation for Hyperspectral Imagery”

B.S. Theses/Projects
Jeffrey Sefl, 1983, "Determination of the transformation relationship of pseudo-invariant features of two Landsat images"
Kirk Smedley, 1986, "Imaging land/water demarcation lines for coastal mapping"
David Sapone, 1988, "Verification of a thermal model through radiometric methods"
Joshua Colwell and Eric Higgins, 1988, "Determination of the modulation transfer function of a thermal infrared line scanner"
Donald Marsh, 1989, "Photometric processing and interpretation of ratioed imagery by multispectral discriminate analysis for separation of geologic types"
Fred Stellwagon, 1989, "Classification of mixed pixels"
Brian Jalet, 1991, "Evaluation of methods of cloud removal in multidate NOAA/AVHRR imaging and its application to vegetational growth monitoring"
Mike Heath, 1991, "Perspective scene generation employing real imagery"
Stephen Ranck, 1991, "Establishment of a simple geographic information system utilizing digital data"
James Schryver, 1991, "Topographical analysis of a raster geographic information system"
Robert Rose, 1992, "Design of the information dissemination technique for a heat loss study"
Joseph Sirianni, 1992, "Production of realistic-looking sky radiance in the SIG process"
Andy Martelli, 1992, "Color calibration of an Agfa matrix QCR camera for Ektar 100 and 125 color print films"
Mike Branciforte, 1993, "An automated video tracking unit based on a matched filter segmentation algorithm"
Brian Heath, 1993, "Use of a quad cell in tracking a unit"
Debbie Wexler, 1993, "Texture generation using a stochastic model"
Michael Platt, 1994, "Evaluation of the feasibility of using digital terrain elevation models for the generation of multispectral images at Landsat resolution"
Cory Mau, 1994, "Incorporation of wind effects in IR scene simulation"
Paul Barnes, 1995, "Introduction of vegetation canopy models into DIRSIG"
Jeff Ducharme, 1995, "Atmospheric downwelled radiance"
Chip Garnier, 1995, "Integrating sphere calibration"
Jeff Allen, 1996, "Comparison of modeled and real vegetation imagery"
Emmett Ientilucci, 1996, "Blackbody calibration of MISI"
http://www.cis.rit.edu/research/thesis/bs/1998/ientilucci/BS_Thesis.htm
Charles Farnung, 1997, "DIRSIG camouflage phenomenology"
Peter Arnold, 1997, "BRDF approximation using a mathematical cone function"
Julia Barsi, 1997, "The generation of a GIS database in support of Great Lakes Studies"
Jason Calus, 1997, "Modeling of focal plane geometry in DIRSIG"
Arnold Hunt, 1997, "Validation of BRDF model in DIRSIG"
Michael C. Baglivio, 1998, “Error Characterization of the Alpha Residuals Emissivity Extraction Technique”
http://www.cis.rit.edu/research/thesis/bs/1998/baglivio/title.html
Brian Bleeze, 1998, “Modeling the MTF and Noise Characteristics of Complex Image Formation Systems”
http://www.cis.rit.edu/research/thesis/bs/1998/bleeze/title.html
Chia Chang, 1998, “Evaluation of Inversion Algorithms on DIRSIG Generated Plume Model Simulations”
http://www.cis.rit.edu/research/thesis/bs/1998/chang/title.html

Peter Kopacz, 1998, “Simulation of Geometric Distortions in Line Scanner Imagery”
http://www.cis.rit.edu/research/thesis/bs/1998/kopacz/index.html
Jason Hamel, 1999, “Simulation of Spectra Signatures of Chemical Leachates from Landfills”
http://www.cis.rit.edu/research/thesis/bs/1999/hamel/title.html
Daniel Newland, 1999, “Evaluation of Stepwise Spectral Unmixing with HYDICE Data”
http://www.cis.rit.edu/research/thesis/bs/1999/newland/title.html
J. Meghan Salmon, 2000, "Derivative Spectroscopy for Remote Sensing of Water Quality"
http://www.cis.rit.edu/research/thesis/bs/2000/salmon/title.htm
Janel Schubbuck, 2000, "Thermal Calibration of MISI"
http://www.cis.rit.edu/research/thesis/bs/2000/schubbuck/titlepage.html
Matt Banta, 2001, “Lunar Calibration Techniques”
http://www.cis.rit.edu/~msb8216
Christy Burtner, 2001, “Texture Characterization in DIRSIG”
http://www.cis.rit.edu/~cjb7385
Adam Goodenough, 2001.”Evaluating Water Quality Monitoring with Hyperspectral Imagery”
http://www.cis.rit.edu/~aag7210
Erin O'Donnell, 2001, “Historical Radiometric Calibration of Landsat 5”
http://www.cis.rit.edu/~emo1683
Nikolaus Schad, 2001, “Hyperspectral Classification with Atmospheric Correction”
http://www.cis.rit.edu/~nas6275
Cindy Scigaj, 2001, “Design and Implementation of a LIDAR Imaging System”
http://www.cis.rit.edu/~cls8343
Eric Sztanko, 2001. “Imaging Fourier Transform Spectrometer: Design, Construction, and Evaluation”
http://www.cis.rit.edu/~ens1849
Eric Webber, 2001, “Sensitivity Analysis of Atmospheric Compensation Algorithms for Multispectral Systems Configuration”
http://www.cis.rit.edu/~erw3700
Adam Cisz, 2002, Multispectral Fire Detection: Thermal/IR, Potassium, and Visual
www.cis.rit.edu/~apc2125
Rose of Sharon Daly, 2002, Polarimetric Imaging
www.cis.rit.edu/~rxd8337
Matthew D. Egan, 2002, Detection and Analysis of Industrial Gas Plumes
www.cis.rit.edu/~mde1583
Carolyn S. Kennedy, 2002, The Testing and Assessment of Texturing Tools Used to Build Scenes in DIRSIG
www.cis.rit.edu/~csk0458
David Pogorzala, 2002, Setting Fire to CIS, Small - Scale Combustion Chamber and Instrumentation
www.cis.rit.edu/~drp9420