HyperMix: A New Tool for Teaching Signal and Image Processing to Electrical and Electronic Engineers

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***Abstract*—This paper describes HyperMix, a tool that has been specifically designed for teaching signal processing to electrical and electronic engineers. The tool is available online (http://hypercomphypermix.blogspot.com.es). HyperMix is an open-source tool that integrates different signal and image processing algorithms, which can be used 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. In this paper, we present a comprehensive description of the tool, as well as a survey and analysis of its educational possibilities, which are based on an exploratory study conducted among users of the tool worldwide. We conclude that HyperMix provides a valuable tool for teaching image and signal processing to electrical and electronic engineers.**

***Index Terms*—Education, signal and image processing, electrical and electronic engineers, graphics processing units (GPUs).**

I. Introduction

Signal and image processing are important aspects for the education of electrical and electronic engineers. The application of the concepts of signal and image processing to real case studies is a very important educational aspect. There are many domains in which signal and image processing have been used for educational purposes. In this work, we focus on remote sensing as an illustrative case of signal and image processing, as we feel it offers significant advantages from the viewpoint of data availability, appeal to students, and possibilities to work in a practical yet relevant application domain. 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 [1]. A hyperspectral data set can be therefore seen as an image cube in which each pixel is given by the spectral signature of the materials in that area of the image (see Fig. 1).

One of the main issues in hyperspectral analysis is the mixed pixel problem [2], which depends on the spatial resolution of the data and also on the characteristics of the area which is beng 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* [3].

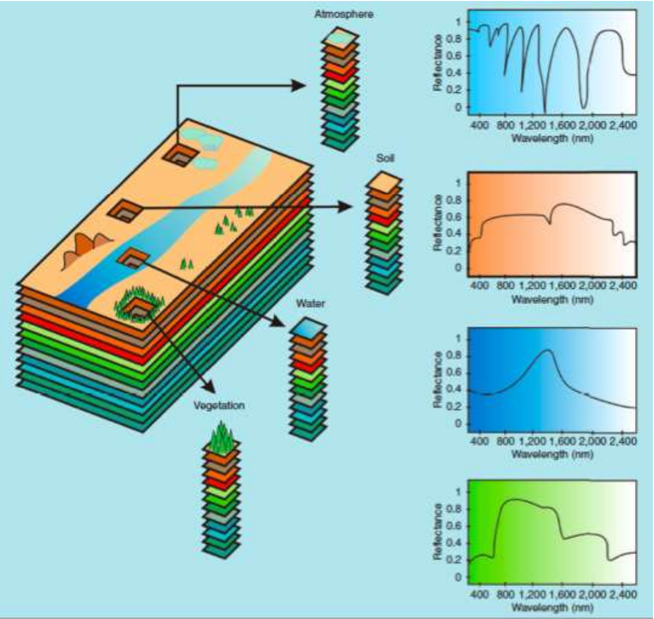

Fig. 1. The concept of remotely sensed hyperspectral imaging.

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 [2]. Two major techniques have been used for spectral unmixing purposes: the linear mixture model, which assumes that the materials are combined linearly, and the nonlinear mixture model, which assumes that there are nonlinear iteractions between the endmember substances [4]. The linear model is generally considered more computationally tractable, but in both cases 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 [5, 6]. For instance, graphics processing units (GPUs) have been widely used to accelerate hyperspectral imaging algorithms [7, 8]. 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.

In this paper we describe HyperMix, an open-source tool which integrates different approaches for signal/image processing and allows building unmixing chains in graphical and configurable fashion, allowing an user to intuitively define spectral unmixing chains for hyperspectral analysis applications. The tool has been used to educate electrical and electronic engineers by intuitively guiding them through the characteristics of spectral unmixing chains for hyperspectral image analysis applications. Although the tool has been presented in previous developments [9], its educational aspects in the context of teaching signal and image processing (particularly to electrical and electronic engineers) 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 in different engineering courses taught in China, Italy and Spain.

II. 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 hyperspectal 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.

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`[1], 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)[2] for the GPU versions, leaving open the possibility to include methods develped in other languages, such as OpenCL[3], or different specific libraries such as the basic linear algebra subprograms (BLAS)[4]. This design strategy provides great flexibility about machine requierements, as well as opportunities to create a community of users able to share and exchange different methods.

The spectral unmixing methods currently included in the tool are the following ones. For the identification of the number of endmembers, the virtual dimensionality (VD) [10] and the hyperspectral subspace identification with minimum error (HySime) [11] are available. The tool also includes methods for dimensionality reduction and preprocessing, such as the principal component analysis (PCA) [12] and spatial pre-processing (SPP) [13]. For endmember extraction purposes, the tool includes methods such as the orthogonal subspace projection (OSP) [14], NFINDR [15], iterative error

[1] http://qt-project.org/

[2] https://developer.nvidia.com/cuda-zone

[3] https://www.khronos.org/opencl

[4] http://www.netlib.org/blas

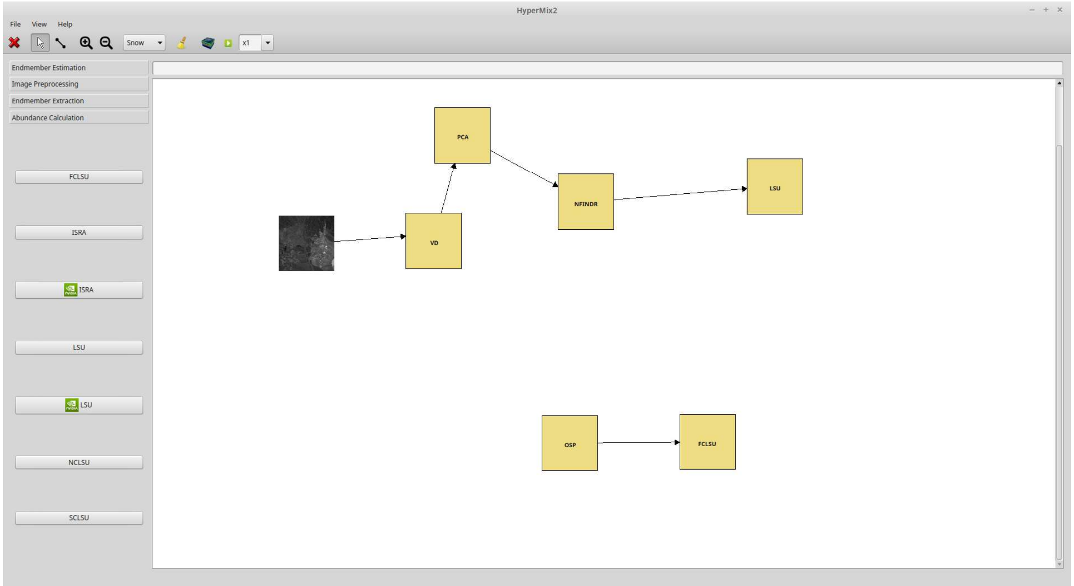

Fig. 2. Flowchart diagram canvas in HyperMix, illustrating the construction of several spectral unmixing chains for a hyperspectral image collected by the AVIRIS instrument.

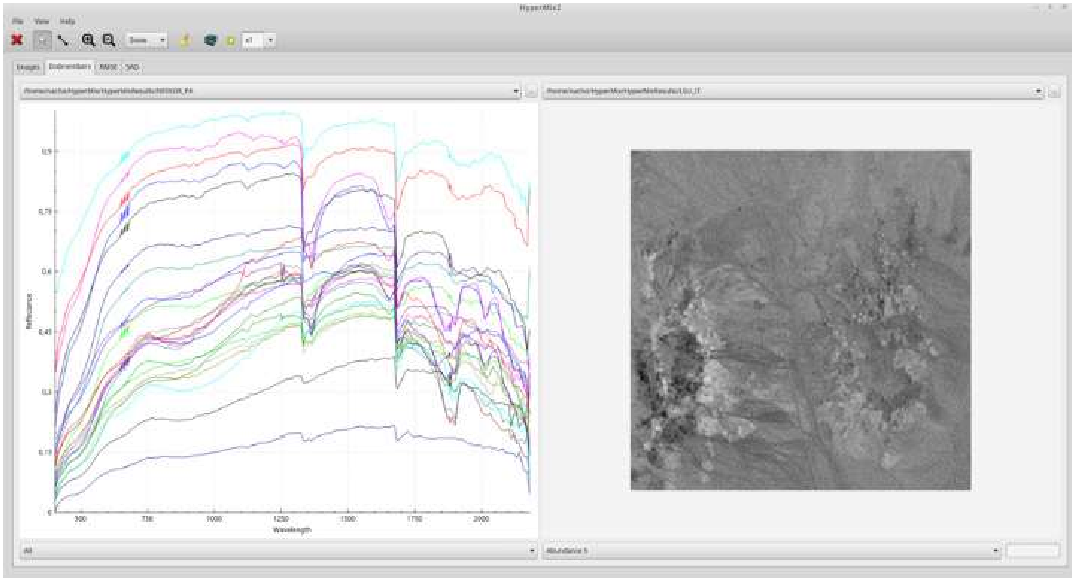

Fig. 3. Visualization of analysis results using HyperMix from a hyperspectral image collected by AVIRIS.

analysis (IEA) [16], and vertex component analysis (VCA) [17]. Finally, the for the abundance estimation step the tool includes the least squares unmixing (LSU) method, the sum-to-one constrained least squares unmixing (SCLSU), the non-negativity constrained least squares unmixing (NCLSU), the fully constrained least squares unmixing (FCLSU) [18], and the image space reconstruction algorithm (ISRA) [19].

A main feature of the tool is the possibility to run the aforementioned 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

Fig. 4. HyperMix tool website at http://hypercomphypermix.blogspot.com.es.

installed. 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 incude them in the tool as binary files, thus simplifying the procedure to create new content and updates and allowing other users to share new developmens. A blog has also been created in the tool website to foster interactions between HyperMix users. A blog has also been created in the tool website (see Fig. 4) to foster interactions between HyperMix users (http://hypercomphypermix.blogspot.com.es).

III. Evaluation of Computational Performance

Our experiments to evaluate the computational performance of the tool are intended to analyze every step of a hyperspectral unmixing chain and also to test the different options that the tool offers. For that purpose, we use two hyperspectral scenes. The first one is the AVIRIS Cuprite data set, available online in reflectance units[5] after atmospheric correction. This scene has been widely used to evaluate the performance of hyperspectral unmixing algorithms. The scene contains 224 spectral bands in the range of 0.4 to 2.5 μm with 350×350 pixels and spatial resolution of 20 meters per pixel. Several bands were removed due to water absorption and low SNR in those bands, leaving 188 reflectance channels. Fig. 3 shows an example of how the image is processed using HyperMix. The Cuprite site has several exposed minerals included in the USGS spectral library[6] and we use several representative mineral signatures to evaluate the quality of the extracted endmembers. The other scene used in experiments was collected by AVIRIS over the World Trade Center (WTC) area in New York City. This image was obtained after the terrorist attacks in 2001. The data set consists of 614×512 pixels and 224 spectral bands, with a spatial resolution of 1.7 m per pixel. The image is available in radiance units and is generally regarded as an benchmark for evaluating parallel implementations of hyperspectral image processing algorithms.

To illustrate the HyperMix tool, we constructed a full spectral unmixing chain (using the canvas feature) and evaluated its performance using the serial and GPU implementations available in the tool. For the considered chain, we used VD for identifying the number of endmembers, SPP for spatial preprocessing, VCA for endmember extraction, and LSU for abundance estimation. The parameters were set empirically as follows: for the VD we used a false alarm probability $P_F = 10^{-3}$ [10], and for the SPP we used a spatial window size of $ws = 7$ [13]. The remaining blocks of the spectral unmixing chain did not require any imput parameters. The experiments were conducted using two different GPUs: one for desktop machines (NVidia GeForce GTX580 with 512 cores and 1536MB GDDR5), and another one for laptop devices (NVidia GeForce GT740M with 384 cores and up to 2GB GDDR3). The computational times measured in the GPUs were compared against those obtained in an Intel Core i7 CPU 920 @ 2.67 GHz x 8 with 6GB of memory.

At this point, it is important to note that all the results reported were obtained after conducting ten Monte-Carlo runs of the same chain for each image, using independent methods implemented in serial and parallel. As shown in Table I, the performance obtained for the whole chain for the Nevada GTX580 is quite remarkable, obtaining a total speedup of 14.820x for the Cuprite scene and 19.142x for the World Trade Center scene. For instance, this allowed us to unmix the World Trade Center scene in just 5.931 seconds in the GTX580 (as opposed to 113.514 seconds in the CPU). Although the speedups reported for the Cuprite scene are lower, this is related to the smaller size of the image (which can be unmixed in just 1.662 seconds in the GTX580). The speedups achieved by each part of the chain vary, but for instance remarkable speedups were obtained for the VD (32.96x when processing the World Trade Center scene in the GTX580) and the SPP (50.33x speedup in the GTX580). The results obtained in the GT740M are also quite remarkable given the fact that this GPU is available for laptop computers. Overall, we can conclude from Table I that the GPU feature in HyperMix allows significantly improved computational performance.

IV. Educational Experiences 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 electrical engineering 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 electrical and electronic engineering course (30

[5]http://aviris.jpl.nasa.gov/html/aviris.freedata.html
[6]http://speclab.cr.usgs.gov

TABLE I
MEAN EXECUTION TIMES (SECONDS) FOR THE SERIAL AND GPU IMPLEMENTATIONS OF THE DIFFERENT PARTS OF THE CONSIDERED SPECTRAL UNMIXING CHAIN AFTER 10 MONTE-CARLO RUNS. THE SPEEDUPS FOR EACH PART OF THE CHAIN ARE REPORTED IN THE PARENTHESES.

Image	Device	VD	SPP	VCA	LSU	Full Chain
Cuprite	CPU	5.162	5.950	12.753	0.752	24.617
	GTX580	0.263 (19.627x)	0.291 (20.446x)	0.948 (13.452x)	0.160 (4.7x)	1.662 (14.820x)
	GT740M	0.784 (6.584x)	1.170 (5.085x)	1.721 (7.410x)	0.244 (3.081x)	3.919 (6.281x)
World Trade Center	CPU	18.923	41.474	49.991	3.126	113.514
	GTX580	0.574 (32.96x)	0.824 (50.33x)	4.254 (11.75x)	0.279 (11.204x)	5.931 (19.142x)
	GT740M	1.912 (9.89x)	3.411 (12.15x)	5.605 (9.919x)	0.507 (6.165x)	11.435 (9.926x)

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 signal and image processing 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 Politecnica de Caceres, 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 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 II summarizes the surveys conducted after the exploitation of the tool at different institutions, indicating wide acceptance.

V. CONCLUSIONS

We have described some educational aspects and results of HyperMix, an open-source tool for teaching signal and image processing to electrical and electronic engineers. Our exploratory study, conducted after using the tool for educational purposes in several official courses at prestigious electric and electronic engineering institutions worldwide, indicates wide acceptance of the tool. This suggests that it can be effectively used for educational purposes, and also for computationally

TABLE II
SUMMARY OF THE TEACHING EXPERIENCES BASED ON HYPERMIX ON DIFFERENT INSTITUTIONS.

Institution (degree)	Course (number of hours)	Students (using HyperMix)	Weight on grade	Evaluation
RADI (Electrical engineering)	Hyperspectral Image Analysis (40)	83 (83)	15%	Very positive
UNIPV (Electronic Engineering)	Remote Sensing Image Processing (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

efficient signal and image processing/analysis of remotely sensed hyperspectral images.

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