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HyperMix: A New Tool for Higher Education of Computer and Remote Sensing Engineers

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Abstract

This paper describes HyperMix, a computer tool that has been specifically designed for the education of computer and remote sensing engineers. The tool is available online (http://hypercomphypermix.blogspot.com.es). HyperMix is an open-source tool that integrates different algorithms for interpreting remotely sensed hyperspectral images collected by Earth-observation instruments. Due to the large size of these images, HyperMix automatically recognizes if the computer in which it is installed has a graphics processing unit (GPU) available, and optimizes the execution of these algorithms in the GPU. This allows for the execution of hyperspectral imaging algorithms in computationally efficient fashion. In this paper, we present a comprehensive survey and analysis of the educational possibilities of the tool, which are based on an exploratory study conducted among users of the tool worldwide. We conclude that HyperMix provides a valuable tool for higher education of a new generation of remote sensing engineers.

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Keywords: Remote sensing education; HyperMix; Hyperspectral; Graphics Processing Units (GPUs).

1. Introduction

The education of a new generation of remote sensing engineers is a very important aspect, since the availability of new instruments for Earth observation from airborne or satellite platforms has been growing exponentially in recent years. For instance, recent advances in Earth observation technologies have made possible the development of advanced instruments such as the NASA Jet Propulsion Laboratory's Airborne Visible-Infrared Imaging Spectrometer (AVIRIS), which covers the wavelength range from 0.4 to 2.5 micrometers (visible and near-infrared spectrum) using 224 spectral channels (Green *et al.*, 1998). A hyperspectral data set can be therefore seen as an

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image cube in which each pixel is given by the spectral signature of the materials in that area of the image (see Fig. 1).

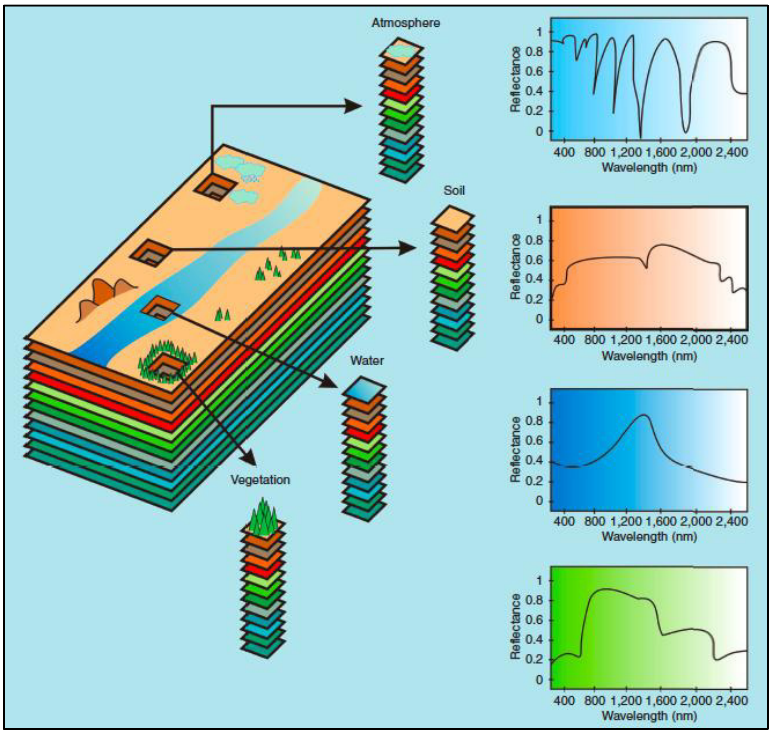

Fig. 1. The concept of remotely sensed hyperspectral imaging.

One of the main issues in the analysis of remotely sensed hyperspectral images is the mixed pixel problem (Bioucas *et al.*, 2012), which depends on the spatial resolution of the data and also on the characteristics of the area that is being imaged. To address this problem, spectral unmixing finds a collection of pure spectral constituents (called *endmembers*) that can explain each (possibly mixed) pixel of the scene as a combination of *endmembers*, weighted by their coverage fractions in the pixel or abundances (Bioucas *et al.*, 2012).

Over the last years, many algorithms have been presented to address the three main parts of the spectral unmixing chain: 1) estimation of the number of endmembers, 2) identification of the endmember signatures, and 3) estimation of the per-pixel fractional abundances (Bioucas *et al.*, 2012). However, the complexity and high dimensionality of the hyperspectral scenes bring computational challenges that make spectral unmixing techniques appealing for implementation in high performance computing systems (Plaza *et al.*, 2011). For instance, graphics processing units (GPUs) have been widely used to accelerate hyperspectral imaging algorithms (Plaza *et al.*, 2011). GPUs are a low-weight and low-cost hardware platform in which it is possible to accelerate operations and methods in order to easily obtain better computational performance. The number of processor cores depends of the architecture and the model of the GPU. The possibilities of these units go beyond their price, and offer an unprecedented potential to accelerate hyperspectral imaging problems. Despite the popularity of hyperspectral unmixing techniques and their high computational demands, to date there is no standardized tool that allows for the computationally efficient execution of spectral unmixing chains in a unified, graphical and fully configurable framework. Such a tool is very important for education of a new generation of remote sensing engineers, who will need to deal with these massive volumes of data in a computationally efficient way.

In this paper we describe HyperMix, an open-source tool that has been specifically designed to educate remote sensing engineers by intuitively guiding them through the characteristics of spectral unmixing chains for hyperspectral image analysis applications. Although the HyperMix tool has been already presented in previous developments (Jiménez & Plaza, 2015), its educational aspects have not been fully explored as of yet. A main innovation presented in this paper is the comprehensive survey and analysis of the educational aspects of the tool, which are based on an exploratory study conducted through practical experience using the tool in remote sensing courses in China, Italy and Spain.

2. The HyperMix Tool

The HyperMix tool was developed following the open-source philosophy for Linux and Windows platforms. The tool is designed to be easy to use; hence it is also suitable for educational purposes. Originally, the tool was mainly intended to visualize algorithm outcomes and to offer an easy way to integrate spectral unmixing methods. However, the interface of the tool has been completely rebuilt and the tool now includes the capability to compose spectral unmixing chains and integrate new spectral unmixing algorithms in a straightforward manner. This is accomplished by means of a flowchart diagram canvas (see Fig. 2) developed in order to allow the end-user to configure a desired unmixing chain in a flexible manner. In other words, the user can create a complete hyperspectral unmixing chain (or several ones at the same time), and the outcomes of each individual stage can be used as inputs to the subsequent stages. Each method (or hyperspectral image) is considered as an object or component that the user can manage independently. Related to this dynamic construction of chains is the visualization of the results provided by them. The tool also allows to load/store/visualize hyperspectral images and endmember/abundance results using different views, as illustrated in Fig. 3.

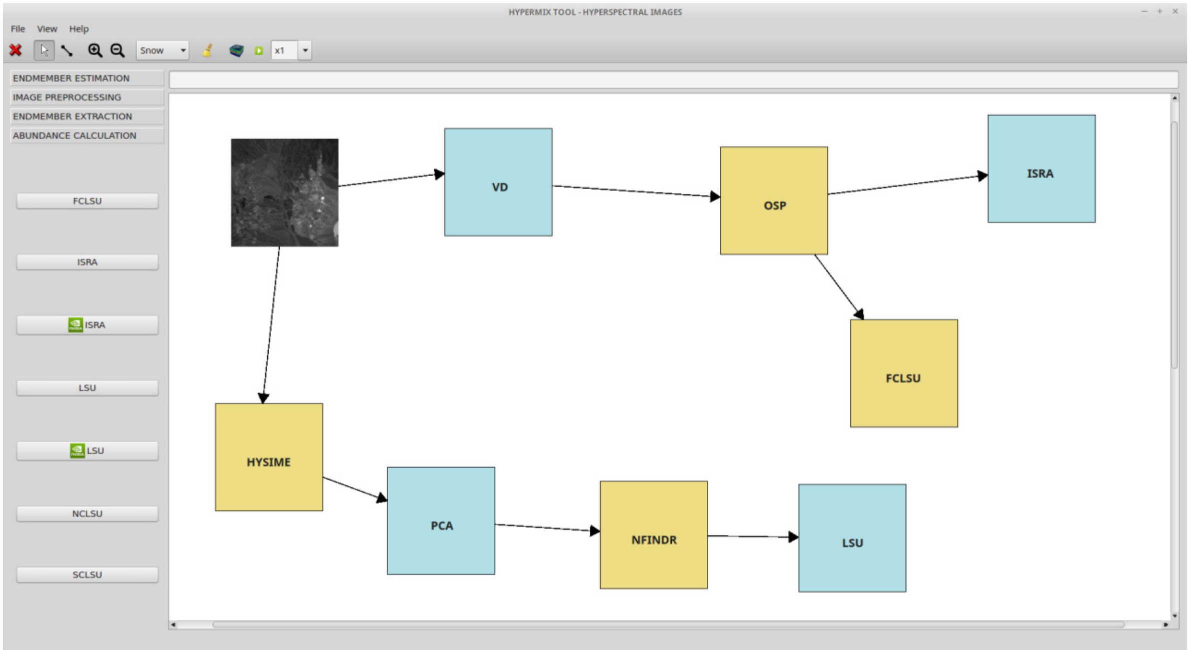

Fig. 2. Flowchart diagram canvas in HyperMix, illustrating the construction of several spectral unmixing chains for a hyperspectral image collected by the AVIRIS instrument.

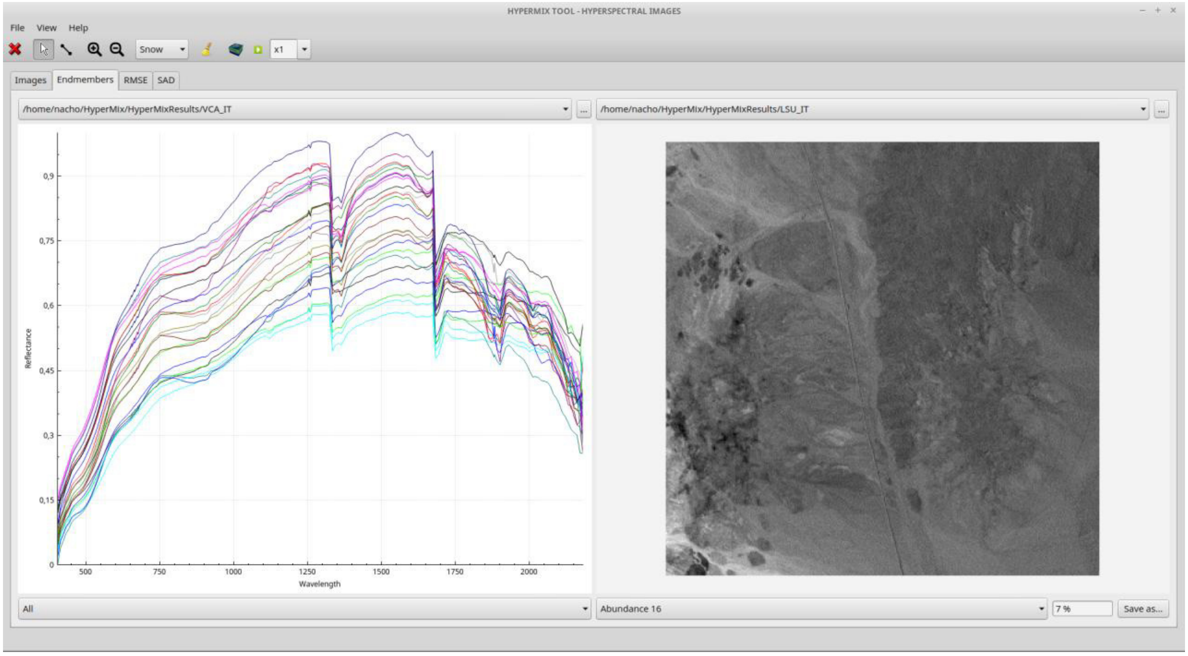

Fig. 3. Visualization of analysis results using HyperMix from a hyperspectral image collected by AVIRIS.

HyperMix has been designed as an open-source application for hyperspectral data processing and evaluation. For this purpose, among other possibilities considered, we developed the tool using the cross-platform application framework Qt[*], which uses the standard C++ programming language with extensions that simplify the handling of events required to implement an easy and powerful tool. Besides, the Qt library can be used by other programming languages via binding languages. This makes it possible to expand HyperMix functionalities by including advanced database management or network support. Presently, HyperMix is able to manage the great memory requirements imposed by high-dimensional hyperspectral images using external binary files in band sequential (BSQ) format, that can be read by the main program, and also managing independent external binary files which implement the different unmixing methods (treated as components). It should be noted that the amount of memory needed to store the images through different data types is limited by the operating system (OS) where the tool is running. While Linux generally has no limits, Windows OS has different limitations depending which version is used. In this regard, our tool has been designed to handle the processing algorithms as external operators that communicate with the main tool through binary files, so that the memory management for each of them depends directly on how the tool is implemented. The main program calls these external operators in a proper order, as indicated by the workflow defined in the diagram canvas. The external binaries can be implemented in different programming languages. This has the advantage that we can easily incorporate new processing algorithms that can be executed as independent processes. In the current version of the tool, we use the C++ programming language for the serial implementations and the NVidia Compute Unified Device Architecture (CUDA)[†] for the GPU versions, leaving open the possibility to include methods developed in other languages, such as OpenCL[‡], or different specific libraries such as the basic

[*] http://qt-project.org/
[†] https://developer.nvidia.com/cuda-zone
[‡] https://www.khronos.org/opencl

linear algebra subprograms (BLAS)[§]. This design strategy provides great flexibility about machine requirements, as well as opportunities to create a community of users able to share and exchange different methods.

A main feature of the tool is the possibility to run hyperspectral image processing algorithms in parallel in an NVidia GPU if the machine in which the tool is installed has one available, thus allowing to significantly reduce the computational complexity of the algorithms. The tool automatically recognizes if the system has a GPU available or not. The configuration parameters for each implemented method are made in the codification itself, i.e. we automatically allocate the number of resources (e.g., compute threads, grids, etc.) based on the characteristics of the hardware platform recognized. The techniques currently included in the tool have been tested under CUDA 6.X compatibility. The recognition of the machine capability to run GPU operators is automatically obtained during the installation of the tool, so if there is no such possibility (i.e. the system has no GPU) only the serial versions will be installed. The GPU implementations of the algorithms currently included in the tool have been extensively described in (Sánchez *et al.*, 2015). Another important advantage of HyperMix is that it is very easy to include new methods to the current set of operators. In other words, any user can produce his/her own algorithms (using different programming languages) and include them in the tool as binary files, thus simplifying the procedure to create new content and updates and allowing other users to share new developments. A blog has also been created in the tool website to foster interactions between HyperMix users (http://hypercomphypermix.blogspot.com.es).

3. Results and Discussion

Acceptance of the tool and the involvement of students had different nuances in each institution in which it was tested. For instance, the acceptance in research organizations and universities has been good. The tool was used for on-site demonstration purposes in a 40-hour remote sensing course (83 students) on *Hyperspectral Image Analysis: Algorithms and Implementations* taught in July 2013 at the Chinese Academy of Sciences, Institute of Remote Sensing and Digital Earth (RADI) in Beijing, China, and students welcomed with interest the project, with a strong degree of involvement. The tool was also used for the practice sessions in a 30-hour remote sensing course (30 students) on *Remote Sensing and Medical Image Processing* given at the Department of Electronics, Engineering School, University of Pavia (UNIPV), Italy, in October 2012. Here, the experiences with the tool were presented as a volunteer project with motivated students. The tool was also used as a demonstration case study in two remote sensing courses (60+ students each) given at the Department of Geography, School of Geography and Planning, Sun Yat-Sen University (SYSU), Guangzhou, China, in July and December 2015. These courses, called *Geospatial Information Systems* and *Image Processing*, were part of the Official Degree on Geographic Information Science at SYSU. Finally, the tool has been used to illustrate algorithm implementations in GPUs in an optional course (24 students) on *Graphics Processing* in the Computer Engineering Degree, Escuela Politécnica de Cáceres, University of Extremadura (UEX), in 2014 and 2015. In addition, since the tool is available online, we collected feedback about the use of the tool from other users present in environments different than research organizations such as RADI or academic institutions such as UNIPV, SYSU or UEX, with particular interest in users based on industrial partners and companies.

At RADI it has been noticed that, as they were senior students, their involvement in the use of HyperMix was very high and so was the quality of their work. At UNIPV, the experiences with HyperMix were presented as a volunteer project for the most motivated students (which turned out to be 10 out of 30 students participating in the course). Their reception was excellent and the students were involved very much; nevertheless, the average number of hours dedicated to the project exceeded by 20% the original plan. This indicated that the tool required more interaction and practical experience than we had anticipated, which calls for the development of additional tutorials and documentation on the project to facilitate interaction of the students. It was also noticed a certain degree of competitiveness between the students that participated in the individual volunteer projects at UNIPV, that we believe may be beneficial since it reflects a personal involvement with the project and desire to excel. Our experiences at SYSU, in turn, indicated that a great number of students who developed activities with HyperMix

[§] http://www.netlib.org/blas

increased their interest in building a research career in remote sensing. Possibly this behavior comes motivated by the greater attention to the student by the teacher, as these students expressed their interest to develop their Master and/or PhD studies in the area of remote sensing and even to pursue their studies abroad (some of these students applied for competitive funds to obtain a degree in remote sensing at UEX).

In the discussion meetings that were held with students of the *Graphics Processing* course at UEX, the following perceptions were recorded: the students were very receptive and said it was an experience that allowed them to intuitively exploit complex image processing algorithms in an efficient and easy way. They noted that, initially, the transfer of responsibilities from the teacher to the students disturbed them, but as they proceeded with the project they developed more autonomous and more independent learning strategies. They agreed that, through the use of HyperMix, the concepts learned stayed longer. In other words, the use of the tool provided them with greater retention over time. Despite some difficulties encountered, all participants recommended this method of learning to the rest of his classmates. The instructors, on their side, were satisfied with the experience, given the good results obtained; however, the project required an immense amount of work from the teachers and it was concluded that its organization should optimize instrument/evaluation criteria to make the evaluation more objective and less time consuming. Finally, the independent evaluations received after experiencing the tool online indicated several suggestions for improvement. Particularly, users suggested that the tool needs to be further adapted to industrial partners, in which educational aspects are not as important as the efficiency of the tool in processing hyperspectral images. This indicates the multidisciplinary component of the tool, which can be used effectively for educational purposes but also for computationally efficient processing and analysis of remotely sensed hyperspectral images. For illustrative purposes, Table 1 summarizes the surveys conducted after the exploitation of the tool at different institutions, indicating wide acceptance.

Table 1. Summary of the teaching experiences based on HyperMix on different institutions.

Institution (degree)	Course (number of hours)	Students in group	Students using HyperMix	Weight on grade	Overall evaluation
RADI (Remote Sensing)	Hyperspectral Image Analysis (40)	83	83	15%	Very positive
UNIPV (Electronic Engineering)	Remote Sensing/ Medical Imaging (30)	30	15	20%	Quite positive
SYSU (Geography)	Information Systems (12)	65	65	15%	Quite positive
SYSU (Geography)	Image Processing (12)	63	63	15%	Quite positive
UEX (Computer Engineering)	Graphics Processing (60)	24	24	10%	Very positive

4. Conclusions

We have described some educational aspects and results of HyperMix, an open-source tool for higher education of computer and remote sensing engineers. Our exploratory study, conducted after using the tool for educational purposes in several official courses at prestigious remote sensing institutions worldwide, indicates wide acceptance of the tool. This suggests that it can be effectively used for educational purposes, and also for computationally efficient processing and analysis of remotely sensed hyperspectral images.

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