Rapid Prototyping of Hyperspectral Image Analysis Algorithms for Improved Invasive Species Decision Support Tools

FINAL REPORT
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Introduction

Nonnative invasive species adversely impact ecosystems, causing loss of native plant diversity, species extinction, and impairment of wildlife habitats. As a result, over the past decade federal and state agencies and nongovernmental organizations have begun to work more closely together to address the management of invasive species. In the 2005 fiscal year, approximately $500M was budgeted by U.S. Federal Agencies for the management of invasive species, where the primary funding included the following: DOD-$15M, USDA-$470M, and DOI-$11M [Simberloff 2005]. Despite extensive expenditures, most of the methods used to detect and quantify the distribution of these invaders are ad hoc, at best. Likewise, decisions on the type of management techniques to be used or evaluation of the success of these methods are typically non-systematic. More efficient methods to detect or predict the occurrence of these species, as well as the incorporation of this knowledge into decision support systems, are greatly needed.

The invasive species known as salt cedar or tamarisk (*Tamarix ramosissima*) is a particular problem in the U.S.’s desert southwest, where it is displacing the native cottonwood, willow, and other native plants. Tamarisk shrubs, or trees, are extremely competitive against native vegetation because they aggressively consume the water supply. Since tamarisk can re-grow from root crown buds, even after burning, the current management practices for tamarisk involve combinations of chemical, mechanical, and biological techniques. Thus, detection of tamarisk when it is in its earliest growing stages, through the use of remote sensing, could greatly reduce the cost associated with this invasive species.

In this rapid prototyping capabilities (RPC) experiment, recently developed analysis techniques for hyperspectral imagery were prototyped for inclusion in the National Invasive Species Forecasting System (NISFS). The new decision methodologies were tested using hyperspectral data obtained with a handheld spectroradiometer and hyperspectral imagery obtained via NASA’s HYPERION sensor. The results of this RPC experiment clearly demonstrated the viability of applying remotely sensed imagery, particularly hyperspectral such as that of HYPERION, to the problem of invasive species detection, as well as the image analysis methods’ potential for improving the existing NISFS decision support system.
Figure 1: Tamarisk stand in Colorado. Native plants are unable to penetrate the thick stands of tamarisk [Photograph: Tim Carlson].

Figure 2: Removal of dead tamarisk using fire at the Bosque del Apache NWR, NM [“Cost Components for Non-Native Phreatophyte Control, November 2006”, Tamarisk Coalition]
**Existing NISFS Decision Support System**

In the three years prior to this RPC experiment, the PIs participated in the NASA invasive species science team meetings for the development of the NISFS [http://bp.gsfc.nasa.gov/isfs_people.html]. We presented our work at the science team meetings, and these presentations are listed on the NISFS website [http://bp.gsfc.nasa.gov/isfs_news.html]. As a result of our meetings with the science team, we worked with members from the team to develop hyperspectral image analysis tools for automated detection of invasive vegetation. Likewise, the PIs are beginning work on a task force, as part of the science team, to develop a “library” of spectral-temporal profiles for invasives. It is currently planned for the National Institute of Invasive Species Science (NIISS) to serve as a clearinghouse, and the library will be developed in conjunction with the USGS spectral library program. This is particularly of interest to the RPC experiment, since the “library” could be potentially used as training data for future (non-tamarisk) applications of the experiment’s resulting tools: hyperspectral image analysis algorithms for detecting invasive species.

**RPC Experiment: Methodologies**

**Hyperspectral Imagery Analysis and Automated Target Recognition Techniques**

Over the past six years, the PIs have researched the use of remotely sensed multispectral and hyperspectral reflectance data for the detection of invasive vegetative species [refs 1-15]. As a result, the PI has designed, implemented, and benchmarked various target detection systems that utilize remotely sensed data. These systems have been designed to make decisions based on a variety of remotely sensed data, including high spectral/spatial resolution hyperspectral signatures (1000’s of spectral bands with spectral resolutions of approximately 3nm, such as those measured using ASD™ handheld devices), moderate spectral/spatial resolution hyperspectral images (100’s of spectral bands, such as HYPERION imagery), and low spectral/spatial resolution images (such as LANDSAT or MODIS imagery). These
algorithms (discrete analysis methods) include hyperspectral exploitation techniques such as the following dimensionality reduction methods:

- Best spectral band selection (i.e. stepwise-LDA band selection)
- Optimized spectral band grouping
- Stepwise PCA component selection

The PIs have extensive experience with combining these recently-developed methods with conventional feature reduction methods, such as Fisher’s LDA, and conventional classifiers, such as nearest neighbor and maximum likelihood classifiers. The end result is an end-to-end automated target recognition (ATR) system for detecting invasive species. The outputs of these systems can be invasive prediction maps, as well as quantitative accuracy assessments like confusion matrices, user accuracies, and producer accuracies.

![Simplified block diagram of discrete analysis pattern recognition techniques applied to hyperspectral imagery.](image)

Figure 3. Simplified block diagram of discrete analysis pattern recognition techniques applied to hyperspectral imagery.

**Hyperspectral Data and Verification and Validation Techniques**

Collaborators at Colorado State University (CSU) and USGS supplied the necessary ground truth via field surveys. Collaborators at NASA supplied hyperspectral signatures from handheld sensors, as well as ASTER co-registered HYPERION imagery of the field sites. The ground truth and hyperspectral data were both collected in the Grand Staircase-Escalante National Monument, in southern Utah. All model design, algorithm development, experimental analysis, and verification and validation (V&V) were conducted by the MSU researchers.
Figure 4. Hackberry Canyon in the Grand Staircase-Escalante National Monument was used as the field study test sight for all experimental data collection (ground truth and HYPERION imagery).
Figure 5. Airborne and satellite imagery of field study test site, Hackberry Canyon in the Grand Staircase-Escalante National Monument.
Figure 6. Temporal photos of tamarisk in Hackberry Canyon, Grand Staircase-Escalante National Monument. [Courtesy of Paul Evangelista].

Figure 7: HYPERION imagery color composite of Hackberry Canyon in the Grand Staircase-Escalante National Monument, with ground truth points overlaid. Red dots indicate ground truth points of tamarisk presence and blue dots indicate ground truth points of non-tamarisk.
**RPC Experiment: Motivation**

For all of the research endeavors described above, the PIs have developed numerous advanced signal and image processing methodologies, as well a suite of associated software modules. These methodologies have been extensively researched, benchmarked, and published in refereed conferences and journals. However, prior to this RPC experiment, the use of the prototype software modules has been primarily contained to in-house use at Mississippi State University (MSU). This RPC experiment enabled

(i) a systematic verification and validation of the hyperspectral image analysis algorithm using both handheld spectroradiometer data and satellite image data, namely HYPERION imager;

(ii) a formal collaboration between remote sensing and invasive species researchers at MSU (Lori Mann Bruce, et al), USGS (Tom Stohlgren, et al), CSU (Paul Evangelista, et al), and NASA (Jeff Morisette, et al);

(iii) a direct comparison of invasive species mapping capabilities of the existing decision support system (NISFS) and the proposed methods (automated analysis of HYPERION imagery).

**Experimental Results**

The results of this research project clearly demonstrate the viability of applying remotely sensing imagery, particularly hyperspectral such as that of HYPERION, to the problem of invasive species detection. As expected, the results show that the tamarisk detection accuracy depends on both spatial and spectral resolutions. The newly developed image processing and pattern recognition methods resulted in accuracies as high as 90% for discriminating tamarisk from native vegetation, such as cottonwoods and willows, when the input hyperspectral sensors had a spectral resolution in the range of 30-100nm and a spatial resolution that allowed for target abundances to be greater than 50%, i.e. mixed pixels had at least 50% ground coverage of tamarisk. These results are very promising and clearly indicate the power and practicality of hyperspectral remote sensing for invasive species detection.
Figure 8. High spectral and spatial resolution hyperspectral signatures of the target invasive vegetation (tamarisk) and nontarget non-invasive vegetation (cottonwood and willow). Signatures are preprocessed with waterband interpolation, truncation to 1650 bands, and normalization to $[0,1]$. 
Figure 9: Classification accuracies (overall accuracies of two class system: tamarisk vs. non-tamarisk (willow, cottonwood, etc)) for varying spatial and spectral resolutions.
Figure 10. HYPERION hyperspectral signatures of the target invasive vegetation (tamarisk - red) and nontarget non-invasive vegetation (cottonwood and willow - blue). Signatures raw data prior to any preprocessing (removal of water bands, normalization, etc).
Figure 11. Classification accuracies (overall accuracies of two class system: tamarisk vs. non-tamarisk (willow, cottonwood, etc)) for HYPERION mixed pixels for varying target abundance.

Transition of Results to ISS

The USGS-NASA team was also awarded a “Earth Science REASoN – CAN” grant to develop an Invasive Species Data Service (ISDS) to provide customized, easily accessible data products and tools to support invasive species management and policy decision-making. The PIs have begun discussions with the principal investigators of the ISDS project on how to use their ISDS to integrate our newly developed tools into the NISFS, as part of a future Integrated Systems Solutions (ISS) project.

Acknowledgments

The researchers gratefully acknowledge our Colorado State University and USGS collaborators, including Tom Stohlgren and Paul Evangelista, and our NASA collaborators, including Jeff Morriseette and Steve Ma.
References


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**Appendix A: Budget**

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