SpecTIR Hyperspectral Airborne Rochester Experiment
Data Collection Campaign

Jared A. Herweg\textsuperscript{a\textsuperscript{b}}, John P. Kerekes\textsuperscript{a}, Oliver Weatherbee\textsuperscript{c}, David Messinger\textsuperscript{a}, Jan van Aardt\textsuperscript{a}, Emmett Ientilucci\textsuperscript{a}, Zoran Ninkov\textsuperscript{a}, Jason Faulring\textsuperscript{a}, Nina Raqueño\textsuperscript{a}, and Joseph Meola\textsuperscript{d}

\textsuperscript{a}Center for Imaging Science, Rochester Institute of Technology
54 Lomb Memorial Drive, Rochester, NY 14623-5406, USA
\textsuperscript{b}Air Force Institute of Technology
2950 Hobson Way, Wright-Patterson AFB, OH 45433-7765, USA
\textsuperscript{c}SpecTIR, LLC
9390 Gateway Dr., Suite 100, Reno, NV 89521, USA
\textsuperscript{d}Air Force Research Laboratory
2241 Avionics Circle, Wright-Patterson AFB, OH 45433-7320, USA

ABSTRACT
A multi-modal (hyperspectral, LiDAR, and multi-spectral) imaging data collection campaign was conducted at the Rochester Institute of Technology (RIT) in conjunction with SpecTIR, LLC, in the Rochester, New York, area July 26 - 29, 2010. The campaign was titled the \textit{SpecTIR Hyperspectral Airborne Rochester Experiment} (SHARE) and collected data in support of nine simultaneous unique experiments, several of which leveraged data from multiple modalities. Airborne imagery was collected over the city of Rochester with hyperspectral, multispectral, and Light Detection and Ranging (LiDAR) sensors. Sites for data collection included the Genesee River, sections of downtown Rochester, and the RIT campus. Experiments included sub-pixel target detection, water quality monitoring, thermal vehicle tracking and wetlands health assessment. An extensive ground truthing effort was accomplished in addition to the airborne imagery collected. The ultimate goal of this comprehensive data collection campaign was to provide a community sharable resource that would support additional experiments. This paper details the experiments conducted and the corresponding data that were collected in conjunction with this campaign.

Keywords: HSI Dataset, HSI signatures, LiDAR, Target Detection, Hyperspectral

1. INTRODUCTION
Coincident multi-modal data are often desired, yet rarely gathered due to logistical or budgetary constraints. Rarely does such an opportunity present itself where an airborne hyperspectral imager, light detection and ranging (LiDAR) sensor, and a high resolution multi-spectral imaging system fly over the same area collecting data of the same targets across modalities. Such a data collection campaign was conducted at RIT in conjunction with SpecTIR, LLC, over the Rochester, New York, area July 26 - 29, 2010. The campaign was titled the \textit{SpecTIR Hyperspectral Airborne Rochester Experiment} (SHARE) and collected data in support of nine simultaneous unique experiments, several of which leveraged data from multiple modalities. Aside from the specific experiments conducted, the impetus for the data collection campaign was to provide a multi-modal data package which would be a resource for additional uni- and multi-modal phenomenology studies. The sites for data collection included the Genesee River, a portion of the city of Rochester, which is included as part of the Digital Imaging and Remote Sensing Image Generation (DIRSIG) Mega Scene 1,\textsuperscript{3} and the RIT campus itself. As such, open water, wetlands, and urban environments are included in the data set.

Further author information: (Send correspondence to J.A.H.)
J.A.H.: E-mail: jxh6389@cis.rit.edu, Telephone: 1 585 475 2453
J.P.K.: E-mail: kerekes@cis.rit.edu, Telephone: 1 585 475 6996

CCC code: 0277-786X/12/$18 · doi: 10.1117/12.919268
Proc. of SPIE Vol. 8390 839028-1

Downloaded from SPIE Digital Library on 08 Jun 2012 to 129.21.58.30. Terms of Use: http://spiedl.org/terms
The objective of this paper is to provide an overview of the data set and experiments performed in order to develop a shared community resource. This report details a description of the experiments conducted, the instrumentation used for airborne imaging and ground truthing and examples of the data collected. In-depth descriptions of individual experiments and results are published separately.

2. INSTRUMENTATION

For this data collect, there were four primary imaging collection systems as well as three non-imaging spectroradiometers. Each is described below.

2.1 ProSpecTIR-VS2
SpecTIR, LLC, flew their ProSpecTIR-VS2 hyperspectral imaging sensor during this data collect on 29 July 2010. The ProSpecTIR-VS2 sensor was configured to collect from 390 - 2450 nm. There were 360 bands with a 5 nm (nominal) spectral resolution and a full-width half-max varying from about 3.8 nm to 8.5 nm, over the full wavelength range of the system. Full sensor specification, calibration procedures, and data processing description (including identified collection issues) is provided on the SpecTIR Project Report\(^2\) found on the SHARE website which can be accessed through the Digital Image and Remote Sensing (DIRS) Laboratory website noted in Section 5. The resulting HSI data from SpecTIR was delivered in the ENvironment for Visualizing Images (ENVI) format.

2.2 Wildfire Airborne Sensor Program System
The Wildfire Airborne Sensor Program (WASP) Imaging System was flown on 26 July 2010. The system consisted of four framing array imagers covering the visible, short-, mid-, and long-wave infrared regions of the spectrum.\(^3,4\) The sensor was comprised of a Geospatial Systems KCM-11 high-resolution color camera covering the visible spectrum and three Indigo Phoenix infrared imagers. The Phoenix-Near infrared imager covered 0.9 - 1.5 \(\mu m\). The Phoenix-Mid infrared imager covered 3.0 - 5.0 \(\mu m\) and the Phoenix-Long infrared imager covered 8.0 - 9.2 \(\mu m\). The WASP sensor operates at a frame rate of 0.25Hz.

2.3 Leica ALS60 LiDAR System
Along with the WASP imaging system, Kucera International flew and operated their Leica ALS60 (Airborne Laser Scanner 60) Light Detection and Ranging (LiDAR) system. The Leica ALS60 is a scanning mirror LiDAR mapping system, which operates with a 1064 nm laser. It has a built in inertial navigation system (INS) to provide fully registered 3-D LiDAR data once processed and delivered in the common LiDAR Data Exchange Format (*.LAS files) by Kucera.\(^5\)

2.4 Ground Thermal Imager
RIT owns a KIR-310 real-time infrared imaging system that produces both standard NTSC video as well as real-time 12-bit digital images. The unit utilizes a Kodak Platinum Silicide 640 \(\times\) 486 array with 25\(\mu m\) square pixels. The array and dual filter wheels holding six filters is cooled to near 77K to reduce thermal noise. The system is sensitive between 1 – 6\(\mu m\).

2.5 Analytical Spectral Devices FieldSpec Pro Spectroradiometer
Material reflectance and full sky irradiance measurements were taken during and shortly after the campaign by two measurement teams using one of two FieldSpec Pro Full Range (FR) spectroradiometers made by Analytical Spectral Devices (ASD), Incorporated. The FR FieldSpec Pros used during the data collection were portable spectroradiometers operating in the Visible/Near Infrared (VNIR) and ShortWave InfraRed (SWIR) wavelength range.\(^6\) The VNIR detector was a 512-channel silicon photodiode array covering a wavelength range of 350 - 1050 nm with a full-width half-max spectral resolution of approximately 3nm. The SWIR component of the field spectrometer utilized two indium gallium arsenide (InGaAs) scanning spectrometers. The first SWIR detector covered 900-1850 nm and the second 1700 - 2500 nm. Both SWIR detectors had a nominal spectral resolution between 10 - 12 nm, which was dependent on the scan angle. Spectral reflectance information was collected from target materials both in-field and in laboratory using the ASD FR FieldSpec Pro.
2.6 Ocean Optics USB2000 Spectroradiometer

Several ground level spectral reflectance measurements were taken over the RIT wetlands using an Ocean Optics USB2000 Miniature Fiber Optic Spectrometer. The USB2000 portable spectrometer used during this collect was designed to cover 0.35 - 1.0 μm.7

3. DESCRIPTION OF DATA COLLECTED

3.1 Airborne Data

For this data collection campaign, the original plan was to have the SpecTIR HSI sensor flown at the same time as the Kucera LiDAR system and the WASP imager. This required two aircraft from two different companies as SpecTIR operated their own aircraft while the LiDAR and WASP systems were flown by Kucera International. Unfortunately weather delays and logistical limitations caused the two aircraft to be flown on two different days. However, both aircraft covered the same flight lines with the same GSD as outlined per target area.

RIT had requested six specific flight lines to be flown over the Rochester, New York, area as shown in Figures 1 and 2. There were four flight lines over the RIT campus, a flight line over Irondequoit High School and Monroe County Frank E. VanLare water treatment plant, and two lines over the Genesee river extending out to Lake Ontario. All data were collected with a solar elevation angle greater than 40° where solar elevation angle is 90° minus the solar zenith angle.

RIT Campus Imagery. The imagery collected over the RIT campus included two North-South flight lines with an approximate 30% overlap between them. Flight line RIT_1 was repeated for change detection analysis. There was also an East-West flight line and a Southeast to North-West flight line centered over the RIT wetlands. This data collected over RIT campus had a ground sample distance (GSD) of approximately 1m for the LiDAR, WASP IR, and SpecTIR HSI sensors. The WASP visible had a GSD of approximately 5 cm. Overall this data supported a range of data requirements for urban dismount detection as well as ecological environmental health studies. Artificial targets were placed in known locations around the RIT campus in support of several of the experiments outlined below. Many targets were placed in full view and some were partially occluded from the viewpoint of the aircraft. Targets varied in size and ranged from 0.25m² to 9m². Table 1 outlines several known targets that were placed in the scene around RIT campus. Large 10.6m × 10.6m calibration targets were also placed on the RIT campus for performing radiometric correction using the empirical line method.8 Additionally,
an instrumented Nissan Titan pickup truck was driven through the scene. The truck was instrumented with temperature sensors located around the body to measure thermal emissions and a global positioning system (GPS) device was used to track its position while driving. Standard flares were thrown from the rear of the truck at strategic times. For the repeated flight line RIT1, known static targets were moved between passes for change detection experiments. However, the targets placed around the RIT campus were in the same location for the first overflight of Flight line 1 and the other three non-repeated overflights.

Examples of the imagery collected over the RIT campus using the different sensors are shown in Figures 3 through 5. Figure 3 shows a georectified high resolution color image from the WASP color camera. Subsets of targets placed around a parking lot and around buildings are included. Figure 4 shows a false color image from flight line RIT3 indicated in Figure 1. The buildings of RIT campus are easily seen in the LiDAR image of Figure 5. The 3-D rendering was done using the Triangulated Irregular Network (TIN) algorithm.

Irondequoit Imagery. There was one flight line flown over a portion of the Town of Irondequoit to support urban and industrial scene analysis. This flight line included the Irondequoit High School and Dake Junior High School as well as the Monroe County Frank E. VanLare water treatment plant. The data for this flight line was collected at a minimum GSD of 2 m for all sensors. There were a few low flying clouds on 26 July 2010 over Lake Ontario and parts of Irondequoit, NY. These clouds did cause some frames from WASP to be obscured. There are also portions of the LiDAR data over the open water of Lake Ontario that do not reflect true water or ground level returns and were therefore considered invalid. The cause for this discrepancy is unknown.

Genesee River Imagery. There were two flight lines flown over the mouth of the Genesee River in support of water constituent retrieval analysis studies. Since this flight line included large portions over water, the LiDAR system was not used on this portion of the data collect. The data were collected at a minimum GSD of 3 m with a 30% imagery overlap for the HSI and multi-spectral sensors.

3.2 Ground Truth Data
An extensive ground truth effort accompanied the collection of this data set in order to provide sufficient truthing of each of the unique experiments being conducted. Given the varied locations that were imaged by the airborne sensors, each location had unique ground truth requirements.

RIT Campus Imagery. Most of the ground truthing performed was with respect to the targets placed around the RIT campus. There were three aspects of ground truth captured for targets on or around the RIT campus: 1) positional data, 2) photo documentation, and 3) material reflectance data. Figures 6, 7, and 8 illustrate several of these efforts, which are described in more detail as follows.

Two sets of positional measurements were collected for each target placed. Linear measurements were taken for each target’s relative position with respect to a large landmark that was visible to the aircraft (i.e., corner of building, corner of parking lot, etc.). These measurements were recorded on a target placement map for ease
Figure 3. True color georectified image from WASP High Resolution camera.

Figure 4. False color georectified image from SpecTIR’s ProSpecTIR-VS2 sensor over RIT campus from the RIT 3 flight line shown in Figure 1.
Table 1. Targets placed around RIT campus during data collect.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>White and black calibration tarps</td>
<td>Calibration targets made of heavy 100% cotton duck cloth.</td>
</tr>
<tr>
<td>Fabric targets</td>
<td>Large fabric tarps made of 100% cotton or 100% polyester dyed either red or blue. Sized either 4 m$^2$ or 9 m$^2$. Placed on asphalt, grass, roof tops, near buildings, and under trees.</td>
</tr>
<tr>
<td>Sub-pixel fabric targets</td>
<td>Fabric targets made of 100% cotton or polyester dyed either red or blue. cut to about 15 cm squares. Squares were mounted on plywood painted flat black and positioned such that they would achieve a 0.25 m$^2$ pixel fill.</td>
</tr>
<tr>
<td>Yellow cotton T-Shirts</td>
<td>Bright yellow T-Shirts positioned as part of the blind detection test. Shirts were moved between overflights.</td>
</tr>
<tr>
<td>Camouflage tarps</td>
<td>Polytarps in a tan, green, and black camouflage print pattern. Tarps were moved between flight lines from asphalt to grass.</td>
</tr>
<tr>
<td>Camouflage netting</td>
<td>Camouflage netting used both for change detection and LiDAR poke-through. One set of nets was moved between flight-lines. Another net was placed over a cardboard box.</td>
</tr>
<tr>
<td>Cardboard boxes</td>
<td>Standard cardboard shipping boxes of various sizes placed in open and under trees or netting. Static for all flight lines.</td>
</tr>
<tr>
<td>Vehicles</td>
<td>Five different vehicles were placed around the parking lots in known locations. Four were moved between flight lines for change detection and one was placed under trees for all flight lines.</td>
</tr>
<tr>
<td>Moving Pickup Truck</td>
<td>A Nissan Titan pickup truck drove in a known pattern with standard road flares manually tossed from rear of truck during overflights.</td>
</tr>
<tr>
<td>Tables</td>
<td>Several five foot long tables placed in known locations around buildings. Not moved between flight lines.</td>
</tr>
<tr>
<td>Kiddie Pools and Black Rooftop</td>
<td>A kiddie pool filled with water and cooled with ice was placed on the Roof of the RIT Center for Imaging Science building. The pool and the bare black roof served as cool and hot thermal calibration sources.</td>
</tr>
</tbody>
</table>

of reference. The second set of positional measurements was absolute latitude, longitude, and height position using a Tremble Surveyor’s GPS device. These units were reported to have sub meter positional accuracy using the nearest Rochester Differential GPS beacon. For the GPS measurements, the Northwest corner of each target was used as a reference point.

The second element of ground truth data includes context photos of every target as placed in the field (see Figures 6(a) and 6(b)). For targets that were moved between flight lines, photos of the targets in each location were captured. There were also photos taken from the roof of the Chester F. Carlson Center for Imaging Science overlooking the entire target placement area to provide additional context. In addition to the photos of the targets on the ground, there were also sky images taken from the perspective of each target to capture the sky view associated with each target’s view of the sky as shown in Figure 8(b).

The third element of ground truth included material reflectance measurements of each target taken with an ASD Field Spectroradiometer. The reflectance of each target was measured as placed on the ground as shown in Figure 7(a). A reflectance measurement was also captured of the backing material (asphalt, grass, concrete, etc.) since many of the targets were thin and transmitted light through to the underlayment. The spectral reflectance measurements were taken outdoor after the overflights were completed. The targets were also each measured independently by the ASD Field Spectrometer in a controlled laboratory setting. For the laboratory collected reflectance spectra, a contact probe with built-in illumination source was used.$^{9,10}$

In addition to the ASD field measurements, an Ocean Optics USB2000 Miniature Fiber Optic Spectrometer was used to capture reflectance information in the RIT Wetlands at the time of the overflights as illustrated in
Figure 5. Example of the LiDAR data collected over the RIT campus. The 3-D rendering was done using the Triangulated Irregular Network (TIN) algorithm. Color specifies height where blue is at ground level and red is among the highest points above ground level.

Figure 6. High resolution photographs used as context ground truth for (a) some of the targets on the ground and (b) one of the positioned vehicles used for change detection during this data collect campaign.

Figure 7(b). Also, water and foliage samples were collected for later laboratory analysis.

Additional infrared ground truth data was collected using the KIR-310 infrared imager to collect images from the roof of the RIT Chester F. Carlson Center for Imaging Sciences building. In this position, low-angle high-resolution infrared images of the Nissan Titan truck in a static position as well as while driving in a defined pattern were recorded.

Finally, thermal temperature measurements of the pool and other materials on the roof of the Chester F. Carlson Imaging Science building at RIT campus and weather data (i.e., wind speed, ambient air temperature, etc.) were recorded.

**Irondequoit Imagery.** Extensive reflectance measurements were previously taken of the area where the Irondequoit overflights occurred.11 These measurements were collected in support of the DIRSIG modeling development and are available for analysis along with this SHARE data set.
Figure 7. Examples of the field spectroradiometer measurements captured during the data collection campaign. The setup for ground level reflectance measurements of targets after overflights completed is shown in (a) and the wetlands team capturing ground level reflectance measurements shown in (b).

Figure 8. Additional examples of ground truth captured showing (b) one of the several sky images taken for each target placed and (a) Nissan Titan truck as seen from roof mounted KIR-310 infrared camera while stationary.

**Genesee River Imagery.** Unfortunately, during the days of the collection, the water was not safe to navigate for the available watercraft so surface measurements could not be taken nor water samples collected.

### 4. DESCRIPTION OF EXPERIMENTS

**Target Detection Blind Test** The objective of this experiment was to provide data in support of a community blind test for unresolved object detection. Hyperspectral imagery with targets identified and imagery with the same targets not identified was to be collected and subsequently made available via a website. Targets for this experiment were yellow T-shirts placed around the RIT campus and moved between overflights. Participants in the community blind test would be provided target spectra and asked to upload results of their target detection analysis for an automated scoring application. Scores of the results from any individuals or teams that participate would be published to encourage participation. It should be pointed out that the selected targets for this test were easily visible in the hyperspectral imagery, thus making the data inappropriate for a blind test.

**Dismount Detection** This experiment sought to investigate the detectability of similar types of clothing material when spectrally mixed with the signature of different types of backing materials and in different levels of
occlusion. Targets consisted of red felt and blue felt (100% polyester) and red broad cloth (100% cotton) placed around the RIT campus. These targets were single layer and each material type had targets constructed to be 9, 4, and 0.25 m² to capture different pixel fill levels. The backing materials included asphalt, lush grass, and sparse grass. The targets were also placed under trees and near buildings.

Physics-based Target Detection This experiment sought to collect airborne HSI data of known targets under a variety of illumination conditions in order to test physics-based target detection algorithms. This experiment utilized the same target set that was deployed in the Dismount Detection experiment. Parameters that were important to the physics-based modeling included Sun shadow, downwelled loading (sky view), target angle with respect to source and sensor, and the background adjacency.

MegaScene I and VanLare Collection This experiment sought to provide additional real-world HSI data for use in conjunction to two areas northeast of Rochester that have been extensively modeled with RIT’s DIRSIG simulation tool. MegaScene I is a computer model of the Irondequoit High School and Dake Junior High School as well as the neighborhoods surrounding. Also included as part of this collection area was the Monroe County Frank E. VanLare water treatment plant. The data were to be used to update, enhance, and verify the DIRSIG simulations. Data related to this part of the overflights was collected at a minimum GSD of 2 m for all imaging sensors.

In-water Constituent Retrieval The objective for this experiment was to perform an investigation into the potential of utilizing a coupled modeling system in conjunction with hyper- and multi-spectral thermal imagery data for water constituent retrieval. The study area consisted of the mouth of the Genesee river, its plume, and deep water portions of Lake Ontario around the mouth of the river.

RIT Wetlands Health Study This study sought to evaluate the differences between and the health of artificial and natural wetlands on the RIT campus. The project goals were to compare the plant diversity, plant health, and water quality for the two different wetlands, as well as map plant physiology spatially. Additionally, this imagery is being used for teaching environmental applications of remote sensing.

Change Detection Experiment For this experiment, data were collected to evaluate the ability of hyperspectral change detection algorithms to detect target location change without being confused by shadowing and illumination variation. Targets for this experiment included green nylon tarps and camouflage netting.

Sub-pixel Infrared Radiometry Experiment This experiment sought to retrieve the surface temperatures of sub-pixel materials from remotely sensed imagery. A pool of cold water as well as a broad black roof were used as the targets.

Thermal IR Vehicle Tracking This experiment sought to collect airborne IR and roof-top IR images of a moving vehicle to evaluate various tracking algorithms.

LiDAR Target Detection This experiment looked at detectability of targets under trees and other obscurants. The targets included folding tables with a simulated woodgrain veneer surface, cardboard boxes of various sizes, a vehicle, and chairs covered by radar nets. It was determined that the smaller targets placed (i.e., boxes and tables) were of insufficient size to be properly resolvable in the LiDAR imagery. However, the vehicles were resolved.

5. CONCLUSIONS

The SHARE data collection campaign successfully collected airborne multi-modal imagery along with extensive ground truth information. There were logistical issues which prevented both imaging aircraft to fly on the same day and other issues related to the HSI sensor. However, this data collection is open and available to the public for additional scientific analysis. With this in mind, all the data were saved in common formats accessible using tools that are likely available to the end users. The processed imagery from WASP were stored in fully registered GeoTIFF format. All data collected with the ASD FR FieldSpec Pro spectroradiometers were saved in both the ASD proprietary format and ASCII format. Likewise, the data from the Ocean Optics were saved in ASCII format. The files from both the ASD and Ocean Optics spectroradiometers contain both the reflectance and corresponding wavelength band centers. The data from the LiDAR sensor were 3-D Geo-tagged point clouds saved in the LAS format. The data from the KIR-210 thermal sensor was saved in video M-PEG and single frame
bitmap image formats. To access this data set, visit the DIRS Laboratory website at http://dirs.cis.rit.edu/. DIRS is a part of RIT’s Center for Imaging Science. Note that users will be required to register first for an account, but once authenticated, they will be able to acquire the data for use as needed.

ACKNOWLEDGMENTS

The authors would like to express appreciation to SpecTIR, LLC, for providing the ProSpecTIR-VS2 instrument and collecting the airborne HSI data. We would also like to thank Drs. Brent Bartlet and Michael Gartley for their guidance. Additionally, the authors would like to recognize the several university students and several high school students, made available by Mr. Robert Callens of Honeoye Falls-Lima Central School District, for their assistance in taking laboratory and field measurements.

DISCLAIMER

The views expressed in this article are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government.

REFERENCES