

HYPERSPECTRAL IMAGERY FOR ENVIRONMENTAL URBAN PLANNING

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Abstract

A strong urban dynamic characterizes towns, a very high spatial heterogeneity of their elements, their 3D geometric shapes (horizontal and vertical) inducing shadows, and their large variety of materials. These characteristics make the collection of information of land surface properties and urban descriptors more delicate. Due to the enhancement of spatial resolution to deepen the observation of urban areas. Nevertheless, such a type of sensors would not contribute to the characterization of the urban land surface properties (chemical composition of materials, species of vegetation, quality of soils, etc.). They and show great potentials might consider Hyperspectral imagery capacities as providing useful products but it becomes mandatory to define which type of information these different sensors can deliver. The ANR HYPE project has the purpose to demonstrate the benefit of a second generation of hyperspectral space borne mission characterized by a high spatial resolution (8m GSD) and a high temporal revisit. After a detailed description of the motivation of such a proposal, applications are given focused on urban vegetation, sealed and impervious areas, solar panel area estimation.

KEY WORDS: Hyperspectral imagery, urban environment, morpho-spatial database, imagery comparison

1 - INTRODUCTION

World population is gathering more and more in urban centers inducing landscape modifications, at local and regional scales. These large urban areas are characterized by, on the one hand, a strong spread to the detriment of natural or agricultural ecosystems and, on the other hand, a densification of the urban fabric (buildings and networks) that can have derelict effects like an increase of urban pollution or urban heat islands. These two combined processes strongly affect the climate [1], but also all the environmental biotic processes [2]. Sustainability issues like livable, viable and sober urban development lead to an increasing need to understand the relations between urban system (urban fabric and activities) and biotic and abiotic compartments. Current management of urban system needs to gain in knowledge and competences to handle such complex relationships and envision future development scenarios. The knowledge is partly resting on spatiotemporal information, often heterogeneous, incomplete or out of age etc. In this case, hyperspectral data offer a real opportunity to ease such data collection [3]. Understanding the various dynamics of urban systems requires the identification and the characterization of specific observables like buildings, mineral surfaces [4],[5], fallow lands, water surfaces and vegetation [6] or aging [8]. In addition, needs for very fine urban land cover cartography have been growing very fast to answer the requirements of several environmental monitoring applications such as the measurement of pollution sources, road condition investigations, micro-climate model development, harmful material detection, smoke analysis, vegetation health analysis, etc.

In the HYPE project, we propose to develop methods, tools and services in order to monitor and measure the impact of public urban development policies based on land-cover classification and change detection products issued from hyperspectral time series. These tools are necessary to help corrective and accelerative decision making by measuring the impact of, for example:

- 1) Financial incentives for solar panel deployment;
- 2) Laws and taxes to decrease urban spreading and ground waterproofing;
- 3) Encouragements of urban biodiversity development, etc.

This presentation aims to deliver an overall view of the project (§2, §3) and some first results on three applications (§4): Urban vegetation, sealed surfaces and solar panels.

2. SCIENTIFIC PROJECT:

2.1 State of the art, advantages and limitations. From 1990, due to the advent of a large variety of new airborne or space optical sensors with a high radiometric quality at a metric or decametric GSD (Ground Sampling Distance), new urban application fields are now accessible by remote sensing. To cope with the complexity of urban areas, on the one hand very high spatial resolution multispectral systems such as Ikonos (PANchromatic PAN GSD 1m, Multispectral MS GSD 4m), Pléiades (PAN GSD 70cm, MS GSD 2.8m) are required to extract and delimit the geometry of urban object... However, the main drawback of these data is the limitation of the spectral range (limited to VIS-NIR) and of the spectral resolution to four bands that cannot give access to urban soil characterization like materials mapping, soils imperviousness assessment, vegetation and biodiversity analyses... On

the other hand, high spectral resolution hyperspectral satellite sensors allow accessing such spectral information with a lower spatial resolution (typically 30m GSD). Indeed hyperspectral sensors already exist on airborne platforms like Aviris-JPL, Sysiphe- ONERA or on space borne platforms like HYPERION (that is on the end of its life). New space hyperspectral camera programs are planned like EnMap (GSD 30 m, spectral range 0.42- 2.45 μ m with about 200 bands, [9], PRISMA (GSD 20 m, spectral range 0.4-2.5 μ m with about 210 bands,) or the next generation, proposed by France, with HYPXIM, potential launch after 2020 (GSD 8 m, spectral range 0.4-2.5 μ m with about 210 bands, with a PAN channel GSD around 2 m). [10], [11] show that urban categories identification is improved when using such features characteristics. More recently, [12] shows that a larger number of urban materials can be identified. Nevertheless, the main limitation of hyperspectral imagery is its spatial resolution. Yet, urban objects require a spatial resolution better than 5 m to achieve an accurate characterization of these objects: buildings, road, their aging [13], sparse urban vegetation [14] [15], or urban planning [16].

2.2 Assessing hyperspectral data with high spatial resolution imageries

The objective of this project is to evaluate the quality of the information extracted from these different hyperspectral sensors for urban planning and urban vegetation and biodiversity applications. The first type of applications stresses the need of regular survey of urban development considering urban sprawl, urban rehabilitation and renewal processes. The second type focuses on vegetation and biodiversity issues considered as major challenges for urban development and sustainability [6]. The benefit of a hyperspectral mission at 8m GSD for these applications has been estimated by comparing its performance to existing or planned missions like : Pleiades (Pan, MS), Sentinel2 (4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m), PRISMA, EnMap [3].

3. METHODOLOGY

3.1 Data

The first step will be devoted to the identification of urban observables characterized by their geometry accessible by a high spatial resolution sensor and their spectral signature reachable by a hyperspectral sensor. This data set is composed of two IGN / ONERA airborne acquisitions done from fall 2012 to fall 2015 over Toulouse. These experiments involve the ONERA Hypspx hyperspectral camera (GSD 1m [0.4, 1.0 μ m] and 2 m GSD [1.0, 2.5 μ m]), the IGN PAN CamV2 camera (20cm GSD). The Hypspx airborne acquisition is used to simulate at top of atmosphere the different space borne sensors with their related GSD in the different spectral bands. The images in radiance at sensor output are then corrected from the atmosphere using 2 different atmospheric correction

methods as described in [17]. As we used the same airborne acquisitions to simulate the top of atmosphere images in the different spectral bands of each sensor, all the images will be correctly registered by construction. It was supplemented by the airborne data acquired over Yakoutz (Saka Republic, Oriental Siberia) and Kaunas from 2012 to 2017 with the Themis Vision Systems 100T developed by NASA (1000 spectral bands, 0.4- 1 μ m) at a 2m GSD. This database was enriched to include the geometry and the morphology of observables using laboratory and in situ measurements, and image acquisitions.

3.2 Methods development (some)

To compare the interests of these different hyperspectral data sets on urban fabric and vegetation biodiversity, the processing tools have been adapted. Knowledge about urban land cover can be extracted from hyperspectral data using either supervised or unsupervised classification.

- The comparison of classification performances from Pleiades, Sentinel 2 and 8m/30m GSD hyperspectral space sensor highlights the benefits of the SWIR spectral range but also the complementarity of the good classification between a high spatial and multispectral image and an 8m GSD hyperspectral acquisition [17]. In addition, it has been shown that using a subset of spectral bands well adapted to a classification problem makes it possible to obtain as good results as using the whole spectrum. In return, experiments on the automatic determination of these well suited bands (position, width) for different case studies have been performed [18].

- In [19] a decision fusion was applied for classification purposes to very high spatial resolution (VHR) multispectral (MS) images (3-4 bands) and lower spatial resolution images with rich spectral configuration. MS VHR images offers a precise delineation of urban objects while hyperspectral images (hundreds of bands) offers a better characterization of these objects. A two-step decision fusion strategy was developed to merge them; it includes a per pixel fusion step followed by a contrast sensitive regularization step. Experiments were performed for a urban materials classification problem on the Toulouse data set with MS image at 1.6m GSD (RGB) and HS image resampled at 8m GSD (405 bands from VNIR-SWIR). Fuzzy "Min", "compromise" and Dempster-Shafer rules give the best results: overall accuracy (OA) increased from 71.2% for HS image alone and 69.2% for MS VHR image alone to 73.5% after fusion (Figure 1).

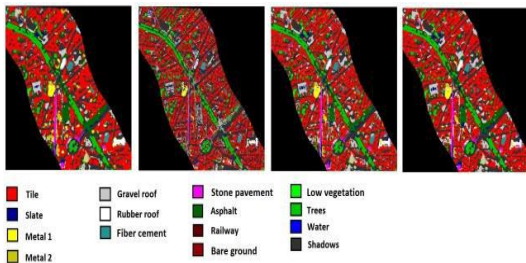


Figure 1: Classification results on Toulouse data set. From left to right; SVM classifications of HS image, of MS image, classification fusion by Compromise rule and regularized classification.

- Existing processing based on multispectral and panchromatic images has been used (supervised classification, oriented object processing or multisharpening). Multisharpening methods have been peculiarly developed to create a fused image that has both the high spatial resolution of the original multispectral image and the high spectral resolution of the original hyperspectral image. To this end, one may use spectral unmixing methods, which yields the following basic scheme. In the framework of the HYPE project, we developed two types of advanced multisharpening methods based on the above unmixing concept, by introducing specific interactions between the unmixing procedures applied to the two images. The first type of methods [20] is intended for the linear mixing model, which is used in most of the multisharpening and unmixing literature. The second type of methods [21] is targeted at the linear-quadratic mixing model, which was shown to be better suited to urban environments that are the focus of the HYPE project. Both types of methods were shown to significantly outperform algorithms from the literature. Unmixing approaches have been studied too and we theoretically and experimentally showed that usual assumptions are not relevant for the urban environments considered in the framework of the HYPE project [22]. First, each type of pure material yields significantly different spectra from one observed pixel to another, e.g. due to variations of illumination, weathering entailed by aging of material, or slightly different mineral compositions. Second, mixing in urban scenes is nonlinear (mostly linear-quadratic), due to multiple reflections of light over the considered three-dimensional structures.

4 - APPLICATIONS: URBAN VEGETATION, SEALED SOILS, SOLAR PANELS

The complexity of urban areas due to the variety of the elements and the variation among them pleads for a wider range of spectral resolution in order to define the best subset of spectral bands. Urban materials, soils, roofs, vegetation strata and species, sealed soil etc., each of these elements can be detected, discriminated and recognized through a defined set of values. Using hyperspectral data provides many more

data on urban elements leading to a better recognition and identification of objects on urban areas. In order to test the various results of the methods developed with our civil servants partners of the Toulouse Metropole (F) three topics have been selected and developed in the project:

4.1 Urban Vegetation

Using a GIS, a marked point process approach has been developed to detect individual trees in urban alignment from airborne data and contextual information (Figure 2)

4.2 Sealed soils participate in the general climatic situation but multispectral data cannot provide a difference between nude soils or asphalt, while this might be reachable with hyperspectral data. High spatial resolution images provide detailed information about the scene objects, in this context, exploiting the objects form in addition to their spectral characteristics, could enhance the recognition and detection process of built-ups.

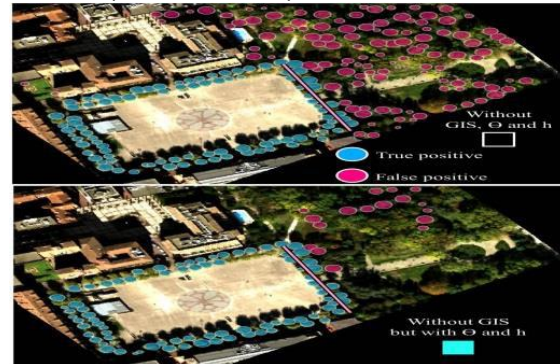


Figure 2: Detection of aligned tree around a square in Toulouse (in blue: true positive, in red false positive).

A 16 bands image with 0.7m GSD, acquired over the city of Kaunas (city center) using a SVM classification by spectral library was carried in a first step to detect the main roof materials [24] (Figure 3)

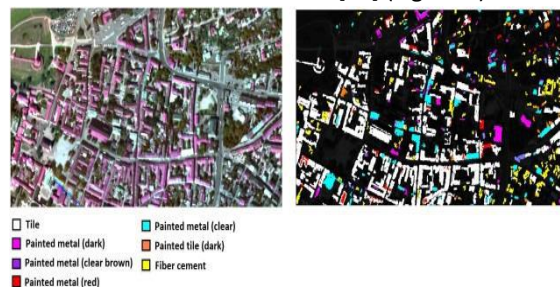


Figure 3: RGB portion of Kaunas image, b) classification by spectral library using full spectral range, c) classification by spectral library using selected bands, and d) classification by spectral library using selected bands, and regularization step.

4.3 Solar panels

The number of operating photovoltaic panels has been increasing rapidly in recent years. Government

agencies and electricity grid operators support their development and therefore need to evaluate their actual locations and areas. Field surveys may be used to this end, but they are costly and time consuming. Faster and less expensive methods are therefore sought. In this framework, hyperspectral data offer an alternative. Hyperspectral unmixing techniques are required to unmix the observed spectra, especially in order to estimate the mixing coefficients that define the locations and areas of photovoltaic panels. In the framework of the HYPE project, we tackled this problem by using two approaches [25]: first applying a standard hyperspectral unmixing method, with a very poor performance and secondly developing an original extension of the above method, which takes advantage of partial knowledge about the spectra of photovoltaic panels. This method yields much better performance.

4. DISCUSSION AND CONCLUSION

The HYPE project has offered to all partners opportunities to deepen common knowledge on hyperspectral data and their interest for urban applications. It has also provided a better understanding of the performances that might be obtained. A final report is ongoing, due September 2018.

REFERENCES

- [1] Shafri et al., 2012, Hyperspectral Remote Sensing of Urban Areas: An Overview of Techniques and Applications, *Research Journal of Applied Sciences, Engineering and Technology* 4(11): 1557-1565.
- [2] Voogt, J.A., & Oke, T.R., 2003, Thermal remote sensing of urban climates. *Remote Sensing of Environment*, 86, 370–384.
- [3] Heldens W., U. Heiden, T. Esch, E. Stein and A. Muller, 2011, Can the Future EnMAP Mission Contribute to Urban Applications? A Literature Survey *Remote Sens.* 2011, 3, 1817-1846; doi:10.3390/rs3091817
- [4] Heiden, U.; Segl, K.; Roessner, S.; Kaufmann, H. Determination of robust spectral features for identification of urban surface materials in hyperspectral remote sensing data. *Remote Sens. Environ.* 2007, 111, 537– 552.
- [5] Weng, Q.; Hu, X.; Lu, D. Extracting impervious surfaces from medium spatial resolution multispectral and hyperspectral imagery: A comparison. *Int. J. Remote Sens.* 2008, 29, 3209–3232.
- [6] Heiden, U.; Segl, K.; Roessner, S., 2003, Kaufmann, H. Ecological Evaluation of Urban Biotope Types Using Airborne Hyperspectral HyMap Data. In *Proceedings of the 2nd GRSS/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas*, Berlin, Germany, pp. 18–22
- [7] M. Alonzo, B. Bookhagen, Dar A. Roberts, 2014, Urban tree species mapping using hyperspectral and lidar data fusion. *Remote Sensing of Environment* 148:70–83 <https://doi.org/10.1016/j.rse.2014.03.018>
- [8] Miller R. & C. Small, 2003, Cities from space: potential applications of remote sensing in urban environmental research and policy. *Environmental Science & Policy* 6: 129–137. doi:10.1016/S1462- 9011(03)00002-9
- [9] Xu W., Wooster M.J., Grimmond C.S.B., 2008, Modelling of urban sensible heat flux at multiple spatial scales: a demonstration using airborne hyperspectral imagery of Shanghai and a temperature-emissivity separation approach, *Remote Sensing of Environment*, 112: 3493-3510
- [10] Cavalli, R.M et al., 2008, Hyperspectral sensor data capability for retrieving complex urban land cover in comparison with multispectral data: Venice City case study (Italy). *Sensors* 2008, 8, 3299–3320.
- [11] Herold M., N. C. Goldstein, K. C. Clarke, 2003, The spatiotemporal form of urban growth: measurement, analysis and modeling. *Remote Sensing of Environment* 86:286–302. doi:10.1016/S0034-4257(03)00075- 0
- [12] Pascucci S. et al., 2010, Hyperspectral remote sensing capability for mapping near-surface asbestos deposits and pollutants dispersion in soils, *Proc. Hyperspectral 2010 Workshop*, Frascati, Italy, (ESA SP-683, May 2010)
- [13] Herold M., Roberts D. 2005, Spectral characteristics of asphalt road aging and deterioration: implications for remote-sensing applications, *Applied Optics*, 44:4327-4334.
- [14] Weng Q., Quattrocchi D.A., 2007, *Urban Remote Sensing*, CRC Press, 432 pp.
- [15] Jensen R.R., et al., 2012, Classification of urban tree species using hyperspectral data, *Geocarto International*, 27:443-458.
- [16] Wania A., Weber C., 2007, Hyperspectral imagery and urban green observation, in *Proc. Urban Remote Sensing Joint Event*, 11-13 April 07, pp. 1-8
- [17] Roussel G., C. Weber, X. Briottet & X. Ceamanos, Comparison of two atmospheric correction methods for the classification of spaceborne urban hyperspectral data depending on the spatial resolution, *IIRS*, Volume 39, 2018 - Issue 5, Pages 1593-1614, <https://doi.org/10.1080/01431161.2017.1410247>
- [18] Le Bris A., N. Chehata, X. Briottet, N. Paparoditis, 2016, Spectral band selection for urban material classification using hyperspectral libraries. *ISPRS Annals DOI: 10.5194/isprs-annals-III-7-33-2016*
- [19] Ouerghemmi W., A. Le Bris, N. Chehata, C. Mallet, A two-step decision fusion strategy: application to hyperspectral and multispectral images for urban classification, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-1/W1, 167-174, 2017.
- [20] Karoui M. S., Y. Deville, F. Z. Benhalouche, I. Boukerch, "Hypersharpener by Joint-Criterion Nonnegative Matrix Factorization", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 55, no. 3, pp. 1660-1670, March 2017.
- [21] Benhalouche F. Z., M. S. Karoui, Y. Deville, A. Ouamri, "Hyperspectral and multispectral data fusion based on linear-quadratic non negative matrix factorization", *Journal of Applied Remote Sensing*, 11:2, pp. 025008-1-18, Apr-Jun 2017.
- [22] Revel C., Y. Deville, V. Achard, X. Briottet, "Inertia-Constrained Pixel-by-Pixel Nonnegative Matrix Factorisation: a Hyperspectral Unmixing Method Dealing with Intra-class Variability", <https://arxiv.org/abs/1702.07630>
- [23] Benhalouche F. Z., Y. Deville, M. S. Karoui, A. Ouamri, "Hyperspectral endmember spectra extraction based on constrained linear-quadratic matrix factorization using a projected gradient method", *Proceedings of the 2016 IEEE International Workshop on Machine Learning for Signal Processing (MLSP 2016)*, pp. 1-6, Salerno, Italy, Sept. 13-16, 2016.
- [24] Ouerghemmi W., S. Gadai, G. Mozgeris, D. Jonikavičius and C. Weber, "Urban objects classification by spectral library: Feasibility and applications," *2017 Joint Urban Remote Sensing Event (JURSE)*, Dubai, 2017, pp. 1-4.
- [25] Karoui M. S., F. Z. Benhalouche, Y. Deville, K. Djerriri, X. Briottet, A. Le Bris, "Detection and area estimation for photovoltaic panels in urban hyperspectral remote sensing data by an original NMF-based unmixing method", submitted to the 2018 IEEE International Geoscience and Remote Sensing Symposium, Valencia, Spain, July 23-27, 2018

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