HyperMix: An Open-Source Tool for Fast Spectral Unmixing on Graphics Processing Units

Luis Ignacio Jiménez and Antonio Plaza, *Fellow, IEEE*

***Abstract*—Spectral unmixing has been a popular technique for analyzing remotely sensed hyperspectral images. The goal of unmixing is to find 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*. 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. However, to date, there is no standardized tool that integrates these algorithms in a unified framework. In this letter, we present HyperMix, an open-source tool for spectral unmixing that integrates different approaches for spectral unmixing and allows building unmixing chains in graphical fashion, so that the end-user can define one or several spectral unmixing chains in fully configurable mode. HyperMix provides efficient implementations of most of the algorithms used for spectral unmixing, so that the tool automatically recognizes if the computer has a graphics processing unit (GPU) available and optimizes the execution of these algorithms in the GPU. This allows for the execution of spectral unmixing chains on large hyperspectral scenes in computationally efficient fashion. The tool is available online from http://hypercomphypermix.blogspot.com.es and has been validated with real hyperspectral scenes, providing state-of-the-art unmixing results.**

***Index Terms*—Graphics processing units (GPUs), HyperMix, hyperspectral imaging, open-source, spectral unmixing.**

I. Introduction

HYPERSPECTRAL remote sensing is based on the capability of imaging spectrometers to collect reflectance data, along different wavelength bands, for the same area on the surface of the Earth. For instance, the NASA Jet Propulsion Laboratory's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) covers the wavelength range from 0.4 to 2.5 μm (visible and near-infrared spectrum) using 224 spectral channels [1]. A hyperspectral data set can be therefore seen as a cube in which each pixel is given by the spectral signature of the underlying materials in that area of the image.

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 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* [3].

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 interactions 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 letter, we describe HyperMix, an open-source tool for spectral unmixing which integrates different approaches for spectral unmixing and allows building unmixing chains in graphical and fully configurable fashion, allowing an end-user to intuitively define the characteristics of spectral unmixing chains for hyperspectral analysis applications. In previous developments [9], the tool included several unmixing algorithms covering the different parts of the unmixing chain. A main innovation presented in this letter is the capability of the tool to define unmixing chains in graphical fashion and to automatically recognize if the computer has a GPU available, in which case the execution of the algorithm is optimized for the available GPU device.

Manuscript received March 26, 2015; revised May 6, 2015; accepted May 15, 2015. Date of publication June 5, 2015; date of current version August 7, 2015. This work was supported by "Tools for Open Multi-Risk Assessment using Earth Observation Data" (TOLOMEO) under Marie Curie International Research Staff Exchange Scheme (PIRSES-GA-2009).

The authors are with the Hyperspectral Computing Laboratory, University of Extremadura, 10071 Cáceres, Spain (e-mail: luijimenez@unex.es; aplaza@unex.es).

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Digital Object Identifier 10.1109/LGRS.2015.2435001

without checking if a different ordering of the endmembers or the reference signatures when performing the matching would improve the results. The second method (average SAD) performs the matching after a number of executions of the minimum SAD algorithm by randomly sorting the endmembers and the reference signatures, thus making sure that a more optimal matching is achieved. Table III shows the SAD scores (in degrees) obtained by the HyperMix tool after comparing the extracted endmembers with the reference USGS signatures. As shown by Table III, the extracted endmembers are very similar, spectrally, with regard to the reference USGS signatures. An evaluation of the NRMSE scores obtained using the HyperMix tool after comparing the reconstructed versions of the two considered hyperspectral scenes also reveals high similarity scores, with values of 0.0185 for the Cuprite scene and 0.0058 for the WTC scene using the considered unmixing chain.

IV. Conclusion And Future Lines

In this letter, we have presented an open-source tool called HyperMix which contains a variety of algorithms (iterative and parallel) for spectral unmixing of remotely sensed hyperspectral data sets. The tool offers an easy way to manage these algorithms and build spectral unmixing chains, along with comprehensive options to display and validate the obtained unmixing results. The developed open-source tool and quantitative comparison of unmixing algorithms is expected to be of great interest to both algorithm developers and end-users of spectral unmixing techniques, as this is the first tool of its kind in the area of spectral unmixing. In addition to the inclusion of additional techniques for spectral unmixing (which is very easy to manage in the current version), our future lines of research will be focused toward offering remote access to a repository of hyperspectral scenes [24] through HyperMix and extending the capability of HyperMix to include other kinds of techniques for hyperspectral image processing. We will maintain and expand the tool with additional versions compatible with new GPU families.

References

[1] R. O. Green *et al.*, “Imaging spectroscopy and the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS),” *Remote Sens. Environ.*, vol. 65, no. 3, pp. 227–248, Sep. 1998.

[2] J. Bioucas-Dias *et al.*, “Hyperspectral unmixing overview: Geometrical, statistical, and sparse regression-based approaches,” *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 5, no. 2, pp. 354–379, Apr. 2012.

[3] A. Plaza, P. Martinez, R. Perez, and J. Plaza, “A quantitative and comparative analysis of endmember extraction algorithms from hyperspectral data,” *IEEE Trans. Geosci. Remote Sens.*, vol. 42, no. 3, pp. 650–663, Mar. 2004.

[4] R. Heylen, M. Parente, and P. Gader, “A review of nonlinear hyperspectral unmixing methods,” *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 7, no. 6, pp. 1844–1868, Jun. 2014.

[5] A. Plaza, Q. Du, Y.-L. Chang, and R. King, “High performance computing for hyperspectral remote sensing,” *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 4, no. 3, pp. 528–544, Sep. 2011.

[6] C. Lee, S. Gasster, A. Plaza, C.-I. Chang, and B. Huang, “Recent developments in high performance computing for remote sensing: A review,” *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 4, no. 3, pp. 508–527, Sep. 2011.

[7] A. Plaza, J. Plaza, A. Paz, and S. Sánchez, “Parallel hyperspectral image and signal processing,” *IEEE Signal Process. Mag.*, vol. 28, no. 3, pp. 119–126, May 2011.

[8] S. Sánchez, A. Paz, G. Martin, and A. Plaza, “Parallel unmixing of remotely sensed hyperspectral images on commodity graphics processing units,” *Concurr. Comput. Pract. Exp.*, vol. 23, no. 13, pp. 1538–1557, Sep. 2011.

[9] L.-I. Jimenez, G. Martin, and A. Plaza, “HyperMix: A new tool for quantitative evaluation of endmember identification and spectral unmixing techniques,” in *Proc. IEEE Int. Geosci. Remote Sens. Symp.*, 2012, pp. 1393–1396.

[10] C.-I. Chang and Q. Du, “Estimation of number of spectrally distinct signal sources in hyperspectral imagery,” *IEEE Trans. Geosci. Remote Sens.*, vol. 42, no. 3, pp. 608–619, Mar. 2004.

[11] J. M. Bioucas-Dias and J. M. Nascimento, “Hyperspectral subspace identification,” *IEEE Trans. Geosci. Remote Sens.*, vol. 46, no. 8, pp. 2435–2445, Aug. 2008.

[12] J. A. Richards and X. Jia, *Remote Sensing Digital Image Analysis*, vol. 3. Berlin, Germany: Springer-Verlag, 1999.

[13] M. Zortea and A. Plaza, “Spatial preprocessing for endmember extraction,” *IEEE Trans. Geosci. Remote Sens.*, vol. 47, no. 8, pp. 2679–2693, Aug. 2009.

[14] J. C. Harsanyi and C.-I. Chang, “Hyperspectral image classification and dimensionality reduction: An orthogonal subspace projection approach,” *IEEE Trans. Geosci. Remote Sens.*, vol. 32, no. 4, pp. 779–785, Jul. 1994.

[15] M. E. Winter, “N-FINDR: An algorithm for fast autonomous spectral endmember determination in hyperspectral data,” in *Proc. SPIE Int. Soc. Opt. Photon.*, 1999, pp. 266–275.

[16] R. Neville, K. Staenz, T. Szeredi, J. Lefebvre, and P. Hauff, “Automatic endmember extraction from hyperspectral data for mineral exploration,” in *Proc. 21st Can. Symp. Remote Sens*, 1999, pp. 21–24.

[17] J. M. Nascimento and J. M. Bioucas Dias, “Vertex component analysis: A fast algorithm to unmix hyperspectral data,” *IEEE Trans. Geosci. Remote Sens.*, vol. 43, no. 4, pp. 898–910, Apr. 2005.

[18] D. C. Heinz and C.-I. Chang, “Fully constrained least squares linear spectral mixture analysis method for material quantification in hyperspectral imagery,” *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 3, pp. 529–545, Mar. 2001.

[19] M. E. Daube-Witherspoon and G. Muehllehner, “An iterative image space reconstruction algorithm suitable for volume ECT,” *IEEE Trans. Med. Imag.*, vol. MI-5, no. 2, pp. 61–66, Jun. 1986.

[20] S. Sanchez, R. Ramalho, L. Sousa, and A. Plaza, “Real-time implementation of remotely sensed hyperspectral image unmixing on GPUs,” *J. Real-Time Image Process.*, vol. 10, no. 3, pp. 469–483, Sep. 2015.

[21] S. Sanchez and A. Plaza, “Fast determination of the number of endmembers for real-time hyperspectral unmixing on GPUs,” *J. Real-Time Image Process.*, vol. 9, no. 3, pp. 397–405, Sep. 2014.

[22] J. Nascimento, J. Bioucas-Dias, J. Rodriguez Alves, V. Silva, and A. Plaza, “Parallel hyperspectral unmixing on GPUs,” *IEEE Geosci. Remote Sens. Lett.*, vol. 11, no. 3, pp. 666–670, Mar. 2014.

[23] N. Keshava and J. Mustard, “Spectral unmixing,” *IEEE Signal Process. Mag.*, vol. 19, no. 1, pp. 44–57, Jan. 2002.

[24] J. Sevilla and A. Plaza, “A new digital repository for hyperspectral imagery with unmixing-based retrieval functionality implemented on GPUs,” *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, vol. 7, no. 6, pp. 2267–2280, Jun. 2014.