INTRODUCING DLR HYSU - A BENCHMARK DATASET FOR SPECTRAL UNMIXING

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ABSTRACT

The DLR HyperSpectral Unmixing (DLR HySU) open benchmark dataset includes airborne hyperspectral and RGB imagery of targets of different materials and sizes on a homogeneous background, complemented by simultaneous ground-based reflectance measurements. The dataset allows assessing dimensionality estimation, endmember extraction with and without pure pixel assumption, and abundance estimation in the frame of spectral unmixing applications, enabling estimations at sub-pixel level. This paper presents the first works in the literature using the dataset, which demonstrate that DLR HySU is filling a gap regarding validation using real imaging spectrometer data with accurately measured targets.

***Index Terms*—** Spectral unmixing, benchmark dataset, dimensionality reduction, endmember extraction, abundance estimation, HySpex.

1. INTRODUCTION

The process of spectral unmixing aims at providing accurate information at sub-pixel level on a hyperspectral scene, by decomposing the spectral signature associated with an image element in signals typically belonging to macroscopically pure materials, or endmembers. The unmixing process is applied regularly within a wide range of research fields, ranging from classification and target detection to generic denoising and dimensionality reduction techniques. However, there is a lack of publicly available reference data sets suitable for the validation and comparison of different spectral unmixing methods. The usual assessments performed in literature on the different steps composing the spectral unmixing workflow (dimensionality estimation, endmember extraction, abundance estimation) are carried out either on synthetic datasets, either on images not having an associated ground truth at sub-pixel level. For the latter case, detected materials and their degree of mixture are usually matched against results obtained by other researchers applying state-of-the-art algorithms [1].

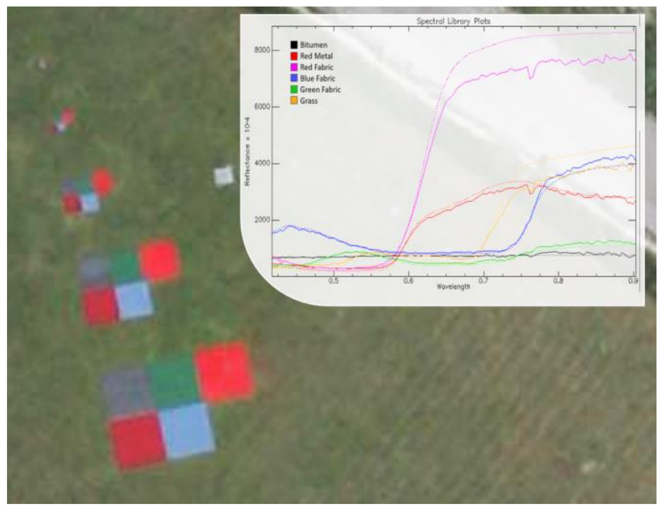

Figure 1. High resolution RGB image (3K sensor) acquired over the targets of five different materials (bitumen, red metal, red fabric, blue fabric, green fabric) deployed over grass. The square targets have a side ranging from 0.25 m to 3 m. In the insert, spectra from airborne imaging spectrometer data (HySpex) available for the same area and spectrometer (SVC) measurements are shown.

The openly available DLR HySU dataset aims at providing an easy to assess scenario employing real imaging spectrometer data for the evaluation of spectral unmixing algorithms. This is achieved by providing the exact size of materials deployed in different configurations within the scene, mixed on a homogenous background.

2. THE DATASET

The DLR HyperSpectral Unmixing (DLR HySU) benchmark dataset (Fig. 1) includes a high-resolution airborne image acquired by the HySpex spectrometer in the visible and near infrared (VNIR) range, completed by high-resolution airborne 3K RGB data, and in-situ SVC spectrometer measurements [2].

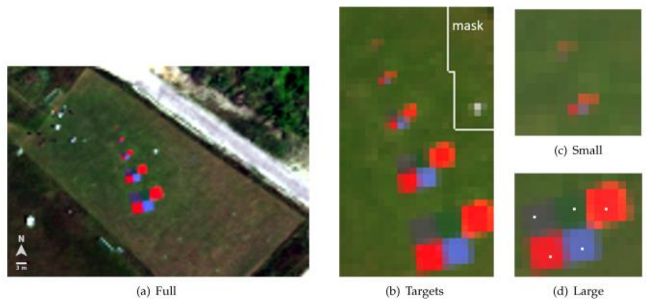

Figure 2. True color composites of HySpex subsets provided in the DLR HySU benchmark dataset: whole scene (a), targets and grass only with additional materials masked out (b), small 0.25 and 0.5 m targets (c), and large 3 m targets (d) with locations for spectra reported in the insert of Fig. 1.

The area of interest, acquired over German Aerospace Center (DLR) premises in Oberpfaffenhofen, contains five synthetic targets of different materials in five different known sizes, deployed on ground in a homogeneous area. The materials include: bitumen, red metal sheets, red fabric, blue fabric, and green fabric. The grass in the background represents the sixth material. The data are further organized in subsets, each of which is aimed at testing specific steps in the unmixing process, for facilitated usage, namely: whole scene, targets and grass with additional materials masked out, large targets, and small targets (Fig. 2). The measurements carried out in situ with a SVC spectrometer on the targets of interest well agree with the spectral measurements related to pure pixels in the HySpex scene (insert in Fig. 1). The dataset has a total size smaller than 5 MB, and is openly available at [3].

3. EVALUATION OF SPECTRAL UNMIXING ALGORITHMS

Results obtained with traditional algorithms for dimensionality estimation, endmember extraction with and without pure pixel assumption, and abundance estimation are reported in [2]. The largest targets, having a size of 3 m x 3 m, ensure the presence of pure pixels in the HySpex dataset which has a ground sampling distance of 0.7 m. As the background is homogeneous, endmember extraction methods with pure pixel assumption can thus be evaluated. On the other hand, the smallest sets of targets occupy only a fraction of an image element in HySpex, allowing evaluating endmember extraction methods without pure pixel assumption, and assess abundance estimation algorithms for difficult cases. For medium and large sized targets, the evaluation of abundance estimation algorithms cannot be assessed for individual pixels, but can be succesfully carried out by matching the total area assigned to a material in a small neighbourhood with the total size of the target across several image elements. The most relevant results include an average error slightly above 2% for the estimation of the total areas for the large targets, and around 20% for the hardest case of the small targets. This appears particularly difficult, as a small target occupies only the 15% approximately of a single image element in the HySpex scene.

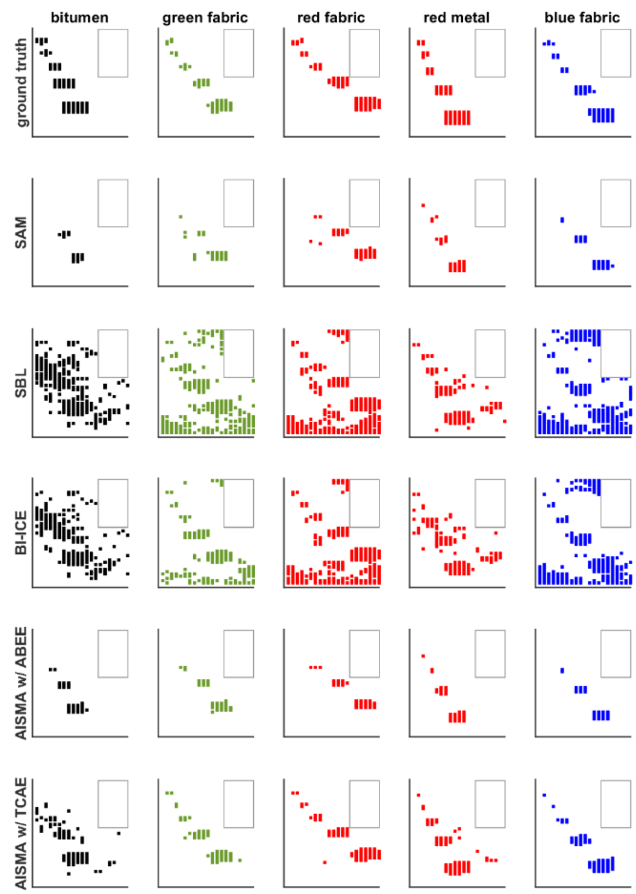

Figure 3. Graphical representation from [4] of abundance of each material in different locations of the image and prediction of different algorithms on the composition of the targets.

The application of state-of-the-art methods to the presented dataset resulted in additional interesting observations. Among them, the drawbacks of enforcing the sum-to-one constraint in least square-based abundance estimation, which can introduce large distortions for targets occupying only a small portion of an image element. Furthermore, the exact equivalence of LASSO and Non-negative Least Squares is reported for a relevant number of cases.

Despite the relative simplicity of the targets arrangement, the described mixing scenarios result more accurate with respect to the ones currently available in the literature, as the surface area of all targets of different materials is known, and no additional materials are present in the scene, enabling a precise assessment of algorithm performances. Further areas of research which can benefit from the DLR HySU dataset include denoising and target/anomaly detection, with the latter being enabled by additional small hidden targets which are placed in the scene over different backgrounds.

4. FIRST WORKS USING DLR HYSU

First published works using DLR HySU as benchmark dataset report different and more accurate validation procedures using the provided real imaging spectrometer data with accurately measured targets, with respect to traditional assessments carried out on synthetic data or compared to results obtained by state of the art algorithms. In [4], authors rely on DLR HySU, in addition to other benchmark dataset, to assess elbow estimation for the selection of the best solution in multiobjective sparse unmixing algorithms. In [4, Fig. 15], here reported in Fig. 3, the performance of different algorithms is assessed according to the reported decomposition in terms of the materials of interest for targets of different size. In the same work, authors also conclude that typical datasets used as benchmark for spectral unmixing applications do not provide ground truth maps, as they are the output of certain algorithms rather than in situ measurements, and should not be considered as such.

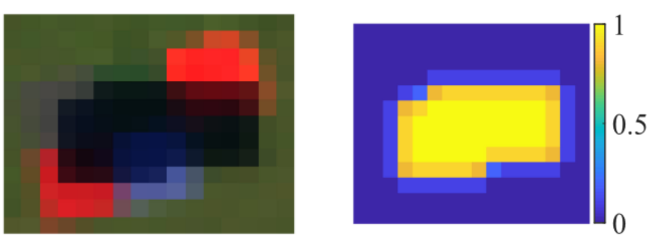

Figure 4. Left: simulation of shadows cast over the large targets of the DLR HySU dataset (true color combination) from [4], used to validate shadow removal algorithms. Right: shadows map.

In [5] (sharing two co-authors with this paper), the dataset is used to assess shadow-restoration algorithms by simulating hard and soft shadows over the large targets: the reconstruction error can then be accurately measured after applying shadow compensation algorithms.

The dataset has bene mentioned as a help in understanding spectral unmixing processes, requiring hyperspectral images acquired with pixel-level knowledge-based ground-truth maps, crucial for shedding light on theoretical considerations and practical implications [6]. It has also been featured in recent overviews on available benchmark datasets [7], where it is reported as the only unmixing dataset. Finally, it is featured in academic online repositories of remote sensing benchmark datasets such as [8].

5. CONCLUSIONS

The DLR HySU dataset consists of a single hyperspectral image of 86x123 pixels acquired in the visible and near infrared range acquired by the airborne HySpex sensor with a ground sampling distance of 0.7 meters. The area of interest comprises five different materials: bitumen, red metal, blue fabric, red fabric, and green fabric, each present in different sizes, namely squares having a side of 0.25, 0.5, 1, 2, and 3 meters. Furthermore, different mixing scenarios are simulated by accordingly distributing the synthetic targets over a uniform background. The image is complemented by selected subsets, including only small (12x12 pixels) or large targets (13x16 pixels). Additionally, measurements carried out in situ with a SVC spectrometer on the targets of interest and a high resolution RGB image simultaneously acquired by the 3K sensor are provided. The main targeted applications are dimensionality estimation, endmember extraction with and without pure pixel assumption, and abundance estimation. Besides, this dataset could also be exploited to test target detection and denoising. Regarding the former, additional small targets have been scattered in the area of interest and are described in the paper. The latter can use the in-situ collected spectra as reference to verify denoising procedures on single targets, especially for bitumen which is characterized by a flat spectrum. Finally, the included higher resolution RGB image can be used to test image fusion and super-resolution methods.

To the best of our knowledge, this is the first time that real imaging spectrometer data with accurately measured targets are made available for hyperspectral unmixing experiments. First works in literature confirm the new and more accurate evaluation for the performance of algorithms with respect to traditional datasets [1], whenever the exact size of a target on ground needs to be estimated, not only limited to spectral unmixing as confirmed by [5]. The DLR HySU benchmark dataset is openly available online [3] and the community is welcome to use it for spectral unmixing, target detection, and other applications.

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