A MATLAB Toolbox for Hyperspectral Image Analysis

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Abstract- **The Hyperspectral Image Analysis (HIA) Toolbox is a collection of algorithms that extend the capability of the MATLAB numerical computing environment for the processing of hyperspectral and multispectral imagery. The purpose of the HIA Toolbox is to provide information extraction algorithms to users of hyperspectral and multispectral imagery in environmental and biomedical applications. The HIA toolbox has been developed as part of the NSF Center for Subsurface Sensing and Imaging (CenSSIS) Solutionware that seeks to develop a repository of reliable and reusable software tools that can be shared by researchers across research domains. The HIA toolbox provides easy access to supervised and unsupervised classification algorithms developed at LARSIP over the last 8 years.**

Keywords-Hyperspectral; Image Analysis; Supervised Classification; Unsupervised Classificaton.

I. INTRODUCTION

Hyperspectral Image analysis is supported by a variety of available software packages. The best known commercial product is the Environment for Visualizing Images (ENVI) [1] of Research Systems Inc., a Kodak subsidiary. ENVI provides code extensibility through the Interactive Data Language (IDL), allowing the possibility for routine and features expandability. Among the educational non-commercial products, the best known is MultiSpec [2] developed at Purdue University by Dr. David Landgrebe and the Remote Sensing research group in Purdue's LARS. Multispec provides similar features to ENVI but does not provide extensibility. At UPRM, researchers at the Laboratory for Applied Remote Sensing and Image Processing (LARSIP) have been working on multi and hyperspectral image processing for over 8 years. To support researchers in environmental and biomedical applications using multi/hyperspectral imagery at UPRM LARSIP and at the Center for Subsurface Sensing and Imaging Systems (CenSSIS), a toolbox that incorporated the HIA algorithms developed at LARSIP along with standard algorithms for classification similar to those included in ENVI and MultiSpec in the MATLAB platform widely used in engineering and science was necessary. The HIA toolbox includes original work in the areas of feature extraction/selection [3],[4] and contextual information classification enhancement [5] developed at UPRM.

This paper presents the first version of the HIA Toolbox. The algorithms implemented in the toolbox were developed during the last 8 years in research projects sponsored by NASA-TCESS, DoD, ARMY TEC, and NSF. Different teams of students developed these algorithms. The key objective of the original work was primarily proof of concept demonstrations. In order to reach a wider audience in environmental and biomedical applications and to be able to use the algorithms in the processing of larger data sets within the MATLAB environment, we worked on the integration, optimization, robustness and user interfaces of the original prototypes.

The new HIA Toolbox was aimed to be the common application for researchers in CenSSIS and LARSIP that use hyperspectral and multispectral imagery in different applications. The following sections will describe the CenSSIS Solutionware concept, the previous HIA prototypes developed at LARSIP, and the new toolbox.

II. CENSSIS SOLUTIONWARE

An important component of CenSSIS research is the incorporation of best algorithms into toolboxes to facilitate its use across diverse applications to demonstrate one of the Center's main paradigms "Diverse Problems – Similar Solutions". CenSSIS researchers will encounter a range of challenging computational and programming barriers. There is a need to develop a repository of reliable and reusable software tools that can be shared by CenSSIS researchers across research domains. The objective of the CenSSIS Solutionware team is to develop a set of catalogued tools and toolsets that will provide for the rapid construction of a range of subsurface algorithms and applications. Solutionware tools will span MATLAB toolboxes, visualization toolsets, database systems and application-specific software systems that have been developed in the Center. The Hyperspectral Toolbox is currently being developed as an element of the CenSSIS Solutionware framework.

Software engineering plays a critical role in developing generalizable and robust software solutions to engineering problems. CenSSIS has followed best practices during the development of Solutionware applications. Since much of the software developed within this environment involves specifying experimental and untested algorithms, we have chosen to follow an exploratory development model [6]. This allows researchers to experiment with new algorithms as they develop a core set of capabilities of a toolbox.

To facilitate programming in this environment, languages such as MATLAB are most appropriate. By programming at a high level of abstraction, the programmer can quickly construct

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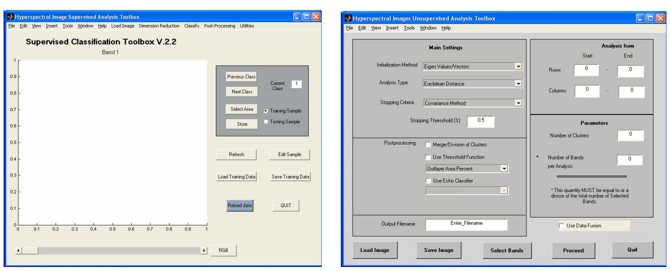
a set of algorithms to solve a problem. Also, MATLAB is capable of providing a framework for proper software engineering practices to be followed.

The HIA Toolbox is used within an optimized MATLAB environment. It provides useful image analysis techniques for educational and research purposes, allowing the interaction and development of new algorithms, data management, results comparisons and post-processing. It is an easy-to-use and powerful software for the CenSSIS community involved with HIA. This toolbox implemented in MATLAB serves as an excellent educational resource for student laboratories, hence improving the classroom experience with graphical examples. A similar approach has been taken in the development of Multi-View Tomography Toolbox, another CenSSIS Solutionware application [7].

III. HIA TOOLBOX

A. *Previous versions*

Figure 1 shows the graphical user interface of the Supervised Classification Toolbox (a) and the Unsupervised Classification Toolbox (b). As a first step, the development was oriented to the optimization and integration of these existing HIA toolboxes. The implementation of both toolboxes was done using MATLAB. The HIA Toolbox contains algorithms to load images of several file formats, routines for dimensionality reduction, supervised and unsupervised classification, and post-processing tools. These algorithms were inherited from these previous versions.



(a) (b)

Figure 1. (a) Supervised Classification Toolbox. (b) Unsupervised Classification Toolbox.

B. *Toolbox Proposition*

The HIA Toolbox proposition is to merge existing functionalities of both existing toolboxes and to optimize the performance of the code being merged. This implementation will be done in MATLAB as a first stage with the final objective of building a stand-alone application.

The Supervised and Unsupervised Classification toolboxes performed HIA independently. We identified algorithms and routines that the supervised and the unsupervised toolboxes shared in order of being able of unifying them for the HIA Toolbox. Such routines are:

1) *Load/Save Images*
2) *Feature Extraction/Selection Algorithms*
3) *Supervised and Unsupervised Classifiers*
4) *Post-Processing Algorithms*

The GUI of the new toolbox is shown in Figure 2. As we can see, the new toolbox is composed of a main window in which the image being analyzed is displayed. Besides the main window, there are also sub module windows that include the supervised classification and unsupervised classification modules.

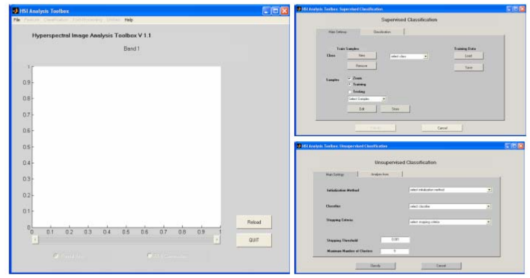


Figure 2. HIA Toolbox: GUI Visualization.

One of the advantages that the new toolbox has to offer is that the users can apply supervised or unsupervised classification algorithms and routines to the same image in the same application in order of doing a more extensive analysis of the data they wish to analyze.

There are other algorithms that are the result of current research projects, which are in the process of being added to the toolbox.

MATLAB version 6.5 was used for the implementation of the HIA Toolbox. We are currently conducting tests using MATLAB version 7.0 to ensure the toolbox is fully compatible.

IV. USING THE TOOLBOX: AN EXAMPLE

A graphical user interface (GUI) in MATLAB has been developed in order to facilitate the use of the HIA toolbox routines. The main window displays the image once it is loaded. All the interaction between the HIA Toolbox and the user is done through the GUI. Advanced users have the alternative of calling the functions from the MATLAB command window.

As an example, we will show how to use the toolbox to analyze a Hyperion image. This image was acquired from Hyperion, a high resolution hyperspectral imager with 220 spectral bands (.4 to 2.5 µm) and a 30m resolution. The area of interest is shown in Figure 3. This area covers some keys in La Parguera, located in the southwestern coast of Puerto Rico. With this image, we will give an example of how to use the HIA toolbox to identify different coastal characteristics.

The first step is to load an image file. The supported image file formats are:

1) *MATLAB (.mat)*
2) *Remote Sensing binary (bil, bis, bsq)*
3) *JPG*
4) *TIFF*

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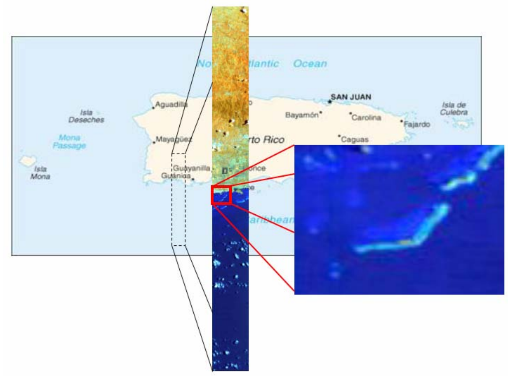
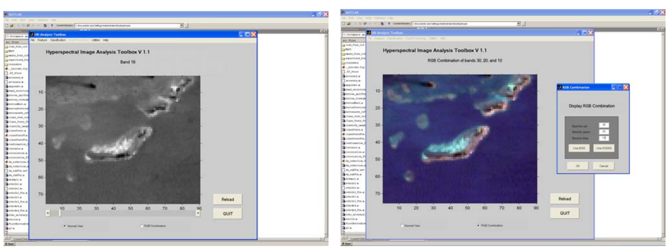


Figure 3. Hyperion hyperspectral image from Parguera PR.

Once loaded, the image can be viewed. The visualization of the image can be done band by band in a grayscale color map. There is a scroll bar for the user to change between bands. If the user wants to visualize an RGB composite of the image, he/she can set the desired RGB bands for visualization.

Figure 4 shows the default (band by band) visualization features (a) and the RGB view (b).



(a) (b)

Figure 4. (a) grayscale view. (b) RGB view.

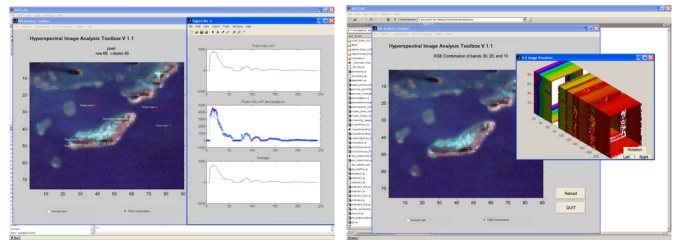
If managing hyperspectral data, the user can select from the available feature extraction/selection algorithms to reduce the dimensionality as a pre-processing step. The available feature extraction/selection routines are:

1) *Principal Components Analysis*[8][9]
2) *Discriminant Analysis*[8][9]
3) *Singular Value Decomposition Band Selection*[3][4]
4) *Information Divergence Band Subset Selection*[4]
5) *Information Divergence Projection Pursuit*[10]
6) *Optimized Information Divergence Projection Pursuit*[4]

Another feature available in the HIA Toolbox is the visualization of the spectral response of each pixel. When the user selects this feature and points with the mouse to the desired pixel, a window containing three plots appears; the first is the spectral response of the selected pixel, the second is the spectral response of the pixel and its 3x3 spatial neighborhood. The last graph is of the average of the neighborhood. With this feature the users can analyze the spectrum of the pixel and identify visually any difference between the pixel and its neighbors.

Another interesting feature is the hyperspectral cube visualization window. With this feature the user can visualize how the values of all the pixels change spectrally.

The user can apply supervised classification, unsupervised classification or both to the current image.



(a) (b)

Figure 5. (a) View spectral response. (b) View hyperspectral cube.

The supervised and unsupervised classification algorithms use the following classifiers:

1) *Euclidean Distance*
2) *Fisher's Linear Discriminant*
3) *Mahalanobis Distance*
4) *Maximum Likelihood*
5) *Angle Detection*

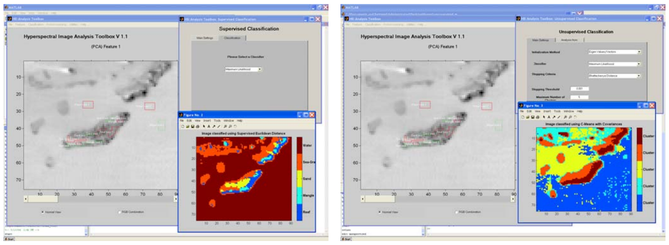
The supervised classification module allows for the selection of areas on the image as training and testing samples for the spectral classes present in the image. It is also possible to load a previously saved set of training samples to the toolbox to perform classification. The unsupervised classification module provides for the user to set the stopping criteria of the iterations as well as the threshold value for the algorithm to stop. The stopping criteria available are to minimize the difference of certain values between iterations. The metrics are:

1) *Bhattacharyya Distance*
2) *Covariance matrix*
3) *Pixel qty variation*
4) *Sum of squared error*
5) *Sum of squared error with covariance matrix information.*

Figure 6 shows samples of classification maps. These maps are result of the classification (supervised or unsupervised) process.

The HIA Toolbox has several post-processing techniques available to integrate contextual information of the scene to the resulting spectral classification map [5]. This integration results in an increase on the classification accuracy. The available routines are:

1) *Supervised & Unsupervised ECHO classifier*
   a) *ECHO 2x2*
   b) *ECHO 3x3*
   c) *ECHO 4x4*



(a) (b)

Figure 6. Classification map. (a) supervised. (b) unsupervised.

2) Spatial Information Integration based on Markov Random Fields

a) 4 neighbors

b) 8 neighbors

The result of applying such post-processing techniques is an enhanced classification map. The user can interact with both maps identifying and analyzing the differences among them.

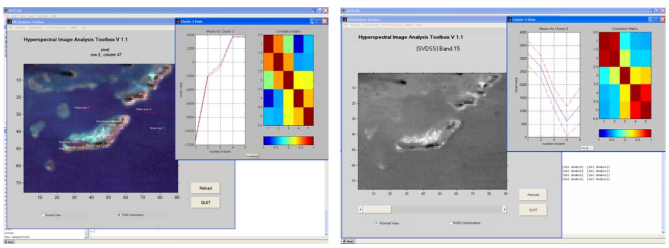


Figure 7. View statistics. (a) class. (b) cluster.

After a set of classes have been defined (supervised classification) or after an unsupervised classification is finished, the user can obtain and visualize the class/cluster statistics. Figure 7 shows an example of such visualizations. The statistics available are the graphical representation of the mean vector and correlation matrix for each class/cluster.

The HIA toolbox also provides an online help available through the MATLAB help window. This help gives the user a description of the toolbox as well as providing examples on how to use it. The help also contains information about the different functions available and how to use them if interacting with the MATLAB command window. This help will provide useful information to beginner and expert users.

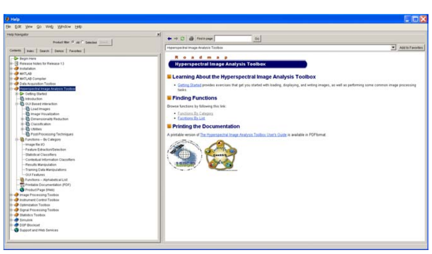


Figure 8. HSI Toolbox help window.

V. Final Remarks

Hyperspectral Imagery has been used in recent years as an efficient tool for Remote Sensing. This technology has been extended to other disciplines such as Subsurface Sensing, biomedical, environmental, and chemical image analysis. LARSIP has contributed to the HIA research community with the development of new feature extraction/selection and contextual information enhancement algorithms.

A MATLAB Toolbox for hyperspectral image analysis was presented. This toolbox is intended for researchers doing hyperspectral image analysis in various fields. The HIA Toolbox provides a unified framework, that gives support to these different disciplines. This unified framework will help in the research and development of new HIA analysis algorithms. The HIA Toolbox is an element of the CenSSIS Solutionware Framework and will continue to improve.

VI. Acknowledgements

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