Annual Report 2000/2001

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 FOREWORD

This has been a year of major growth and change for the DIRS lab. Cindy Schultz has taken on the role of secretary and den mother. Georgia Giummarra is providing administrative support to the FIRES program and Gary DiFrancesco who has been with the Center for several years, is now spending half of his time with us helping to set up and operate our spectral measurements lab. The Personnel section contains more information on all the DIRS staff. Another major change this year was the formation of the Laboratory for Advanced Spectral Sensing (LASS). This new research entity, housed within DIRS, is a joint industry-government-university collaboration focusing on improving the knowledge base for multidimensional imaging of the earth. The LASS formalizes our commitment to expand the horizons of spectral sensing through research and education programs. It also focuses our commitment to partner with government and industry to foster our mutual need for more fundamental understanding of spectral sensing and the development of tools for analysis of remotely sensed spectral data. I am very pleased to report that industry and government have been quick to see the value of the LASS concept and join in this venture. I'd also like to thank the Institute for supporting the formation of LASS and providing the seed funding. The LASS Program and initial technical thrusts are described in more detail in the Project Descriptions section of this report.

It is the students that keep DIRS going and this year has seen even more coming and going than usual. The education and certification of students is one of our stated and cherished goals. The incredible demand by industry, government and other graduate programs for our students reflects the quality of our education and research programs. The overwhelming comments from recruiters relate to the seamless transition our students make into their careers. We believe this is a function of both our curriculum and the extensive research component of all our degrees. We try through our teamed approach to research, to emulate the research and production environment our graduates will face. By working with faculty, staff and other students in a stimulating and demanding environment, the students produce much of our research output while preparing for their careers. The research work emphasized this year is outlined in the Project Descriptions sections with the completed degrees listed in Capstone Projects section. The Lab's overall long-term contribution comes in two forms, our graduates and the scientific publications we produce. This year's publications are listed in the Publications section. We were particularly honored this year when, a freshly hooded Dr. Erick Hernandez-Baquero, received the award for the best paper by a student at the IGARSS 2000 meeting.

In closing, I want to thank the faculty, staff and students who have made this year so successful and to once again thank and honor the memory of Fred Wiedman, whose generosity enables much of what we do.

Thank you.
John R. Schott
November 2001

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 11 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.

3 PERSONNEL

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4 PROJECT DESCRIPTIONS

This section contains a short description of the projects worked on by students and staff over the past year. We recognize that these short descriptions will only whet the appetite of some readers so at the end of each description we have included any available references to publications. Further details may also be found on our web site (http://www.cis.rit.edu/~dirs/).

4.1 The Laboratory for Advanced Spectral Sensing (LASS)

4.1.1 LASS Overview

The LASS was formed in 2000 to fill a growing need within the remote sensing community for a national resource in spectral research and education. The LASS is strongly supported by long term funding commitments from U. S. Government Agencies and corporate partners with strong interest in remote sensing. The founding partners are Eastman Kodak Company, The Boeing Company, ITT Industries, and the National Reconnaissance Office.

The core research conducted within the LASS focuses on pre-competitive research that is widely shared with all the LASS partners. For 2001, research focus areas have included phenomenology and algorithms related to the littoral zone (where the water meets the land), improvements to modeling and simulation software, the initiation of a material measurements laboratory, and the development of figures of merit that enable the evaluation and comparison of spectral data sets.

Directed research projects are funded by individual sponsors and distribution of the results is developed in conjunction with the sponsor. Areas of research have focused on the development of hyperspectral data processing and management systems and specific processing algorithms of spectral data sets.

With the early success of the LASS, additional partners are being considered. The spectral remote sensing field is continuing to expand rapidly with new applications being considered for scientific and government applications. The LASS would like to add several new partners, over the next 12 to 18 months, that complements the existing group of partners. Several organizations within the government and from industry appear to be ideal candidates and their membership would continue to solidify the capability of the LASS.

The first LASS Board of Advisors meeting was held on July 17, 2001. The LASS board is made up of representatives from each of the sponsoring organizations. The purpose of the board meeting was to review the core research status, understand the current and future needs of the LASS members, and solicit input for 2002 research focus areas.

4.1.2 DIRSIG Improvements

The Digital Imaging and Remote Sensing Image Generation (DIRSIG) model has continued to be a significant focus of our research efforts. The model is an integrated collection of independent first principles based submodels which work in conjunction to produce radiance field images with high radiometric fidelity in the 0.3 – 30.0 µm region. The improvements for this year have been largely focused on improving the phenomenology and modeling of the scene and the utility of the model for specific sensing applications.

More information about the DIRSIG model can be found on the DIRSIG homepage at:
http://www.cis.rit.edu/~dirsig

4.1.2.1 Mega-Scene

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 current process is very time consuming and does not scale well for building significantly larger “mega-scenes” (2.5 miles square). For this task, a new set of well designed and well implemented scene creation tools are under construction that should 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 constructing one mega-scene each year for general use by the user community. The target area for this first year is the northeast side of Rochester, NY that includes urban residential, urban commercial, rural and coastal regions.
The work on the new scene construction tools and the Rochester scene are underway. The overriding principle behind the tool design is to allow the user to use imagery of the subject area to aid in the construction process. The mock-up tool in Figure 1 illustrates what the DIRSIG scene editor will look like. In the example below, IKONOS imagery is being used as a virtual “tracing paper” to place 3D models of the various buildings, trees, etc. into their relative locations. The tool will also enable the user to load elevation and algorithm products (for example, classmaps and mixture fractions) and implement feature extraction algorithms that aid the user in finding the locations of building, trees, etc. Wire frame of fully attributed CAD objects can then be placed via a simple drag-and-drop procedure at these locations. The end result is an application which contains tools such as feature extraction, spectral unmixing, and classification algorithms that aid the user in constructing large-scale synthetic scenes on a more timely basis.
The final scene will feature target and background spectral databases resulting from a significant ground truth campaign performed as part of other lab activities.

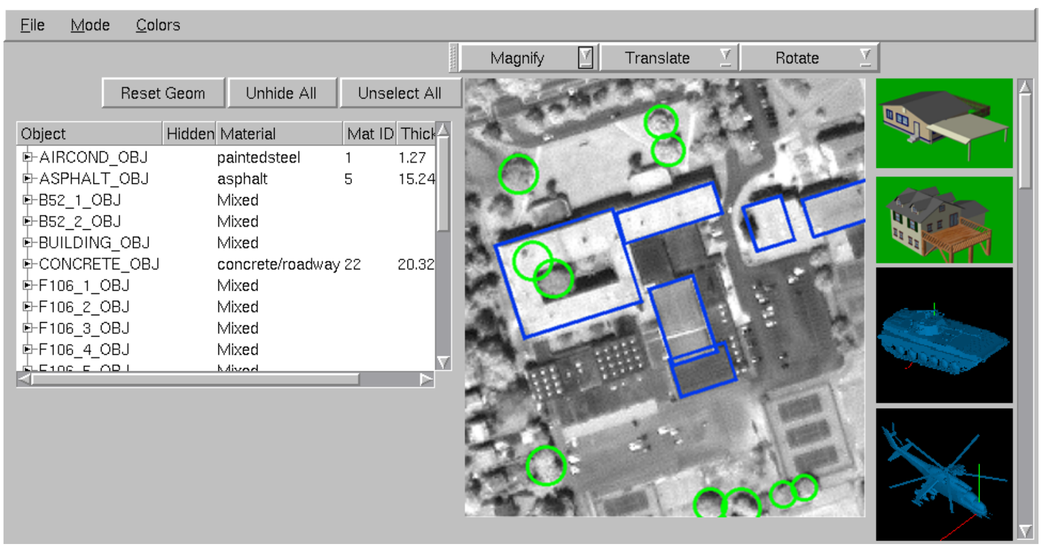


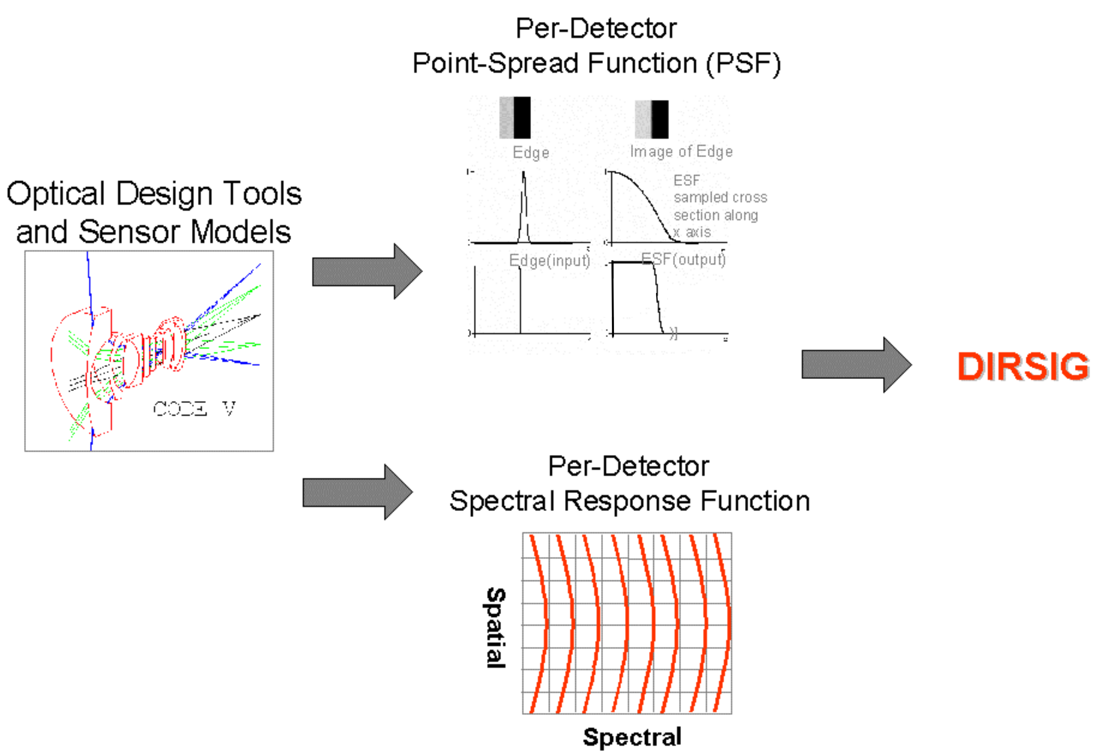
Figure 1

Research Team: Emmett Ientilucci, Scott Brown, Mike Ryan

4.1.2.2 Improved Sensor Model

The DIRSIG model has been developed to address a variety of application areas. One of the more popular uses of DIRSIG in recent years has been for performing sensor design trade studies. For this application, the DIRSIG model is used to evaluate the critical instrument design trades by allowing the user to easily manipulate instrument properties ranging from optical focal lengths and platform altitudes to focal plane sizes and detector spectral responses. Ideally, the model is flexible and robust enough that the user can manipulate any properties of the instrument which system engineers wish to experiment with. Although DIRSIG provides extensive access to most aspects of actual imaging systems, the model did lack the ability to model some elements of the complex optical and detection systems utilized in next generation sensors.

The enhancements currently underway will allow the DIRSIG model to vary the spectral point-spread function (PSF), spectral response function, and spectral noise function on a per-detector basis. This will result in a simple low-level interface that should allow sensor designers to model and evaluate an even larger array of potential design issues. This interface should allow organizations with proprietary in-house sensor models to link their rigorous optical and focal plane models with DIRSIG for an integrated solution. This interface will also allow future versions of DIRSIG to be more tightly integrated with common optical modeling tools such as Code V.



Research Team: Scott Brown, Cindy Scigaj
Reseach Webpage: http://www.cis.rit.edu/~dirsig

4.1.2.3 Atmospheric Inhomogeneities in DIRSIG

The goal of this research is to incorporate atmospheric inhomogeneities into DIRSIG. This is a very important step towards improving the overall accuracy and modeling fidelity in DIRSIG.

This ability will allow DIRSIG to include such features as horizontally varying water vapor and aerosol concentrations, and eventually clouds, in the synthetic atmosphere.

There are two modeling improvements that have been identified. The first improvement involves the generation of the atmospheric database using MODTRAN. Another hurdle is within DIRSIG itself. Currently, 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. (Figure 1.) The ray from DIRSIG, therefore, incorporates the lower layers of the atmosphere, even though the object is above these layers. This leads to more atmospheric effects than expected. This problem was previously ignored due to the fact that nearly all of the objects to be modeled were relatively close to the ground altitude where the changes in atmospheric effects were negligible. However, for objects with higher altitudes, (such as clouds or mountains) these changes can be very significant. Also, DIRSIG does not take into account azimuthal variation of the atmosphere.

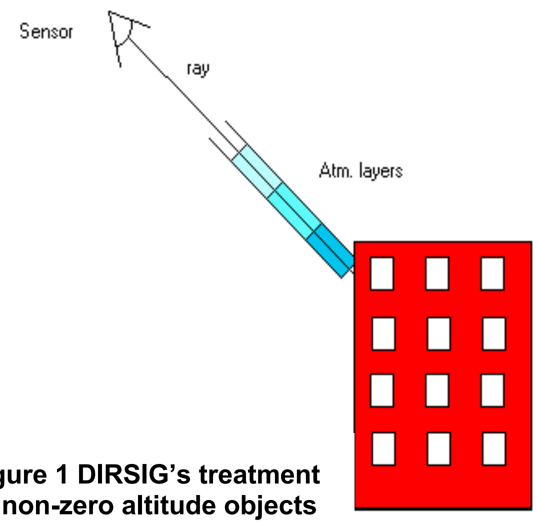
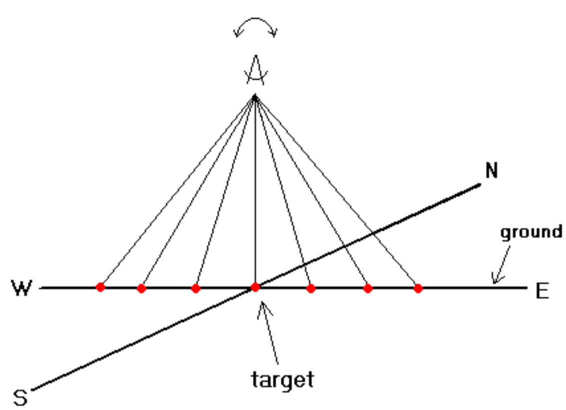


Figure 1 DIRSIG's treatment of non-zero altitude objects

The proposed improvement involves the generation of an expanded atmospheric database and an improved interrogation by DIRSIG with better source-target-sensor geometry.
We are now testing and refining an interpolator to attempt to fix these problems. The way a current DIRSIG runs works, is that it creates an atmospheric database in which a series of MODTRAN runs are made for a number of different zenith angles about the target, as shown in figure 2. We intend to expand this database to include multiple heights and multiple azimuth angles for each of those zenith angles, as in figure 3. Then, this interpolator will more accurately estimate the radiometry for any sight path in DIRSIG.

The second modeling improvement is at the preliminary stages of development. The Air Force's MODTRAN (used by DIRSIG) models the atmosphere as homogenous slabs. The atmospheric properties can vary as the altitude increases, by changing the characteristic of higher layers, but horizontal variation is not possible. Some ideas to incorporate horizontal variability into DIRSIG are currently being investigated. One of these is to actually build an object in DIRSIG, using optical data (transmission, scattering, extinction, etc.) from existing water vapor and aerosol

Figure 2.

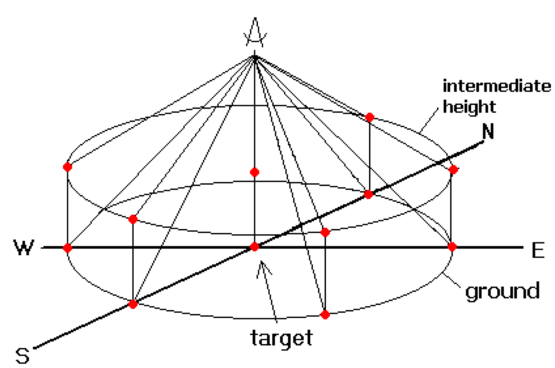


Example of points* used in current atmospheric database

* - each point (•) represents a specified MODTRAN run

Figure 3

(example pattern for each zenith)



Example of points* used by proposed interpolator.

maps. (see Figure 4) Also, the feasibility of calling a separate program when clouds or aerosols are encountered is being studied.

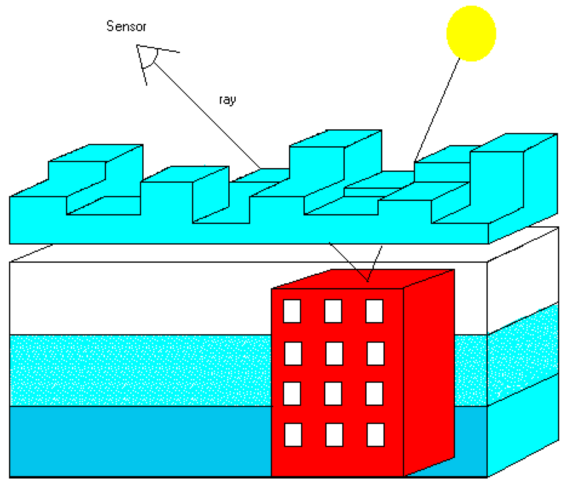


Figure 4 Example of proposed "cloud object" in DIRSIG

Research Team: Brian Dobbs, Scott Brown
Research Webpage:
http://www.cis.rit.edu/research/dirs/AnReport01/present/DIRSIG/atms_inhomo/index.htm

4.1.2.4 Spectral Polarimetric Modeling Using DIRSIG

Synthetically generated hyperspectral imagery has proven useful in many aspects of remote sensing. Synthetic imagery is currently used in support of sensor design studies, algorithm development and evaluation, phenomenology studies, and analyst training. A major benefit of synthetic imagery is the inherent ground truth data that makes it easier to understand the system being studied. Current synthetic image generation programs lack the ability to model polarimetric characteristics. The purpose of this research is to investigate the intricacies of modeling hyperspectral polarimetric phenomenology. This research will develop the foundation for including the modeling of hyperspectral polarimetry within RIT's synthetic image generation program DIRSIG.

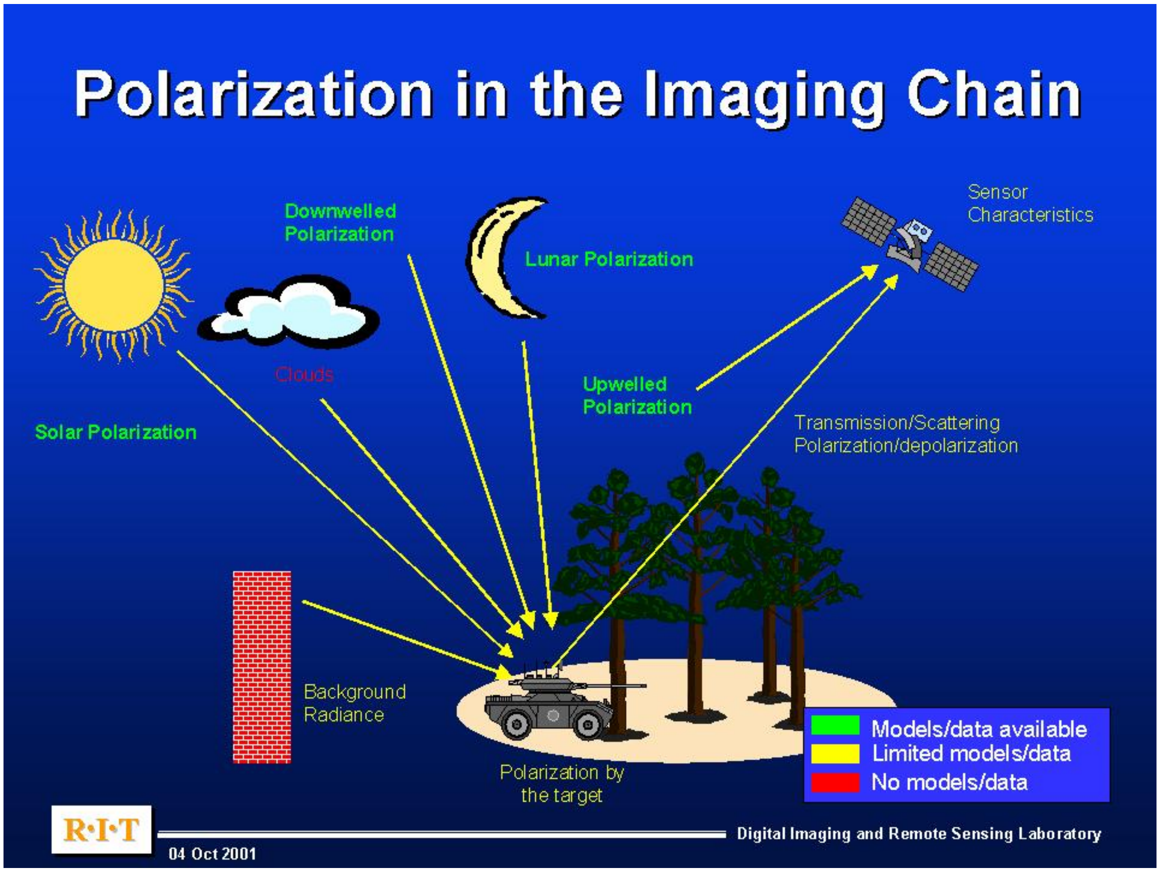
Adding hyperspectral polarimetric modeling to DIRSIG will be an evolutionary process. The problem requires modifications of four main areas of the DIRSIG model: atmospheric illumination (both direct and scattered), atmospheric transmission, target and background reflectances, and sensor characterization. Each of these areas will be addressed in varying degrees. Emphasis will be placed on developing the ability to incorporate future improvements in polarimetric modeling of each component in DIRSIG.

The majority of the effort will be focused on including the capability to model polarimetric phenomenology within DIRSIG. This requires the use of Stokes vectors to characterize the polarization components and Mueller matrices to propagate the polarization effects along the image chain. This will require modifications to the following components of the DIRSIG model:

- **Solar and Sky Illumination** - DIRSIG currently uses the Air Force MODTRAN code to obtain information about the solar and sky irradiances. The current version of MODTRAN does not model the polarimetric characteristics of either solar or sky irradiance; however, AFRL is currently working on developing that capability. Until such capability exists, the polarization characteristics will be estimated from tabulated measurements combined with non-polarimetric data from MODTRAN.

- **Atmospheric Propagation** - As stated previously, MODTRAN is used by DIRSIG to model atmospheric propagation. Atmospheric propagation will likely be treated in a similar fashion as solar and sky irradiance.
- **Target and Background Reflectances** - DIRSIG currently has a simplified bidirectional reflectance model capable of using available hyperspectral reflectances. This capability will be expanded to accommodate polarimetric dependencies once these data become available. Methods of interpolating and extrapolating bidirectional reflectances will be investigated. This will provide the ability to estimate the spectral and polarimetric dependencies until databases become better populated.
- **Sensor Characteristics** - This research will leverage related efforts to build a generic sensor model for DIRSIG. The ability to specify a sensor's polarimetric characteristics will be included in the model and used within DIRSIG.

The testing and validation efforts will be divided into three levels of effort: laboratory simulations, a simple scene, and a complex (AKA the Mega) scene. Efforts will be coordinated with the Air Force Research Labs (AFRL) which is conducting related laboratory and outdoor polarimetric experiments. Ideally, AFRL will be able to provide some polarimetric images from real systems along with measurements of various material properties used in the DIRSIG modeling.

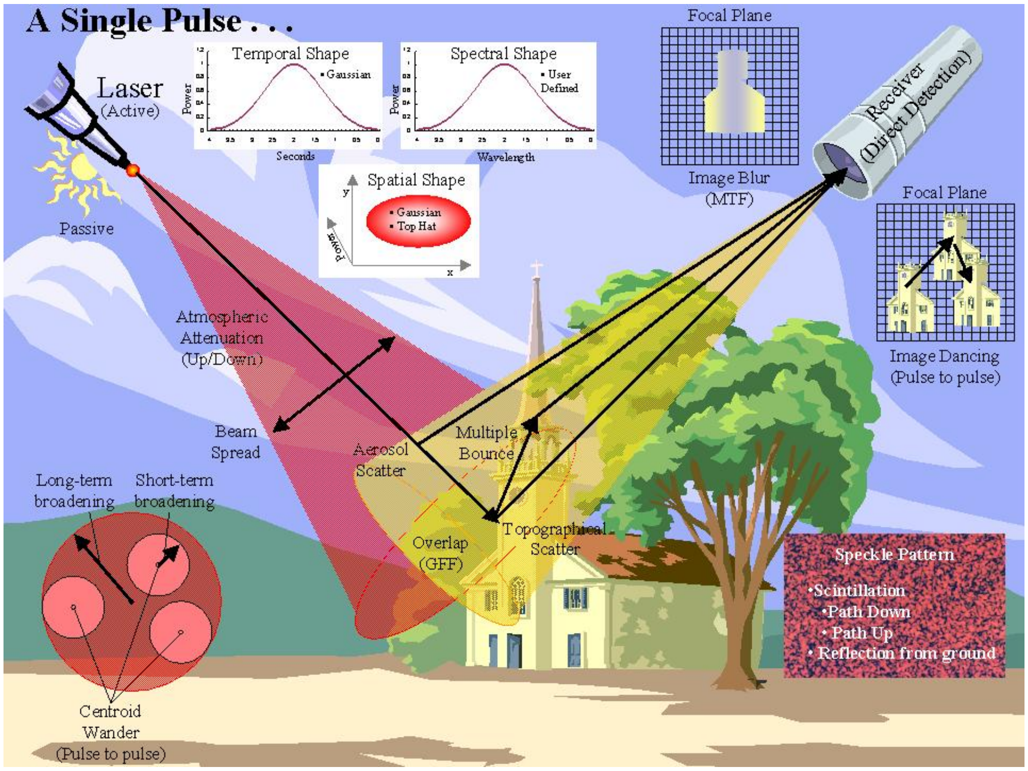


Research Team: Jason Meyers, Scott Brown. John Schott
Research Webpage: http://www.cis.rit.edu/~jpm7934/Research/

4.1.2.5 Incorporating a LIDAR model into DIRSIG

Recent enhancements in DIRSIG include the development and modeling of light detection and ranging (LIDAR) systems. Recently, (passive) low-light-level phenomenology has been developed. This base line effort has lead the way for studying other types of (active) sources. Once such source commonly found in a LIDAR system are LASERS. Significant progress has been made in the modeling of single scattering atmospheric and topographic LIDAR returns.

The off-line code carefully accounts for the geometrical form factor and compression effect for both coaxial and biaxial LIDAR systems. This code will be integrated with DIRSIG code to produce simulated still frame imagery from a typical LIDAR system. Additional effects to be incorporated in the near term include transmission through translucent objects, speckle noise, and the effects of multiple scattering.



Research Team: Robin Burton, Scott Brown, Emmett Ientilucci
Research Webpage: http://www.cis.rit.edu/research/dirs/AnReport01/present/LIDAR/index.htm

4.1.3 Littoral Zone Phenomenology and Algorithms

One of the areas that has been identified by the LASS for spectral studies is the area of Littoral Zone phenomenology and algorithms. The goal of this research is to develop, refine, and integrate simulation modeling tools and techniques that will aid in designing and evaluating algorithms for the littoral regime. A sampling of DIRS early activities towards this goal include the following.

- Design and testing of a modeling architecture that will allow an in-water radiative transfer code (HYDROLIGHT) to address realistically complex littoral scenes.
- Incorporation of surface wave models to simulate physical phenomena that will produce high fidelity spatial and spectral image simulations.
- Evaluation of an existing bathymetry algorithm on real littoral scenes.

The following paragraphs provide a synopsis of these activities.

4.1.3.1 Hydrolight

One of the most important resources on the planet is water. Covering three-fourths of the planets surface, water has become of interest lately as effects like El Niño show how important water is to our planet's functioning. Trying to monitor ocean and lake conditions by boat is a nearly impossible task in an age that has come to expect up to the minute reports. Current satellite imagers, allow us to monitor more area in greater detail than ever before. The price paid for this area coverage is the loss of direct water measurements. A satellite can not put a sensor in the water to determine what is in it. Instead, we must be able to determine what is present in the water by the spectra of light reflected from the water. To aid in this, DIRS is developing modeling tools that allow for the creation of water surface reflectance given a variety of water quality parameters, illumination sources, and physical geometries.

To generate the reflectance that would be seen for a given set of water conditions, we use a program called Hydrolight distributed by Sequoia Scientific Inc. Well documented and tested, this program is the backbone of the model that focuses on water. The world as seen from Hydrolight is fairly simple though (see Figure 1).

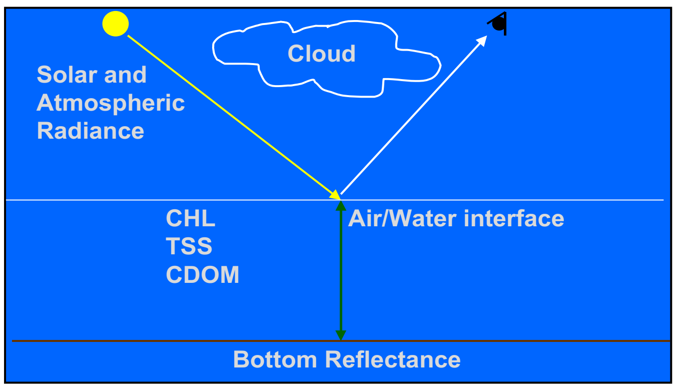


Figure 1- Pictoral Diagram of Hydrolight Inputs

The world is very rarely composed of a flat water surface and a flat bottom. Each Hydrolight run only generates the reflectance for one point on the ground. Our current modeling focus is to expand this simple 1D model into a more realistic 3D model. In this case, the world looks more like Figure 2:

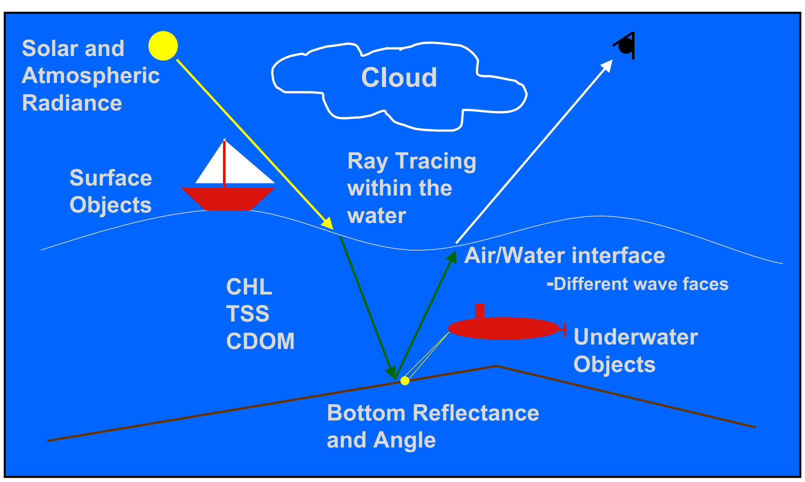


Figure 2- More realistic model of the world incorporating dimensions other than depth.

By taking into account illumination propagation, refraction effects on a non-flat surface, object interference, and non-uniform bottom conditions, the world become much more complicated and starts to incorporate some of the variability seen in more realistic conditions.

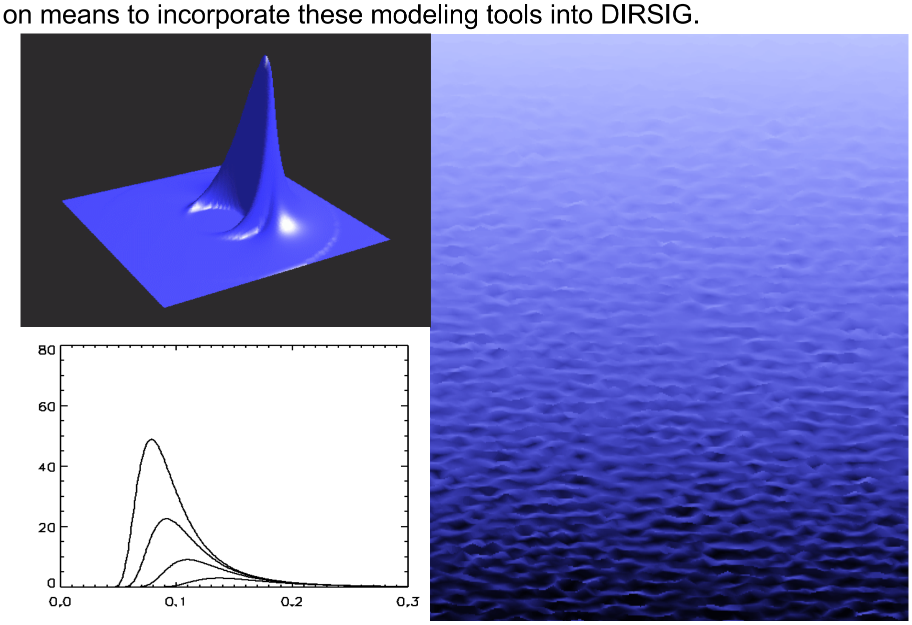
Raqueño, R.V., Raqueño, N.G., Fairbanks, R.R., Schott, J.R., Vodacek, A., Hamel, J., "Hyperspectral analysis tools for the multiparameter inversion of water quality factors in coastal regions," Proceedings SPIE, Vol. 4132, pp 323-333, San Diego, August 2000

Raqueño, R., Simmons, R., Fairbanks, R., and Schott, J., "A model-based approach to hyperspectral analysis of water constituents," Presented at AVIRIS Earth Science and Application Workshop, February 2001

Research Team: Jason Hamel, Rolando Raqueno

4.1.3.2 Integration of waves into DIRSIG

The problem of predicting waves accurately from a given set of conditions is faced in many different areas of research. Preliminary investigations were directed towards the computer graphics industry, as their primary objective is to create realistic physical models of water waves. Although not successful in and of itself, this initial research identified three major methodologies in the synthetic generation of waves. The first was a statistical approach based on the knowledge that wave slopes have a statistical distribution equal to the Gaussian probability density function with variance dependant on wind speed. In spite the fact that waves generated from such models were statistically accurate (being based on statistics themselves), they did not produce realistic physical models. This process will, however, be used in situations when the slope statistics are all that is needed of the wave model since it is easy to implement. The second process involved the use of a parametric model (based on a trochoid waveform) to create waves. This approach allowed for a greater degree of control in the handling of refraction, diffraction, and breaking waves than the other two models. Nonetheless, although the results of this method were physically pleasing, the prediction capabilities necessary to recreate wave conditions were shaky at best. Its capabilities might serve well in shallow water conditions should other techniques fail. The final method of wave generation was based on a technique used by most of the scientific community to predict waves. It involves the calculation of a water wave spectrum based on the conditions related to the formation of the waves. Such spectra can then be processed to generate the surface—as shown in the accompanying figure. This technique has proven to be the most promising if only because significant research exists on the topic. On going work is focusing on means to incorporate these modeling tools into DIRSIG.



Clockwise from bottom left: Pierson-Moskowitz wave spectrum for varying wind speeds; Directional wave spectrum; Resulting surface waves

Goodenough, Adam, “Evaluating Water Quality Monitoring with Hyperspectral Imagery,” presented at the Great Lakes Research Conference (GLRC), Syracuse, March, 2001
**Awarded Best Student Research Project

Goodenough, Adam, “Evaluating Water Quality Monitoring with Hyperspectral Imagery,” presented at the Chester F. Carlson Center for Imaging Science Industrial Associates Meeting, Rochester, May, 2001

Research Team: Adam Goodenough, Rolando Raqueno
Research Webpage: http://www.cis.rit.edu/~aag7210/ResearchProject/index.htm

4.1.3.3 Principal Components Analysis of Hyperspectral Imagery for Bottom Type Classification and Water Depth Determination

Many recreational, military, and commercial activities take place in shallow coastal waters; therefore, interest is high in characterizing these areas. A variety of methods have been employed to determine water depths and classify the bottom using remote sensing. This research proposes to apply principal components algorithms for bathymetric mapping to a MISI hyperspectral image, whereas previously this approach has been applied to synthetic data. The algorithm takes advantage of the ability to implement a deepwater correction, and in this linearized space, perform an eigenvector analysis to determine maximum variance in the data, which is related to depth. Unsupervised classification was performed on the first two principal components scores, resulting in a qualitative depth map and bottom type map.

An extensive water measurement campaign was conducted in Lake Ontario in order to characterize the optical properties of the water at the time the MISI (http://www.cis.rit.edu/research/dirs/research/misi.html) images were taken. These properties were used as inputs to the HydroMod (http://www.cis.rit.edu/research/dirs/research/hywater/HydroModSlides/index.htm) radiative transfer model in order to generate sensor-reaching radiance values for various depths and over different bottom types characteristic of a test site on the central New York shore of Lake Ontario. A principal components regression was performed using the algorithm-processed HydroMod model radiances and image data in an effort to determine the inputs to the image, i.e. depth and bottom type, without having a priori information. The limitations of the algorithm as well as the regression approach are discussed in Wilson 2000.

Wilson, Nikole. "Hyperspectral imaging for bottom type classification and water depth determination," M.S. Thesis, Rochester Institute of Technology, Center for Imaging Science, 2000.

Research Team: Gary Hoffmann, Nikole Wilson, Rolando Raqueno
Research Webpages:
http://www.cis.rit.edu/~rvrpci/dirs/bathymetry/
http://www.cis.rit.edu/research/dirs/AnReport00/present/NIKIdfnse/index.htm

4.1.4 Material Measurement Laboratory

2001 saw the establishment of a laboratory tasked with developing and maintaining highly accurate spectral measurement capabilities. The main focus of the work would be the spectral reflectance of background materials found in remotely sensed images. The material spectra would be used to populate a database for use in synthetic image generation and image interrogation activities. However, the scope of the measurement activity would include most all measurements taken by workers in the DIRS Lab, such as weather, surface temperature, and instrument calibration. Coupled with these efforts would be the gathering of the instrumentation necessary to gather accurate spectra. The lab will also develop collection methods, and train data collectors to enhance the credibility of the measurements.

Instruments have been identified that will provide spectral coverage from 0.35 to 20 microns in both laboratory and field measurement environments. A field spectrometer manufactured by Analytical Spectral Devices (ASD) has been in the DIRS Laboratory inventory for over 2 years, and provides coverage from 0.35 to 2.50 microns. An order has been placed for a Surface Optics Corporation (SOC) 400T IR Reflectometer that will enable field IR reflectance measurements from 2.0 to 20 microns. With the recent awarding of funding through NYSTAR, orders are being prepared for the purchase of a Varian Cary 500 Spectrophotometer with a 150 mm Integrating Sphere, and a SOC 100 IR Reflectometer. These instruments will provide the ability to make very accurate spectral and directional reflectance measurements under controlled laboratory conditions.

Other instruments acquired for field and lab. Measurements include a meteorological station that can be moved to collect sites, a Heitronics Pyrometer, and numerous smaller field instruments. In addition to the above tasks, the Measurement Lab. will be maintaining calibration standards and developing methods to insure the calibration of DIRS instruments, such as the above instruments, MISI, and field collection equipment.

This past summer saw the first major data collection activity in which spectra from approximately 400 different materials were collected, processed, and added to the new database. Unlike some other existing material databases, it was decided early on that the DIRS database would be extremely well documented. Each entry is well described, and includes digital images of measurement material and the surrounding area. In order to handle all the new data and make the database useful, a new structure with powerful searching capability was developed with the efforts of undergraduate student Carolyn Kennedy.

Reseach Team: Gary DiFrancesco, Nina Raqueno, Carolyn Kennedy

4.1.5 Spectral Figures of Merit

When designing and developing instruments to acquire remotely sensed imagery of the earth, it is desirable to know the minimum resolution requirements of the sensor that will allow the extraction of the desired data and information. Knowing these requirements can help to reduce costs and materials in the construction of sensors and tune processing algorithms applied to the data. Logic suggests that a decrease in spectral and spatial resolution, as well as the signal to noise ratio, should result in a reduction of the accuracy and reliability of the information derived from the scene. The goal is to quantify the significance of these spatial-spectral-noise trades. Preliminary research, based on these trades (cf. Figure 1), have been conducted on hyperspectral algorithm performance (Klatt, 2001).

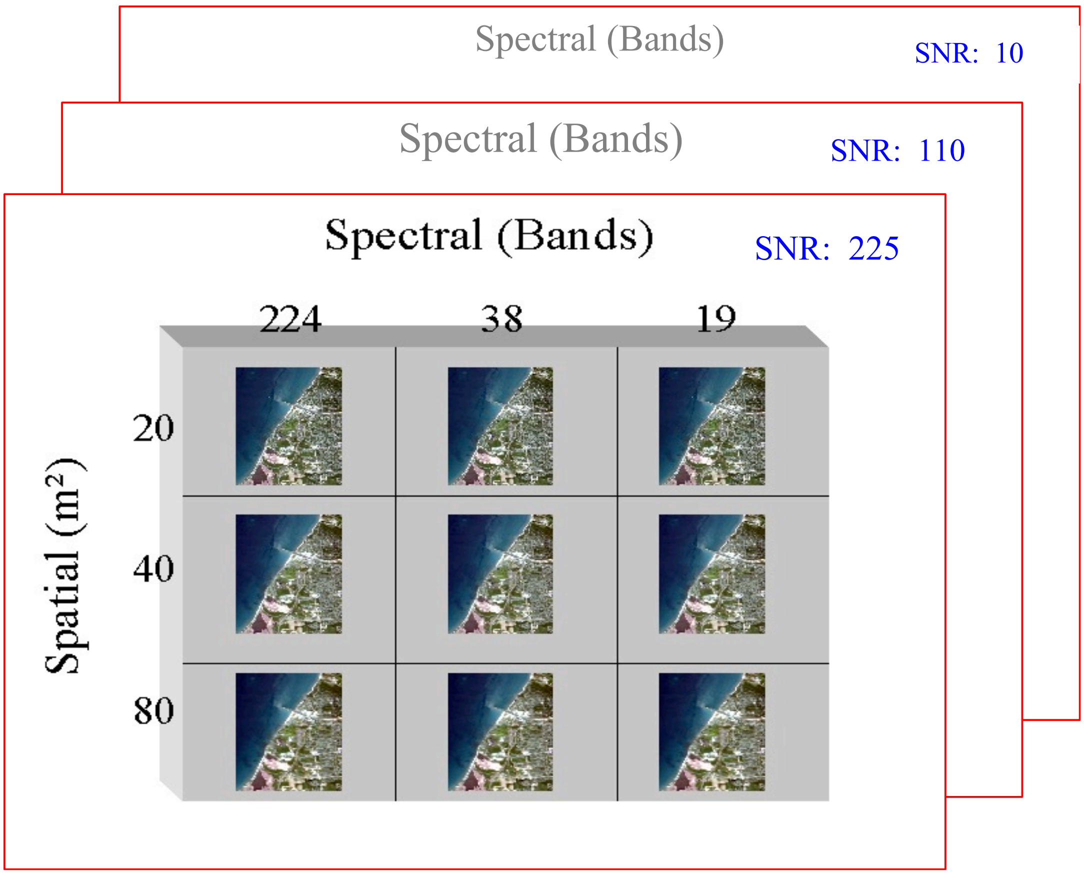


Figure 1. Image Degradation Matrix

A sample performance curve for the SAM classification algorithm is depicted in Figure 2. This research, however, focused on scene derived spectral libraries that are applicable only to the scene from which they were collected. Atmospheric and sensor variation from scene to scene limits the utility of these spectral libraries beyond a single scene. This precludes the hyperspectral process from becoming operational because it requires heavy operator-in-the-loop interaction to build these spectral libraries. Use of laboratory and field spectral libraries, on the other hand, shows promise in an operational setting. In order to take advantage of these laboratory and field spectral libraries, however, hyperspectral data sets need to be converted from radiance to reflectance through the application of atmospheric correction algorithms.

The current research extends this spatial-spectral-noise space to include an atmospheric correction dimension using three separate algorithms (ELM, Total Inversion, and ACORN) to quantify their performance effects on the hyperspectral algorithms studied by Klatt, 2001. This task is of particular interest because it tests the robustness of these classification and detection algorithms. This not only identifies the hyperspectral algorithms that perform well, but also specifies a performance requirement for the quality of the atmospheric corrections necessary for the other algorithms to perform adequately.

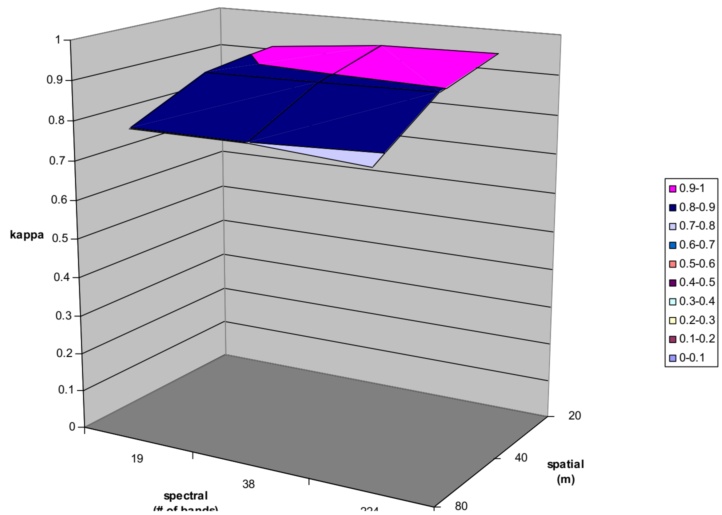


Figure 2 : Radiance kappa SAM

Klatt, J., Error Characterization of Spectral Products using a Factorial Designed Experiment, M.S. Rochester Institute of Technology, New York, 2001

Webber, E., Raqueño, R.V., and Schott, J.R., “Sensitivity analysis of atmospheric compensation algorithms for multispectral systems configuration,” RIT/DIRS Report 00/01-76-161, January 2001

Research Team: Rolando Raqueno, Nik Shad, Jon Antal, Eric Webber

4.2 FIRES

4.2.1 Forest fIRes imaging Experimental System (FIRES) Overview

FIRES is a scientific research project focused on the accurate observation (detection and monitoring) of wildfires. The scientific goals of this project are to study the phenomenology of wildfires, accurately model the phenomenological characteristics of wildfires, and predict the performance of various approaches of detection and monitoring. The systems goals for this project are to understand the needs of the ultimate user of the wildfire data in order to factor these needs into the system requirements. The programmatic goals of this project are to continue to advance the state-of-knowledge in fire detection and monitoring and to communicate that knowledge to any private or government entity that may wish to field such a system.

Key research partners include; Telespazio (Rome, Italy) and the Regional Applications Center North East (Auburn, NY). Telespazio’s research has focused on understanding the European User requirements, alarm delivery, and algorithms for processing existing satellite data. RACNE has been investigating the needs of US Users and alarm delivery within North America.

FRIES Year 1 focused on understanding the details of fires and by-products of fires such as smoke and particle emissions. This was accomplished through literature searches, discussions with experts in the field, and actual field measurements during controlled burns. Some preliminary modeling of the phenomenology was accomplished using RIT developed analytical modeling tools that enables the optimum spectral bands for detection to be determined. Year 1 also focused on systems engineering and understanding the needs of the User, both in the United States and in Europe. A preliminary assessment of the economic impact of wildfires has been established as a basis for creating a business case for an operational system

FIRES Year 2 will focus on detailed modeling of the phenomenology so as to determine the optimum methodologies for detection and monitoring of wildfires. The project will also establish a formal set of system requirements for detectability, timeliness of alarm delivery, and other critical User elements. Finally, Year 2 will continue to investigate possible methodologies for alarm delivery and type of metadata that should accompany a detection alarm. The FIRES Workshop will occur during Year 2 and is expected to yield considerable information on needs of Users and the challenges faced by the User community.

The research activities have been supported by two faculty members, three talented Graduate Students and a team of full time staff researchers. The primary research projects and results to date are described below.

Research Team: Andy Fordham, Domenic Luisi, Stefanie VanGorden, Dr. Anthony Vodacek, Dr. John Schott, Robert Kremens, Rolando Raqueno, Scott Brown, Michael Richardson

FIRES Web site: http://www.cis.rit.edu/research/dirs/research/fires.html

4.2.2 Band Selection and Algorithm Development

The environmental threats posed by wildfires are fast becoming an issue of local, regional and global concern. Remote sensing techniques are an ideal tool to use for monitoring these threats. Unfortunately, most existing satellites were built for other purposes and are less than ideal for the problems associated with detecting, assessing and monitoring fires. This research examines the phenomenology of fires and rank orders several non-traditional detection strategies that have the promise of greater accuracy and lower susceptibility to false alarms than existing fire-detection algorithms.

While none of these algorithms can be implemented on existing satellite platforms, the hardware requirements associated with these algorithms make it possible to implement them on lower cost platforms than the satellites (e.g. GOESS, AVHRR) that are currently used for operational fire detection. These algorithms emphasize detecting fires using two-band "color" measurements . Two possible algorithms use a thermal color measurement to detect the heat signature associated with fire. A third relies on a NIR measurement to detect the flame-related emission lines of fire.

Research Team: Andrew Fordham, Dr. Anthony Vodacek, Dr. John Schott

Research Webpage: http://www.cis.rit.edu/~ajf8207/public/defense.ppt

4.2.3 Sensor Modeling and Evaluation

This element of the FIRES project is focused on the conceptual design of a sensor system(s) that would take advantage of the phenomenology and algorithms identified by the other elements. In particular, the effort has focused on development of tools to assess the feasibility of using uncooled thermistor bolometer array technology in a dual-band fire detection sensor. The evaluation includes opto-mechanical, detector radiometry, radiation propagation and electronic/noise issues. The trade space includes consideration of ground sample size, subpixel detection limits (% target within pixel), fire types (temperature) and false alarms. Early design trades have focused our attention on pushbroom designs with an emphasis on uncooled approaches to reduce cost and complexity. Initial results indicate that a midwave/longwave uncooled sensor should be feasible and capable of achieving high detection rates and very low false alarms. On going work is focusing on refinement of the trade space using more advanced inputs based on the modeling and simulation element of the FIRES program.

Research Team: Dominic Luisi, Dr. Anthony Vodacek, Dr. John Schott

4.2.4 Fire and Smoke Modeling in DIRSIG

The purpose of this research is to create a physics based fire and smoke model in DIRSIG. This model is intended for use in evaluating detection algorithms, and sensor platforms. The main objectives are to utilize data outputs from current models as well as research on emissions to create a 3D view of wildfires. A Mie scattering approach will then be applied to the model to represent the optical properties of the wildfire. The treatment of wavelengths or spatial regions where a single scattering assumption is invalid is beyond the scope of this research. This model attempts to incorporate all pertinent areas of fire science including:

- flame intensity, and emissions treatment based on fuel composition (FARSITE Plus)
- estimation of fire shape based on elliptical propagation
- fire emission lines and chemical reaction zones
- plume simulations yielding concentrations of pertinent gases and particle sizes (ALOFT-FT)
- treatment of optical properties by a Mie scattering calculation.

<u>Fuel Characterization</u>
It is very important to treat the fire from the ground up because the behavior of wildfires depends on the reactants (fuel, heat, and oxygen). The reactants yield estimates of fire intensity and emissions which are necessary for modeling temperature distribution and smoke dispersion. Numerous factors influence the percent of combustion which drive estimates of carbon dioxide. From carbon dioxide estimates, a linear relationship is assumed for all the other important emissions. Wildland fuels are very complex and the behaviors of different fuels with varying levels of moisture and wind drives information about wildfires. Therefore, the FARSITE model outputs will be used to estimate fire parameters such as flame height, intensity, and elliptical shape information.

<u>Flame Characterization</u>
The flame is a very complicated reaction zone that should be treated as such. Limited spatial characteristics should be sufficient to create an adequate model of flames. Optical emission lines from sodium and potassium contribute to what we consider as the orange flame color. These are very fast reactions on the order of nanoseconds. Field Spectrometer data has been collected and is applied to estimate the intensity of these lines. All carbon particles will be treated as Planckian Black Body emittors such as burn scar, the fuel under the active flame, and Carbon particles suspended in the atmosphere.

<u>Smoke Modeling</u>
It is important to have a 3D estimate of the plume shape with necessary information about composition. This is main reason that ALOFT-FT will be used since it provides concentration information about major gases as well as PM10 and PM2.5 (Particulate matter sizes) necessary for scattering calculations.

The above components will work together to represent wildfires in DIRSIG.

VanGorden, Stefanie, "Wildfire Modeling in DIRSIG", presented at the Chester F. Carlson Center for Imaging Science Industrial Associates Meeting, Rochester, April 2001.

Vodacek, A., Kremens, R., Fordham A., Luisi, D., Schott, J.R., and VanGorden, S., “Spectral features of biomass fires,” Presented at the *SPIE Northeast Regional Conference on Optoelectronics, Photonics, and Imaging*. Rochester, NY April 2001

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,” Accepted by the *International Journal of Remote Sensing,* 2001

Research Team: Stefanie VanGorden, Scott Brown, Dr. John Schott, Dr. Anthony Vodacek

4.2.5 FIRES Data Collection

This year we have undertaken an extensive laboratory and field data collection program to provide needed input for algorithm development, detector development and smoke and fire scene modeling. The physical parameters needed for modeling efforts and algorithm development (emissivity of the flames, flame temperature, ground temperature, burn scar temperature, etc.) are not generally available in the literature.

We conducted three major data collection campaigns in collaboration with NASAs Regional Application Center for the Northeast (RACNE), the U.S. Forest Service, and the U.S. Army. Two of the campaigns took place in the field, one at Fort Drum, NY and the other at the Finger Lakes National Forest (FLNF). These field experiments were designed to collect spectral, temperature and spatial information during controlled burns at the two locations. During the FLNF burn we conducted an over flight using the MISI hyperspectral camera and obtained high resolution visible spectral data as well as infrared data that has helped in verification of algorithms and explanation of basic fire phenomenology (Figure 1). During the Fort Drum experiments, we followed the USFS/USA team into the forested area and were able to take close-up data on several types of forest fuels. Teams on the ground performed the following tasks during the field collects:

1. Deployed calibration targets during the MISI overflights.
2. Used local ponds as water calibration source for MISI overflights.
3. Measured emitted spectra using the Analytical Spectral Devices FR portable spectrometer.
4. Measured burn scar temperatures as a function of time using a handhold radiometer.
5. Recorded IR video of the fires in the 8-12 μm waveband using a Inframetrics model 600
6. Recorded visible video of the fires using a conventional digital video camera.

Photographs from our data collections at Fort Drum and FLNF are shown in Figure 2 and Figure 3, respectively.

One data campaign took place at the combustion test chamber at the USFS Rocky Mountain Research Station (RMRS) in Missoula, MT. These experiments were conducted in well-controlled surroundings using highly characterized fuels, and the goal was to obtain as much spectral information as possible for several fuel types. The experiments were highly instrumented, with spectrometers covering, at several resolutions, wavelengths from 0.28 - 10.6 μm. We performed six experiments using 4 different fuel types to observe variations in spectra with fuel type. A photograph of the fuel bed and instruments is shown in Figure 4. The following measurements were made:

1. Total power in the 10-12 μm waveband as a function of time.
2. 30 frame-per-second IR videography in the 10-14 μm waveband.
3. Visual videography.
4. High-speed (120 frame-per-second) visible videography. (RMRS)
5. High-resolution (3 nm FWHM) spectra from 0.35 - 2.5 μm.
6. High resolution spectra (0.25 nm FWHM) 0.28 - 1 μm. (RMRS
7. Total power in 5 ~100 nm IR bands from 2.5 - 10.6 μm. (RMRS)
8. Mass loss as a function of time (RMRS)
9. CO_2 emission measured as a concentration as a function of time.

Teams from RIT and RMRS are currently analyzing the data from this experiment. We believe that the spectral data from this experiment series to be some of the widest spectral bandwidth, highest resolution ever obtained from a wood fire under wildland fire conditions.

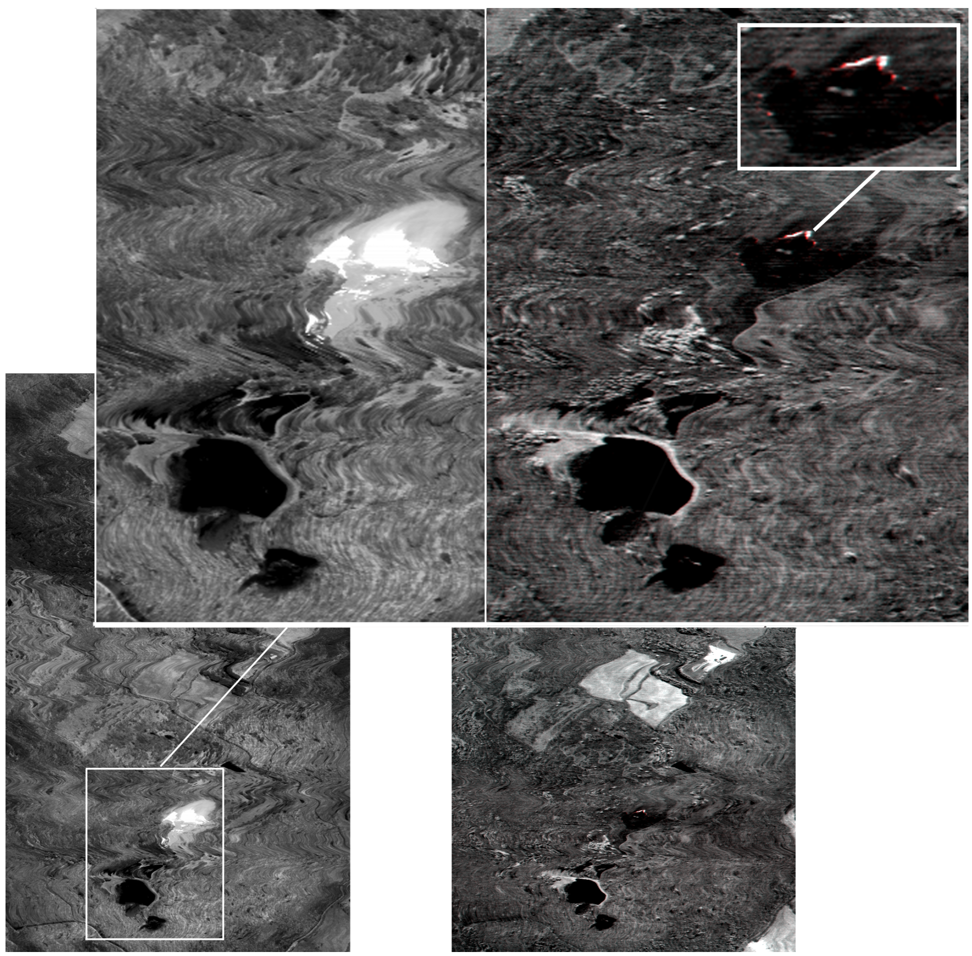


Figure 1. Two MISI images of a burn at Finger Lakes National Forest. The red pixels represent high Potassium emissions, which are correlated with flaming combustion. The thermal image shows the hot burn scar and the areas of active combustion.

Figure 2 - Controlled burn at the Fort Drum Military Reservation near Watertown, NY.

Figure 3 - A burned over area at the Finger Lakes National Forest that was analyzed for burn scar cooling rates.

Figure 4 - A fire instrumented at the Rocky Mountain Research Station combustion chamber in Missoula, MT

4.2.6 MISI Upgrades for FIRES

MISI (*M*odular *I*maging *S*pectrometer *I*nstrument) is a hyperspectral line scanner with 2 milliradian spatial resolution and spectral coverage from 0.4 - 13 μm. Prior to the FIRES upgrade, this instrument recorded data in 70 - high resolution (10 nm FWHM) bands from 0.4 - 1 μm, and 5 wider bands from 8 - 13 μm. MISI has been used previously to study near-ambient (~300K) thermal events and observe conventional terrestrial reflective targets. Use of the instrument for fire experiments required major changes in the hardware to allow wider dynamic range in the far IR and coverage of the short and mid-IR bands. The following modifications have been performed or are in process:

- Upgrade data acquisition system to 80 simultaneous channels.
- Design, manufacture and installation of new, low noise integrated first stage amplifiers and signal processing.
- Design, installation and test of 5 additional short and mid-IR channels: 1.18-1.48 μm, 1.525-1.875 μm, 1.92-2.35 μm, 3.3-4.1 μm, 8.4.-9.98 μm.
- Design, manufacture and installation of wide dynamic range front-end amplifiers for the FIRES-specific spectral bands.
- Upgrade the power supply and power distribution system to allow for the new electronics.
- Improve and modify the control system to allow better acquisition and instrument control.
- Spectral recalibration of the visible detectors to allow detailed study of important atomic transitions.
-

We flew the upgraded MISI over a controlled wildland burn at the USFS Finger Lakes National Forest, and expect to fly again over a controlled experimental burn (using known fuels and fire sizes) in Spring 2002. MISI fire over flights will provide valuable data for verification of fire detection algorithms and development of novel fire detection techniques. The optical and detector components of MISI are shown in Figure 1.

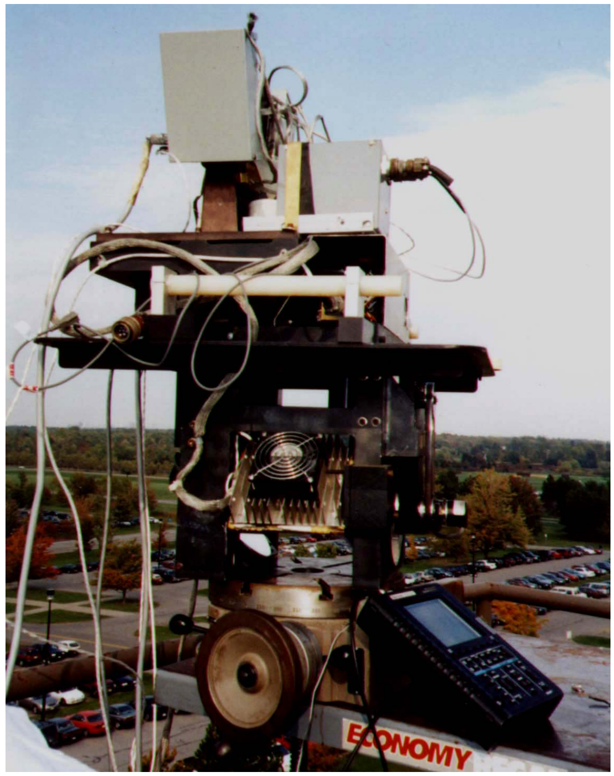


Figure 1 - MISI undergoing check-out and calibration on the RIT rooftop laboratory

4.3 Other Research Areas

4.3.1 Historical Calibration of Landsat 5's Thermal Band

There has not been a rigorous study of Landsat 5's thermal band since 1985, the year after its launch. Nevertheless, those who utilize this thermal imagery have been using it under the assumption that the sensor is operating correctly. This research was done to determine if the thermal band of Landsat 5, has been radiometrically stable over its lifetime. This was done using various Landsat 5 images of the thermal bar in the Great Lakes that were taken over the lifetime of the satellite. The focus of this research was to study radiance from the Great Lakes and compare this with the radiance values calculated from the Landsat data. In addition, Landsat 5 was cross-calibrated with Landsat 7 (Figure 1). These early results suggest that Landsat 5's thermal band has remained in nominal specification since launch.

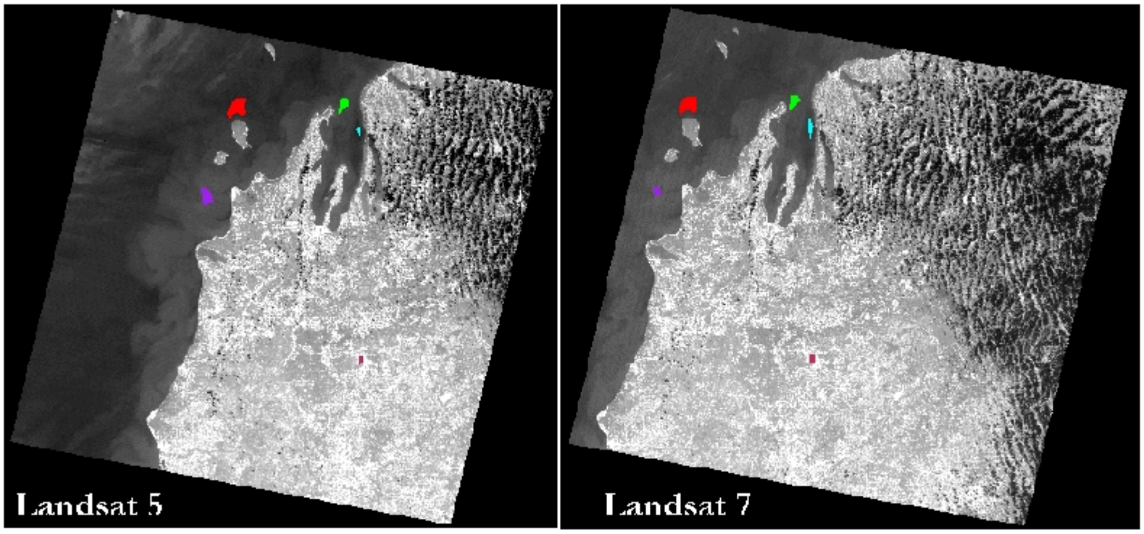


Figure 1. This image of Lake Michigan shows the common coverage of the two sensors on June 3, 1999. The regions shown in color are the common regions selected that were compared for the cross calibration.

O'Donnell, Erin, "Thermal Calibration of Landsat 5 & 7 using Great Lakes Imagery," presented at the SUNY College of Environmental Science and Forestry for Great Lakes Research Consortium Student/Faculty Conference, Syracuse, March, 2001

O'Donnell, Erin, "Thermal Calibration of Landsat 5 and Landsat 7," presented at the Rochester Convention Center for Opto NE, Rochester, April, 2001

O'Donnell, Erin, "Thermal Calibration of Landsat 5 using Great Lakes Imagery," presented at the Chester F. Carlson Center for Imaging Science Industrial Associates Meeting, Rochester, May, 2001

Research Team: Erin O'Donnell, Bryce Nordgren, Dr. Schott
Research Page: http://www.cis.rit.edu/~emo1683/senres/

4.3.2 Sensitivity Analysis of Atmospheric compensation Algorithms for Multispectral Systems Configurations

This study evaluates a series of atmospheric correction techniques developed at RIT called Total Inversion. The ability to convert remotely sensed image data to physically meaningful scientific units, such as surface reflectance, has been demonstrated for hyperspectral systems. This capability, however, has not been proven with the use of multispectral satellite-based remote sensing systems. The goal of this study is to determine the feasibility of adapting the Total Inversion techniques for multispectral sensors and understanding the capabilities and limitations of these techniques for operational use. This means that the algorithmic process being used must be image based, have practical run times, require little or no user intervention and produce consistent results within acceptable error tolerances. Three tasks were performed to study the feasibility of using Total Inversion for multispectral sensors. Task one evaluated the potential for using a pre-built set of lookup tables (LUTs) for use with the radiative transfer based spectral matching atmospheric correction methods. Task two is a sensitivity analysis for using independent ancillary estimates for elevation and water vapor inputs. Task three of this study focused on the comparison of two algorithms for the estimation of aerosol visibility. These included the regression intersection method (RIM) for spectral fitting and the non-linear least squares spectral fit method (NLLSSF). For all these tasks the study utilized existing image data and ground truth to enable evaluation and demonstration of quantitative performance of various approaches. Figure 1 show a comparison between image derived spectra and “truth” spectra that indicates that multispectral data can in many cases be satisfactorily inverted to surface reflectances using operational approaches.

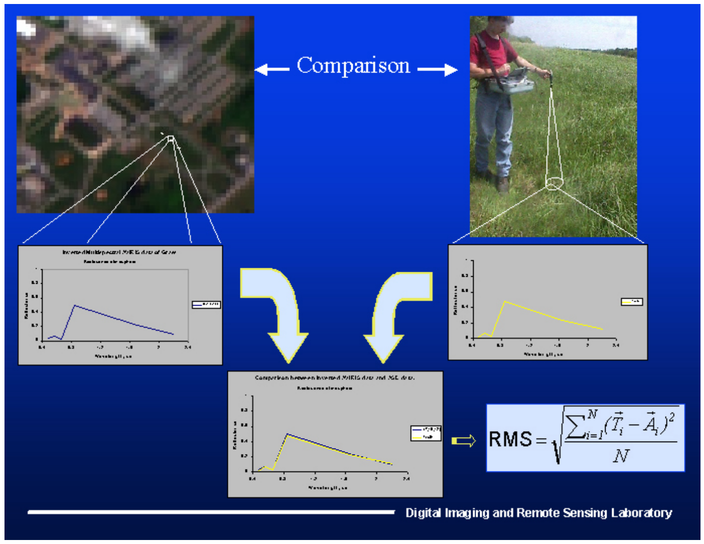


Figure 1: Spectra from the corrected image is compared against ground truth reflectance data taken with the ASD (Analytical Spectra Device).

4.3.3 Solar and Lunar Radiometric Calibration

The current generation of Earth-imaging satellites is used primarily to produce photographic quality images that are corrected for inherent non-uniformity in the focal plane (flat-fielding) and non-linearity in the sensor. The next generation of satellites requires the extraction of target reflectance with 1-2% uncertainty from these images. This requires the payload to be radiometrically calibrated to 1% uncertainty, or less.

In order to achieve these levels of uncertainty, a radiometric standard is needed that is accessible from low Earth-orbit. Unfortunately, there is no such standard currently available. One common approach is to utilize man-made source standards that have calibration traceable to NIST (or other primary standards). Another method is to use detector-based standards (also traceable to NIST) and available uncalibrated sources. Unfortunately, these approaches suffer from degradation during exposure to the low Earth-orbit, which causes an unknown departure from the calibrated state (and increases the radiometric uncertainty of the standard).

This study addressed the question of using the sun and the moon as radiometric standards for space based imaging systems (see Figure 1).

The solar modeling community is helping to address the uncertainty of the illumination source through some new solar models. These models have the capability to reduce the uncertainties in spectral and bolometric (integrated) solar irradiance. Included are geometric improvements that reduce the uncertainty from 3.5% to 1%, and solar activity models that further reduce the uncertainty from 1% to 0.1%. Similar improvements are expected to increase our knowledge of lunar radiance to a few percent in the near future.

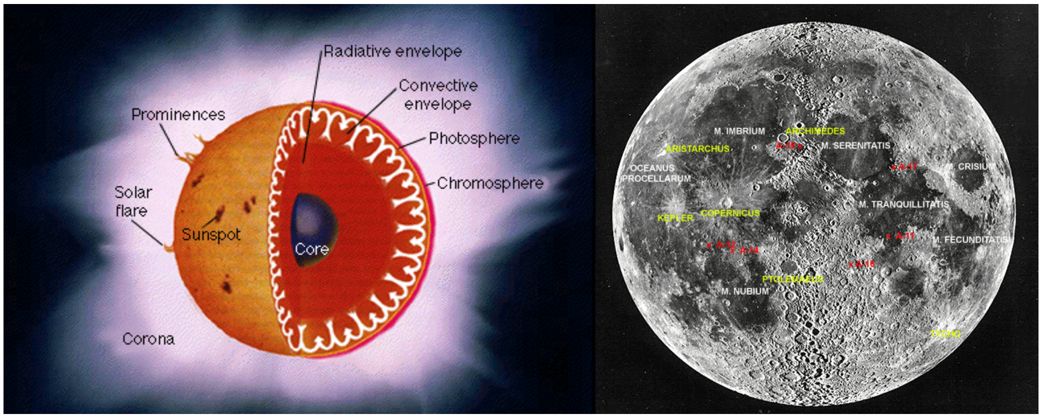


Figure 1 Illustration showing various layers of the Sun and b) image of the Moon.

Ientilucci, E.J., Schott, J.R., and Banta, M.S., “Solar and lunar radiometric calibration,” RIT/DIRS Report 00/01-68-163, August 2001

Research Team: Emmett Ientilucci, Matt Banta

4.3.4 Mapping Nuisance Algae in the Rochester Embayment

The purpose of this research is to combine hyperspectral imagery with field collect data in order to map chladophora algae in the Rochester Embayment. The objective of this study is image processing of the hyperspectral data for the following purposes:

1. Extraction of bottom features
2. Generation of chlorophyll-a, CDOM and TSS maps
3. Comparison of hyperspectral data to field collect information

The Rochester Embayment is a portion of Lake Ontario extending from Bogus Point (Parma, NY) to Nine Mile Point (Webster, NY). Monroe County, Finger Lakes – Lake Ontario Watershed Protection Alliance and the Great Lakes Protection Fund, has provided the funding for this project.

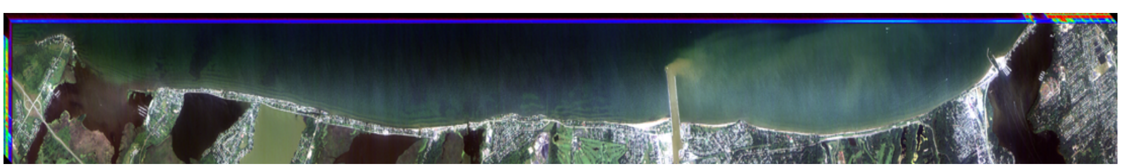


Figure 1: AVIRIS image of Rochester Embayment

Chladophora algae is prevalent in the Rochester Embayment. This type of benthic algae attaches itself to rocky bottom such as cobble or bedrock. In the summer months the algae detaches itself from its rocky home and washes ashore where it decays. The rotting algae promotes the growth of coliform bacteria, which not only makes the beaches aesthetically unpleasing but hazardous to health. There have been numerous beach closings because of this nuisance algae.

The believed cause of the algae is excessive nutrients such as phosphorus in the water. The following can cause this excess of nutrients:

1. Agricultural runoff
2. Storm water runoff
3. Wastewater treatment facilities
4. Sewage disposal systems
5. Atmospheric deposition

Airborne hyperspectral analysis can assess near shore water quality. The DIRS group is using images from AVIRIS, Landsat 7and MISI (RIT's Modular Imaging Spectrometer Instrument) in order to help map the chladophora algae. The images are being processed in order to extract bottom features and produce maps of these features using histogram stretching in ENVI, band ratios (Wezernak, 1974) and principal components analysis (Wilson, 2000).

Field collections in the Rochester Embayment include latitude, longitude, depth, temperature, algal biomass and chlorophyll-a measurements. The equipment used in these collections are a bottom grabber, secchi disk, GPS and water collection bottles.

Bottom types in turbid or deep waters are determined with the bottom grabber which pulls up algae, sand, sediment or whatever is on the lake bottom. The secchi disk measures water depth and estimates lake water quality. Latitude and longitude are measured with the GPS. Water sample collections are analyzed for chlorophyll-a, colored dissolved organic matter and total suspended solid concentrations. Water samples are filtered and concentrations are measured with a Schimandzu spectrophotometer.

Bottom mapping and image processing are underway. More field collections are needed for comparisons to bottom feature maps and chlorophyll- a, CDOM and TSS maps.

Wezernak, C.T., Lyzenga, D.R., Polcyn, F.C., "Chladophora Distribution in Lake Ontario (IFYGL)." Ecological Research Series. EPA. U.S Government Printing Office, December 1974

Wilson, Nikole. "Hyperspectral imaging for bottom type classification and water depth determination," M.S. Thesis, Rochester Institute of Technology, Center for Imaging Science, 2000

Kelly, K., "Comparison of 1972 Airborne Imagery of Lake Ontario Cladophora Distributions to Recent Airborne and Satellite Imagery", Great Lakes Research Consortium Student Faculty Conference, 2001

Research Team: Kristen Kelly, Dr. Anthony Vodacek

4.3.5 SIREEL Support

The Army's National Ground Intelligence Center (NGIC) has been sponsoring a program to construct the Simulated Infrared Earth Environment Lab (SIREEL) web site. This web site is meant to educate soldiers on what particular vehicles look like through infrared sensors and teaches them why things look the way they do in infrared. The site also features areas of interest, specifically Korea, Iraq and Bosnia, which enables soldiers to click on a specific area and learn about the geographical details and different types of vehicles in the area.

This web-based presentation will be built upon a variety of image simulation tools. The image renderings will be eventually replaced with real-time simulations. The current state-of-the-art simulation tools cannot predict accurate temperatures for backgrounds at real-time speeds. Simulation tools that run at near real-time speeds sacrifice the ability to accurately reproduce important elements of phenomenology such as shadows. The use of a predictive code, rather than using field collected imagery, will allow the user to visualize a scenario under different weather and viewing conditions that would otherwise require a large database of pre-collected imagery.

In support of these current and future simulation tools, the DIRSIG model is being enhanced to simulate the backgrounds (for example, the terrain) of the scenes that will be presented to the user. The backgrounds rendered by DIRSIG will feature spatial material and temperature variations derived by the physics-based solutions currently supported by the model. These background renderings will be pre-computed at high spatial resolutions and then mapped onto low-resolution geometry models for real-time rendering purposes. This application of DIRSIG is very similar to the LASS Mega-scene. DIRSIG will be utilized to produce high-spatial resolution radiance and temperature maps for a large area terrain (5 – 10 square km) based on a physical description of the ground. The SIREEL backgrounds will also be derived from available multi and hyperspectral imagery.

The specific enhancements to DIRSIG for this purpose includes adding an orthogonal camera model to create distortion free projections of the rendered background and the improvement of some internal calculations to improve the thermal radiance calculations for a mixed material.

Research Team: Scott Brown
Research Webpage: http://www.csl.mtu.edu/~sejanick/sireel

4.3.6 Veridian Scene Construction

The Mega-Scene and SIREEL efforts reflect a growing need by the DIRSIG user community to create new scenes and scenarios for specific applications. Historically, the construction of new objects (for example, a car, a building, etc.) required the talents of a person with experience with computer-aided design (CAD) software such as AutoCAD. The learning curve for a person without CAD experience was formidable and as a result very few new objects were created. Once an object is constructed, it then needs to have material properties manually assigned to each facet (a process known as “attributing”). Finally, attributed objects must be combined and placed with respect to each other to form scenes. Although these procedures have been performed repeatedly at RIT over the last ten years, the overall process is very slow and largely undocumented.

Veridian Systems in Dayton, OH (formally ERIM) has been an active user of the DIRSIG model for many years and offered to support a development contract to combine a set of prototypes tools we had made for importing and attributing objects from various CAD packages. In addition, this tool would be expanded to address the needs to assemble objects into scenes. The completed tool would be front ended with a graphical user interface (GUI) that provides an intuitive environment for performing these tasks in a streamlined manor.

In addition, under this effort we will create the materials and agenda for a short course that will teach users how to use an inexpensive and easy to use CAD program called “Rhinoceros”. The course will include tutorials focused on techniques and strategies for constructing common scene and object elements such as buildings, vehicles, etc.

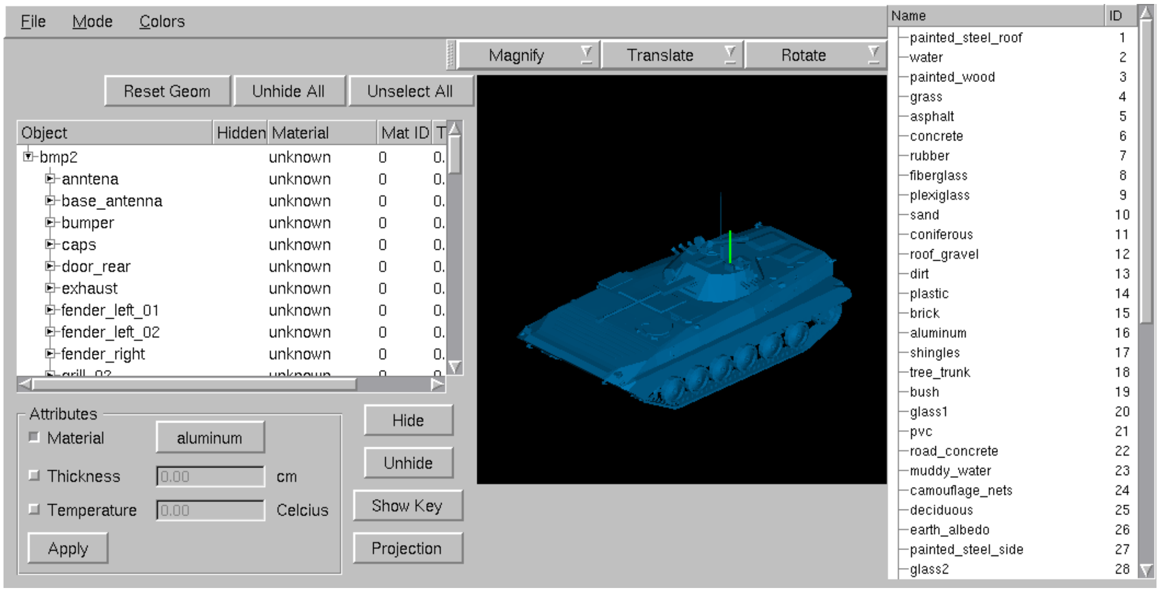


Figure 1 Preliminary "mock-up" of the geometry editing tool in the "object attributing" mode.

Research Team: Scott Brown
Research Webpage: http://www.cis.rit.edu/~dirsig

4.3.7 Large Format Video Sensor Technology Roadmap

The video sensor technology roadmap project was a technology survey project that was intended to establish business and technical trends of video rate image sensors for use in satellite systems. The project was conducted by researching technical papers, patents, and direct discussions with image sensor companies to establish the state of video sensor technology and anticipated future directions.

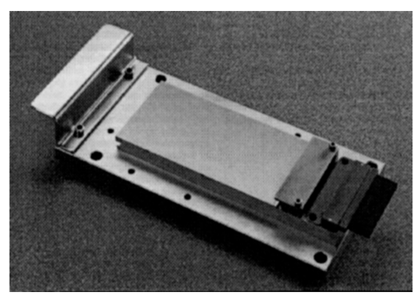


Figure 1. Buttable 2K x 4K CCD for astronomical applications

The project goals were to consider barriers to developing integrated focal planes with resolutions greater than 30 million pixels. Today, manufacturing processes preclude the fabrication of extremely large image sensors with limitations in fabrication equipment and product yield. Effort is currently being put into butting (sensors are designed such that they can be physically butted together to form a mosaic of sensors) and the use of CMOS sensors. CMOS sensors are interesting because they not only have highly integrated drive electronics, which reduces weight and power, but can be manufactured in large formats. A major global investment is being made in the transitions to 12 inch CMOS manufacturing facilities that would enable the fabrication of extremely large sensor. However, compared to CCD technology, CMOS still suffers from performance limitations driven by noise and dynamic range.

Research Team: Robert Kremens

4.3.8 A Subpixel Target Detection Algorithm on Hyperspectral Image

The goal of this research is to develop a new algorithm for the detection of subpixel scale target materials in hyperspectral imagery. The classical signal decision theory is typically to decide the existence of a target signal embedded in the random noise from an observation. This means that the detection problem can be mathematically formalized by the signal decision theory based on the statistical hypothesis test. In particular, since hyperspectral sensor provides spectrally sampled signatures that are embedded in a structured noise such as background or clutter signatures as well as broad band unstructured noise, the problem becomes more complicated, and particularly much more under the unknown noise structure. The approach is based on the statistical hypothesis method known as Generalized Likelihood Ratio Test (GLRT). The use of GLRT requires estimating the unknown parameters, and assumes the prior information of two subspaces describing target variation and background variation respectively. Therefore, this research consists of two parts, one for implementation of GLRT and the other for characterization of two subspaces. The radiance spectra reaching the sensor from a target material can be measured as various signatures due to the spatial and temporal variation of atmospheric and geometric conditions. These target signatures can be estimated by using a radiative transfer code such as MODTRAN, and can be modeled as the target subspace using a geometrical method. The background spectra will also be modeled as the background subspace. In order to determine the background space directly from the scene imagery, scene endmembers are first estimated using a new method for endmember selection. Then the background subspace is extracted from the scene by eliminating a possible overlap between target subspace and background subspace to fulfill the fact that two subspaces must be independent from one another. Results obtained from computer simulation, HYDICE sensor and AVIRIS sensor show that it is feasible to detect sub-pixel scale materials.

Figure 1. Result of hyperspectral target detection algorithm for tennis court spectra.

Research Team: Kyungsuk Lee, Rolando Raqueno

4.3.9 Spectral Misregistration Compensation for Hyperspectral Image

Radiometrically calibrated hyperspectral images can be converted into a reflectance image using atmospheric correction in order to extract useful ground information. However, there are some artifacts in the converted reflectance image due to spectrally misregistered sensor and atmospheric model error. These artifacts give coherent saw-tooth effects in the spectra of the reflectance imagery. These effects degrade the performance of classification and target detection algorithms and make them difficult to compare with ground target spectra. Three spectral misregistration compensation methods were developed in order to compensate the systematic saw-tooth noise effects. Ground Truth method uses ground truth spectra to calculate a correction coefficient. The other two methods use the Cubic Spline smoothing technique. Cubic Spline smoothing is a kind of fitting algorithm with a non-local smoothing method. Cubic spline smoothing can smooth out the saw-tooth noise in the spectra then the correction coefficient can be calculated. The second is a Uniform Region method that is to identify the pixels with small standard deviation values among neighbor pixels. The third method is a Least Ratio method that calculates ratios (standard deviation between smoothed and non-smoothed spectra divided by average reflectance of the spectra) then calculate the correction coefficient using the pixels found to have small ratios.

Spectral misregistration were also simulated using MODTRAN lookup tables and DIRSIG (The Digital Imaging and Remote Sensing Image Generation) synthetic images to understand and characterize the effect of spectral misregistration. Figure 1 shows the simulated spectral misregistration effect on DIRSIG image when spectral locations of bands were shifted 3nm.

The spectral misregistration compensation algorithms were tested and verified by the performance measurement of classification and target detection algorithms for test images (see Figure 2).

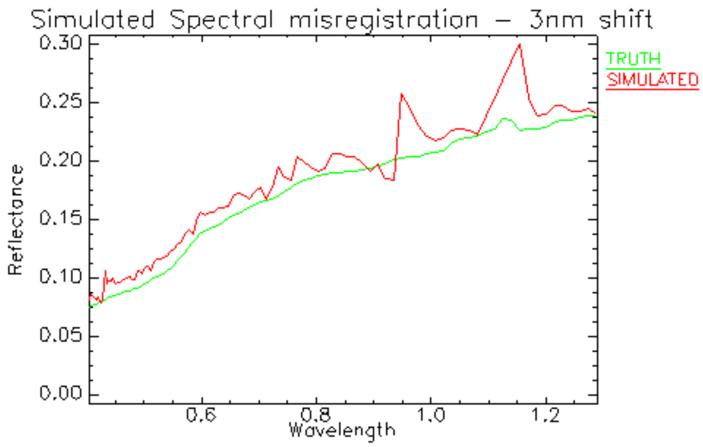


Figure 1 Simulated spectral misregistration effect. The test DIRSIG image was lowpassed by 3 by 3 lowpass filter in order to make more realistic image because the spectra of DIRSIG image are too pure. Then 3nm shift was simulated to the lowpassed DIRSIG image

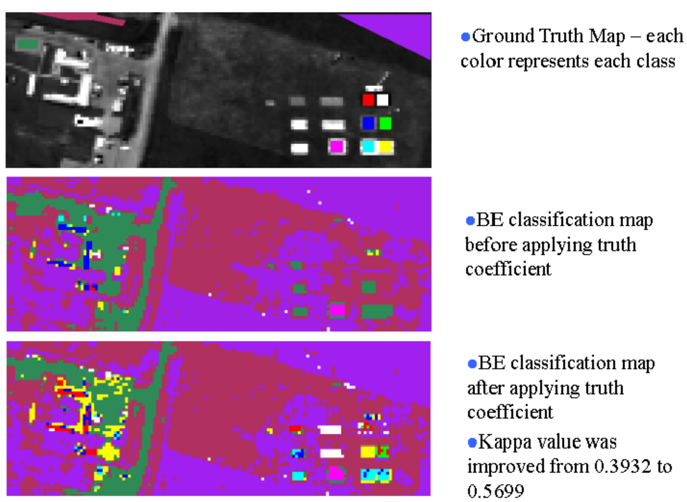


Figure 2 The classification maps of Binary Encoding classification algorithm showing Ground Truth map and BE classification maps before and after applying the correction coefficient in order to show the classification improvement.

Research Team: Hyeungu Choi, Rolando Raqueno

4.3.10 **Improved Modeling of Plume Dispersion and Temperature Effects for Synthetic Imaging Applications**

The purpose of this work is to simulate a variety of phenomena related to the discharge of gaseous effluents. The characteristics of a discharge can be exploited to yield information about activities. Observation of factory stack gases, for example, may indicate the level of pollutants being emitted into the atmosphere or the nature of a chemical process being carried out in the factory.

This work has developed improved models of plumes in two major areas. First, we have developed an improved model of plume dispersion for smokestacks and other factory-type plumes. The technique is based on a new EPA model that discretizes the plume into a series of small puffs (rather than the implicit monolithic form used in prior regulatory and SIG work). The locations and sizes of these puffs are then perturbed to approximate the location and size of the plume at any given instant. The model also incorporates the effects of high-frequency wind fluctuations and generates random wind sequences based on known wind statistics.

In addition to determining the dispersion of mass in the plume, SIG applications also require knowledge of plume temperature for simulation of self-emitted radiation in the infrared wavelengths. We have incorporated an improved model for plume temperature and a more accurate method for calculating the aggregate self-emitted radiance for rays traced through the plume. The results of this work are shown in Figure 1, which shows a simulated gas plume at two different times.

The second major area that has been advanced by our research is the simulation of gaseous discharges that warm their surroundings. These discharges, which may only be of air, are likely not directly observable, but their effect on the surround is. We have developed a model for discharges parallel to the freestream wind; this model is fully analytic and scaleable at run-time to the specific flow parameters. We have also successfully incorporated the results from computational fluid dynamic (CFD) results into synthetic images. The results of this work are shown in Figure 2, which shows a realistic scene with three different plume models present. A factory plume similar to the one in Figure 1 is in the center. On the building in the upper left corner are two warmed areas (thermal scars). The larger one is for an axial vent parallel to the wind stream, and the smaller one (which may not be visible if viewed in hard copy) is from a CFD simulation of a vent directed downward.

Finally, we have established a protocol for future modification of plume calculation algorithms by end-users of DIRSIG and implemented the present method as a prototype. This Generic Plume Interface (GPI) protocol includes definition of common and method-specific problem definition sections in the DIRSIG input file and a message set that is used by DIRSIG to communicate with the plume algorithm. The message set is used to request that the plume effect along a particular ray be calculated and to communicate back to DIRSIG the concentrations and temperatures along the ray. With this construct in place, any off-the-shelf tool can be interfaced with DIRSIG through a simple user-written interpreter to make appropriate inputs to the tool for each ray and to translate the output into the proper format.

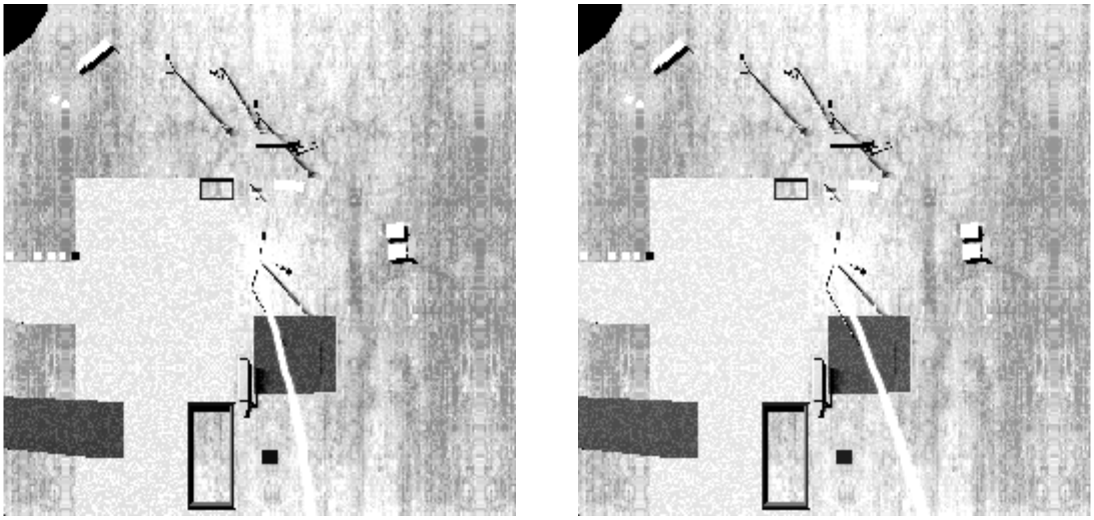


Figure 1 – SO2 plume over simulated Nevada Test Site (35 seconds apart)

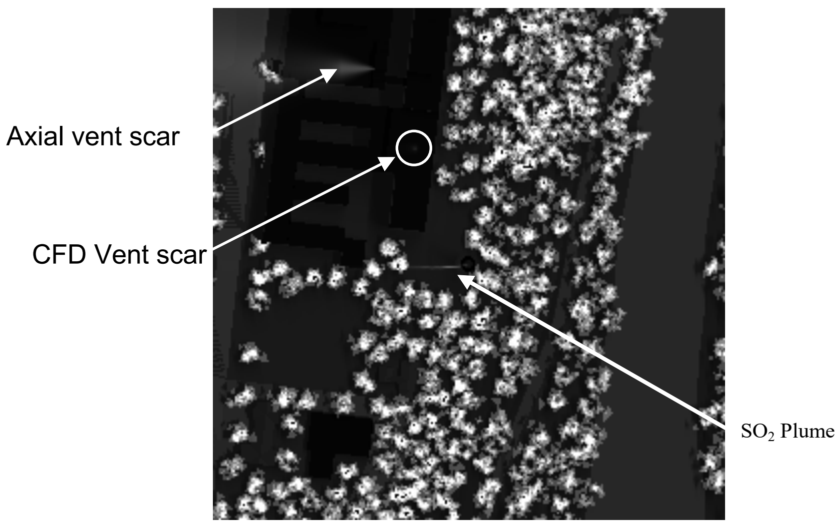


Figure 2 - Simulated Kodak Hawkeye plant scene (1186 nm)

Research Team: Jonathan Bishop, Erin O'Donnell, Scott Brown, Dr. John Schott

5 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.

One of the largest efforts DIRS participated in was the high school summer internship experience in imaging science. During the summer of 2000, DIRS volunteered to be the first research group to participate in this evolving concept by hiring a local Rush-Henrietta student. Based on the lessons learned during the first experimental year, CIS decided to expand the program to include five local students (see *CIS Mentors High School Summer Interns*). During the summer of 2001, DIRS mentored three students: Tim Gill, Bethany Choate, and Kim Baker. The students worked with DIRS faculty, research scientists, undergraduate and graduate students on a daily basis. At the conclusion of the internship each student summarized their experience with a presentation to CIS. (http://www.cis.rit.edu/~dirs/presentations/interns)

DIRS participated in the Rochester area GLOBE (Global Learning and Observations to Benefit the Environment) educator training workshops by providing remote sensing expertise and Nina Raqueno was trained in the GLOBE sampling protocols. Dr. Schott presented an introduction to remote sensing highlighting DIRS Great Lakes research. Contacts were made with numerous educators through this involvement, which will assist DIRS in the ongoing development of remote sensing activities for the Rochester area.

DIRS research scientists participated in two STANYS (Science Teachers Association of NYS) events. A Center for Imaging Science information booth was manned by DIRS scientists at the annual STANYS conference. Hundreds of teachers were introduced to the imaging science program, remote sensing images, and thermal cameras. DIRS scientists also provided workshops and an information booth at the regional STANYS Science Exploration Days.

Many of DIRS students and staff participated in countless laboratory tours, open houses, and school visits. A few of these events are reviewed in *Update: The Center's Outreach Activities.*

In an ongoing attempt to increase CIS graduate enrollment, the DIRS group recruited at RIT and regional universities. Remote Sensing presentations were made at SUNY Geneseo, SUNY Brockport, SUNY Potsdam and Monroe Community College. DIRS continues to utilize the excellent R.I.T. resource of computer science and physics students in many of the research projects. Hopefully some of these students will consider applying to the CIS graduate program.

This year DIRS continued its outreach activities to the public. Dr. Schott presented an overview of DIRS research to the Athenaeum, a R.I.T. academy of learning for individuals over 50. DIRS faculty and research staff formed a relationship with the Rochester Museum and Science Center to educate the public about Rochester based imaging science reasearch. DIRS is thrilled with this opportunity to reach the volumes of students and parents that visit the RMSC each year. An initial plan for immediate, short term and long term projects were identified.

CIS Mentors High School Summer Interns

After last summer's successful high school internship trial, CIS decided to take the lessons learned and expand upon this program. This summer five students were accepted into the internship program.

The Munsell Color Laboratory chose two students to assist in calibration of scientific instruments and help conduct visual experiments. The Digital Imaging and Remote Sensing Laboratory selected students to expand its outreach efforts through the compilation, design, and presentation of environmental remote sensing applications.

All of the interns had the opportunity to work closely with CIS faculty, research scientists, undergraduate and graduate students. Two of the DIRS high school students became an integral part of DIRS field collection team working side by side visiting NASA scientists.

DIRS interns, Beth and Kim calibrate meteorological instruments.

The interns summarized their summer activities in presentations to CIS. The presentations produced an opportunity for both the interns and the CIS undergraduate recruitment committee to rate their experiences and make enhancements for next years interns. The interns will present this material to their individual high schools as a recruitment tool highlighting their summer of science exploration. The internship program was a cooperative learning experience for all involved. CIS faculty and staff were treated to a refreshing view of what excites young minds.

One exciting outcome of the internship program is that two of the interns will be applying to the imaging science program! After two years of success CIS will continue the internship program in the summer of 2002.

For more information please contact Joe Pow at: *pow@cis.rit.edu* or call (716) 475-7323

Update: The Center's Outreach Activities

The CIS outreach program moved into high gear over the winter with faculty, staff, and students spreading the word about RIT's imaging science program in school districts throughout New York.

Following the plan developed in the fall by members of the department's outreach committee, teams of people from CIS personally contacted over a dozen separate schools in an effort to develop long-term partnerships. The initial contact with each prospective partner is used to determine the type of interaction the school's faculty and administrators feel would be most beneficial to their students. Once that's been established the CIS outreach team begins planning an activity which is tailored to meet the school's specific needs. As a result, each interaction is unique, and is intended to heighten awareness of the imaging science program among the secondary schools.

Dake Middle School student learns about polarization.

One of our more ambitious projects resulted from a request by Dake Middle School in West Irondequoit for help in teaching their eighth-graders about the properties of light. After two months of planning, a group of 15 CIS volunteers set up six separate demonstrations in the school's library, and over the course of an entire day gave 250 students a chance to learn first hand about spectroscopy, diffraction, polarization, and radiometry. The feedback from this session was very positive, and a select group of students from Dake will be making a follow-up visit to CIS to get a more in-depth look at visual perception, remote sensing, and color science.

Here are some of the graduate students, faculty and staff who participated. Thanks to everyone who helped to make our first outing a success.

Strong ties were also forged as the result of another recent outreach initiative. CIS teamed with five local school districts on a winning proposal for a "Targeted Instructional Staff Development" grant from the state Department of Education. The purpose of the grant is to increase student achievement by bringing new, innovative instructional techniques into the classroom. The CIS recommendation to focus on the use if imaging technology and image processing to convey mathematical and scientific principles was adopted by the proposal team, and the state awarded $200,000 to pursue this concept.

Rob Light, an imaging science graduate student, explains how to use the spectrometer.

While projects such as these form the basis for relationships which should bring in more imaging science students over the next several years, the outreach team has high hopes that this summer's CIS internship program will have a near-term impact on our enrollment. Team members are currently evaluating applications from high school juniors looking for a two-month paid internship in the department. Up to six interns will be chosen to work side-by-side with faculty and staff researchers throughout the summer, getting valuable experience and learning more about the employment opportunities available to imaging scientists after graduation.

Colleen Desimone welcoming Dake Middle school students to an imaging science experience in their library.

Funding from the Industrial Associates program is being used to support CIS outreach and recruitment efforts. CIS Director Ian Gatley feels this is an effective way to use these resources. "Our industrial partners have made it clear that they want more imaging science graduates. Therefore, using the resources of the Industrial Associates program to bring more students into the department is a wonderful way to provide our members a return on their investment." Gatley is also confident that the outreach team's efforts will have a profound effect on the recognition of imaging science as a growing, dynamic field of study.

For More Information about our CIS School Partnership Program visit:
www.cis.rit.edu/info/partnership/top.html

6 PUBLICATIONS (2000-2001)

BOOK AND JOURNAL ARTICLES

Sanders, L.C., Schott, J.R., and Raqueño, R.V., "A VNIR/SWIR atmospheric correction algorithm for hyperspectral imagery with adjacency effect," Remote Sensing of Environment Vol. 77, p. 1-11, 2001

Schott, J. R., Barsi, J.A., Nordgren, B.L., Raqueño, N.G., de Alwis, D. "Calibration of Landsat Thermal Data and Application to Water Resource Studies," Remote Sensing of Environment Vol. 78, p. 108-117, 2001

Vodacek, A., "Environmental Applications of Remote Sensing," Informatik: Sustainable Information Society, No. 4, pp. 21-26, August 2000

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," Accepted by the *International Journal of Remote Sensing,* 2001

PUBLISHED PROCEEDINGS

Arnold, P.S., Brown, S.D., and Schott, J.R., "Hyperspectral Simulation of Chemical Weapon Dispersal Patterns using DIRSIG". *SPIE* Vol. 4029, p. 288-299, July 2000

Brown, S.D., Alain, F., Schott, J.R., "Simulation environment for modeling Fourier transform imaging spectrometer (FTIS) instruments,) presented at the Ground Target Modeling and Validation Conference, Houghton, MI, August 2000

Brown, S.D., Gray, R., Schott, J.R., "Scene construction methodologies and techniques for simulating forest areas," presented at the Ground Target Modeling and Validation Conference, Houghton, MI, August 2000

Fairbanks, R.R., Schott, J.R., and Vodacek, A., "The Impact of Clouds on SeaWiFS Derived Water Quality," Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS) 2000

Green, S., Vodacek, A., Ma X., Wells-Budd, J., "The optical environment of Lake Superior," Pacifichem 2000, Honolulu, Hawaii, December, 2000

Hernandez-Baquero, E.D. & Schott, J.R., "Atmospheric and surface parameter retrievals from multispectral thermal imagery via reduced rank multivariate regression, Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS) 2000

Hernandez-Baquero, E.D. & Schott, J.R., "Atmospheric compensation for surface temperature and emissivity," SPIE's AeroSense International Symposium, 2000

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

Raqueño, R.V., Raqueño, N.G., Fairbanks, R.R., Schott, J.R., Vodacek, A., Hamil, J., "Hyperspectral analysis tools for the multiparameter inversion of water quality factors in coastal regions," Proceedings SPIE, Vol. 4132, pp 323-333, San Diego, August 2000

Raqueño, R., Simmons, R., Fairbanks, R., and Schott, J., "A model-based approach to hyperspectral analysis of water constituents," Presented at AVIRIS Earth Science and Application Workshop, February 2001

Sanders, L.C., Schott, J.R., Raqueño, “An atmospheric correction algorithm featuring adjacency effect for hyperspectral imagery,” Proceedings SPIE, Vol. 4132, pp 218-229, San Diego, August 2000

Schott, J.R., “Combining image derived spectra and physics based models for hyperspectral image exploitation,” AIPR/SPIE Workshop, Washington DC, 2000

Teillet, P.M., Helder, D.L., Markham, B.L., Barker, J.L., Thomes, K.J., Morfitt, R., Schott, J.R., Palluconi. F.D., “A lifetime radiometric calibration record for the Landsat thematic mapper,” Proceedings of the Canadian Remote Sensing Society, Quebec, 2001

Vodacek, A., Knobelspiesse, K., “Monitoring turbidity plumes in Lake Superior with remote sensing,” IAGLR, Green Bay, WI, June, 2001

Vodacek, A., Light, R., Green S., “Spectral irradiance and scalar irradiance measurements in Lake Superior,” IAGLR, Green Bay, WI, June, 2001

TECHNICAL REPORTS

Brown, S.D., Ientilucci, E.J., Raqueño, R.V., and Schott, J.R., “DIRSIG/GENESSIS hybrid hyperspectral system simulation of the Fort AP Hill,” RIT/DIRS Report 00/01-71-162, January 2001

Ientilucci, E.J., Brown, S.B., Schott, J.R., "Low-Light-Level Simulations and Extended Area Source Modeling", RIT/DIRS Report 00/01-68-159, January 2001

Ientilucci, E.J., Schott, J.R., and Banta, M.S., “Solar and lunar radiometric calibration,” RIT/DIRS Report 00/01-68-163, August 2001

Kloiber, J.C., Klatt, J.W., Schott, J.R., and Brown, S.D., “Error characterization and tutorial of spectral products,” RIT/DIRS Report 00/01-75-160, February 2001

Webber, E., Raqueño, R.V., and Schott, J.R., “Sensitivity analysis of atmospheric compensation algorithms for multispectral systems configuration,” RIT/DIRS Report 00/01-76-161, January 2001

PRESENTATIONS, ABSTRACTS, TUTORIALS

Goodenough, A., “Evaluating Water Quality Monitoring with Hyperspectral Imagery,” presented at the *Great Lakes Research Consortium Conference*, Syracuse, March 2001

Goodenough, A., “Evaluating Water Quality Monitoring with Hyperspectral Imagery,” presented at the *Chester F. Carlson Center for Imaging Science Industrial Associates Meeting*, Rochester, May 2001

Ientilucci, E.J., Brown, S.B., Schott, J.R., "Low-Light-Level Simulations", presented at the *SPIE Northeast Regional Conference on Optoelectronics, Photonics, and Imaging*. Rochester, NY April, 2001

Kelly, K., “Comparison of 1972 Airborne Imagery of Lake Ontario Cladophora Distributions to Recent Airborne and Satellite Imagery,” presented at the *Great Lakes Research Consortium Conference*, Syracuse, March 2001

Kremens, R., Kastner, J., Lerner, D., Merrill K., and Kaminski, C., “Detailed site evaluation of the South Pole in the MWIR using the SPIREX/ABU telescope,” Presented at *the SPIE Northeast Regional Conference on Optoelectronics, Photonics, and Imaging*. Rochester, NY April 2001

Kremens, R., “Image Processing System Applications: From Barbie Cams to the Space Telescope,” Invited Educational Seminar at the *IEEE CICC Conference*, San Diego, CA, May, 2001

Meyers, J., "Overview of DIRSIG: Digital Imaging and Remote Sensing Image Generation," presented at the AFRL/VS quarterly review meeting, Kirtland AFB, Albuquerque, NM, November 2000

O'Donnell, E., “Thermal Calibration of Landsat 5 & 7 using Great Lakes Imagery,” presented at *Great Lakes Research Consortium Conference*, Syracuse, NY, March 2001

O'Donnell, E., “Thermal Calibration of Landsat 5 and Landsat 7,” Presented at the *SPIE Northeast Regional Conference on Optoelectronics, Photonics, and Imaging*. Rochester, NY, April 2001

O'Donnell, E., “Thermal Calibration of Landsat 5 using Great Lakes Imagery,” presented at the *Chester F. Carlson Center for Imaging Science Industrial Associates Meeting*, Rochester, NY, May 2001

Schott, J.R., “DIRS Great Lakes Research,” presented at Great Lakes Research Consortium Seminar, Potsdam, NY, Nov 2000

Schott, J.R., “An Introduction to Remote Sensing Research at R.I.T.,” presented at the R.I.T. Anthenaeum, Rochester, NY, Dec 2000

Schott, J.R., “An Introduction to Remote Sensing and DIRS Great Lakes Research,” presented at the GLOBE Teacher Workshop, Rochester, NY, Dec 2000

Schott, J.R., “Combining image derived spectra and physics based models for hyperspectral image exploitation,” presented at Western New York Image Processing Workshop 2001

VanGorden, Stefanie, "Wildfire Modeling in DIRSIG", presented at the *Chester F. Carlson Center for Imaging Science Industrial Associates Meeting*, Rochester, NY, April 2001

Vodacek, A., Kremens, R., Fordham A., Luisi, D., Schott, J.R., and VanGorden, S., “Spectral features of biomass fires,” Presented at the *SPIE Northeast Regional Conference on Optoelectronics, Photonics, and Imaging*. Rochester, NY April 2001

7 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"
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