SHARE 2012: Large Edge Targets for Hyperspectral Imaging Applications

Kelly Canham, Daniel Goldberg, John Kerekes, Nina Raqueno, and David Messinger
Center for Imaging Science
Rochester Institute of Technology
54 Lomb Memorial Dr.
Rochester, NY, 14623 USA

ABSTRACT

Spectral unmixing is a type of hyperspectral imagery (HSI) sub-pixel analysis where the constituent spectra and abundances within the pixel are identified. However, validating the results obtained from spectral unmixing is very difficult due to a lack of real-world data and ground-truth information associated with these real-world images. Real HSI data is preferred for validating spectral unmixing, but when there is no HSI truth-data available, then validation of spectral unmixing algorithms relies on user-defined synthetic images which can be generated to exploit the benefits (or hide the flaws) in the new unmixing approaches. Here we introduce a new dataset (SHARE 2012: large edge targets) for the validation of spectral unmixing algorithms. The SHARE 2012 large edge targets are uniform 9m by 9m square regions of a single material (grass, sand, black felt, or white TyVek). The spectral profile and the GPS of the corners of the materials were recorded so that the heading of the edge separating any two materials can be determined from the imagery. An estimate for the abundance of two neighboring materials along a common edge can be calculated geometrically by identifying the edge which spans multiple pixels. These geometrically calculated abundances can then be used as validation of spectral unmixing algorithms. The size, shape, and spectral profiles of these targets also make them useful for radiometric calibration, atmospheric adjacency effects, and sensor MTF calculations. The imagery and ground-truth information are presented here.

Keywords: Hyperspectral, ground-truth, and SHARE 2012

1. INTRODUCTION

Ground-truth information is needed to validate many image processing techniques and to calibrate aerial and space-based sensors. Acquiring ground-truth information is an extensive task in both time and money. During September of 2012, a large ground-truthing campaign was conducted at Avon, NY, by the Digital Imaging and Remote Sensing (DIRS) Laboratory (see Figure 1 for an overview of the Avon site). During this campaign targets for spectral unmixing, radiometric calibration, unique signatures, and several other tests were deployed. The campaign lasted one day and was imaged by over four different aerial sensors and two space-based sensors. Two of the many targets deployed during this experiment were a set of large (9m square) bright and dark tarps that neighbored grass and sand background materials. These targets can be used for many different purposes including radiometric calibration, spectral unmixing, atmospheric adjacency analysis, and MTF calculations. Here we describe these large targets and possible uses for them.

Ground-truth material spectral libraries have been generated for a handful of sites around the world. Two of the most well-known images that have extensive ground-truth and/or spectral libraries are Cuprite, Nevada, and Indian Pines, Indiana. These two datasets are featured extensively as a means of improving or validating new algorithms. This is because these two sites have freely available imagery and ground-truth information. The data were imaged by the HSI AVIRIS sensor and the ground-truth data were collected on the day of collection. SHARE 2012 data can be included in this short-list of validation imagery once the data have been made available to the scientific community.

Further author information: (Send correspondence to Kelly Canham or David Messinger.)
Kelly Canham: E-mail: kac7669@rit.edu
David Messinger: E-mail: messinger@cis.rit.com, Telephone: +1 585 475 4538
This paper is separated such that Section 2 discusses the targets themselves, Section 3 discusses the natural materials surrounding the targets, Section 4 briefly describes the some of the applications which can use the targets and associated imagery, and Section 5 discusses how these targets will be used in future work within the DIRS Laboratory.

2. SHARE 2012 LARGE TARGETS

During the SHARE 2012 field campaign three large targets (or tarps) were deployed; one black felt, one white TyVek®, and one gray felt. The uniformity of the black target was measured prior to SHARE 2012 by using an ASD spectroradiometer with the bare-fiber held approximately 1m above the target so that the area measured covered a 1m area (including a portion of the operators legs and feet). Seven transects were completed on the black felt target; each transect was spaced approximately 1.5m from the previous transect and a total of 10 spectral files were saved and each file consists of 10 averaged spectra (for a total of 100 individual spectral measurements during each transect). Averaging all of the relative spectral reflectance from this uniformity analysis gives the average spectral reflectance profile of the target as shown in Figure 3. Additionally, a covariance plot of the spectral information was compiled and is presented in Figure 2(b). This covariance matrix calculates the spectral covariance between each of the 70 (seven transects with 10 spectral files) reflectance measurements to all the others collected over the entirety of the tarp. A spectral angle metric (SAM) was also computed between all the spectra, and the resulting SAM matrix is shown in Figure 2(c). The black diagonal line in Figure 2(c) represents an exact spectral match (or a SAM of 0.0) and white represents a SAM value of 0.248. This uniformity analysis was collected on a clear Rochester day with the tarp laid out on top of a gray asphalt parking lot and may be subject to minor atmospheric conditions. A 4in square Spectralon white reference was used to optimize the ASD and convert the input radiance measurements into relative reflectance. Similar uniformity measurements will be conducted for the white and gray tarps as future work (dependent on clear Rochester weather conditions).

All three large targets deployed during SHARE 2012 measured 9m by 9m (with an error of no more than 10cm deviation from the 9m requirement). The size was determined so that each target was approximately nine pixels along an edge for a 1m GSD sensor (such as a panchromatic image from Quickbird or IKONOS or from the SpecTIR HSI aerial sensor flown at an altitude of approximately 2500ft). The size was selected to guarantee at least one pure material pixel at the center of each target while at the same time containing enough edge pixels to be used in a novel spectral unmixing approach. The material of each target was selected to be spectrally flat and to span the dynamic range of most remote sensing sensors. The ground-truth data from SHARE 2012 shows the black felt has an average reflectance value of 7%, the white TyVek has an average reflectance value of 81%, and the gray tarp has an average reflectance of 26% over the
visible through SWIR wavelengths (400-2500nm). Figure 3 shows the SHARE 2012 average spectral profiles for each of the targets (black, gray, and white). The average spectral profiles are a result of averaging 100 individual spectra from the same material together and were collected for an approximate 6cm diameter spot size (using a 3°fore-optic positioned approximately 1m above the ground/target).

The layout of the three large targets during SHARE 2012 was carefully considered so that multiple analyses could be performed using the same targets. The gray tarp was positioned in a parking lot that was covered in old gravel and asphalt. The black and white targets were positioned side-by-side to form a highly contrasting straight edge between them. It was determined that the large contrasting targets should be placed in a location such that multiple background materials would form an edge with the targets. As such, a sand volleyball pit surrounded by a grass field within the Avon park was determined to be the ideal location for the black and white target. The placement of these two targets allowed for two edges of the black target to be adjacent to grass, one edge of the white tarp to be adjacent to the grass, one edge of the black tarp to be adjacent to sand, and two edges of the white tarp to be adjacent to sand (as seen in Figure 1).

The edge between the black and white targets was positioned so that it falls at a heading of approximately 11° from the originally planned SpecTIR sensor’s flight-line. This angle is needed for both the novel spectral unmixing validation approach as well as for MTF calculations, but deviations from this angle occurred due to wind conditions during overflight. Due to the wind’s impact on the actual flight-line, measured GPS coordinates of the targets are more important than originally planned. The GPS coordinates for the eight corners (two of which are duplicated along the black-white edge) are presented in Table 1. From this information and the imagery, validation of the orthorectication process can be completed as well as determining the exact angle of the black-white edge in the imagery.
3. BACKGROUND MATERIALS

The placement of the black and white large tarps in relation to the background materials was determined so that the different material edges can be used for both a novel spectral unmixing validation approach as well as a means to quantify the atmospheric adjacency effect and MTF calculations. During SHARE 2012 field work, the reflectance of each of these background materials was measured. The same number of spectra were collected for the background materials as were collected for the targets (100 spectra) using the same collection configuration (6cm spot size). During the spectral collection process large swaths of these background material areas were walked so that spatial variability could be considered within the different materials.

The sand proved to be a good medium upon which to stake the targets because lawn stakes were easy to fasten and remove and the sand could be raked to form a flat surface upon which to layout the targets. During a test deployment, it was determined that footprints and water content within the sand (due to recent rain and dew) caused undesirable BRDF affects, therefore a large area (approximately 10m by 20m), south of both the black and white targets, was raked prior to imaging and reflectance measurements. By raking the sand a more uniform area with consistent BRDF was achieved, as can be seen in Figure 6(b). Some of the sand spilled over into the surrounding grass which will cause mixed materials when performing spectral unmixing. Therefore, when compiling the grass spectral reflectance, the grass region spectrally measured was located approximately 2m away from the sand volleyball pit, thus reducing the amount of sand present in the spectral measurements, but also keeping the type, color, and health of the grass even with the grass located right on the sand pit edge.
Figure 4. Digital photos of all three targets during SHARE 2012 ground-truth collect. Figure 4(a) shows the black tarp deployed in the volleyball pit, Figure 4(b) shows the white tarp deployed in the volleyball pit, and Figure 4(c) shows the gray tarp laid out over parking lot gravel.

4. APPLICATIONS FOR SHARE LARGE TARGETS

There are many applications for which the large SHARE targets can be used. These include vicarious radiometric calibration, automatic gain correction, spectral unmixing, atmospheric adjacency effects and analysis, Modulation Transfer Function calculation, and geo-correction to name a few. The following sections discuss how spectral unmixing validation could use the available large target data as well as touching upon vicarious radiometric calibration. However, this is not the limit to this dataset, as noted by the lengthy list of applications before.

4.1 Spectral Unmixing

Spectral unmixing methods identify and separate the constituent materials (or endmembers, EMs) within a single HSI pixel. EM spectra and EM abundance maps are the results of spectral unmixing. Most spectral unmixing is based on a linear mixture model where the pixel spectrum $x$ is approximated as a linear combination of the $N$ different EMs $(e)$ and their abundances $(\alpha)$,

$$x \approx \hat{x} = \sum_{i=1}^{N} \alpha_i e_i. \quad (1)$$

However, without a spectral library (or truth data) which associates the EM spectra to known materials, it is not possible to convert the unmixed EM abundance maps into material abundance maps. Additionally, validating most of the steps involved in spectral unmixing is a challenging topic, for which this SHARE dataset can be used.
During the identification and extraction of the EMs in spectral unmixing, the EMs are considered to be the pure materials in the imagery. This is because the linear mixture model identifies the EMs as the corners of the convex hull and all other pixels which fall within the hull corners are a combination of the EMs. However, how do we validate that the extracted EM (or material distribution) is the correct pure pixel (or distribution)? Using a small image chip extracted to include the region around the black and white targets in the SHARE SpecTIR dataset (see Figure 5), it is easy to identify the black tarp, white tarp, grass, and sand. Outlines of the pure material regions can be made by using the GPS data and ground-truth photos, and for the black and white tarp it would seem logical to assume that the center of these tarps would contain the purest pixel (or the endmember) for these two materials. Therefore, if endmember extraction routines are applied to this image chip and do not pick out the center pixel of the black and white tarps further investigation needs to be conducted on why these two approaches for determining single pixel purity do not agree (see Figure 7 where the SMACC algorithm is used and three EMs are found not corresponding to the center of the tarps). Additionally, after finding the EMs, statistical analysis can be applied to determine how similar the EMs are to the average ground-truth material spectra or where the EM falls within the ground-truth spectral distribution of that material; in other words, how well does a single pure EM represent the material distribution.

4.2 Vicarious Radiometric Calibration

Vicarious radiometric calibration is a method for monitoring the operational status of a sensor. It also allows for multiple sensors to be cross-calibrated to each other. However, to accomplish vicarious radiometric calibration, the absolute radiance from a target must be known on the ground and the atmosphere through which the radiance travels must also be well-behaved, understood, and modeled. The black and white targets can be used to establish the brightest and darkest materials in the Avon scene. As such the dynamic range of each imaging sensor can be stretched to fully span both of these targets. Using the multiple temporal radiance measurements made of the large targets (one in the morning at 10:15am and a second at 2:30pm), the full day’s worth of constant-panel full-sky radiance measurements (stationed near the large gray target), and the two radiosonde data collections, the absolute radiance being reflected by the three large targets can be computed using an atmospheric ray tracing program like MODTRAN. Additionally, these radiance values can be propagated through the atmosphere to compute top-of-the-atmosphere radiance values which can be compared to the different imaging sensors. By this method the error in radiance that each sensor observed can be determined and cross-calibrated amongst each other. Additionally, because of using multiple large targets (each with a different uniform reflectance value) any gain correction needed to be applied to the sensors can be identified as well. The only draw back to the data provided is that the targets only...
Figure 6. Digital photos of the background materials for the large targets. Figure 6(a) shows the grass surrounding the volleyball pit, Figure 6(b) shows the sand within the volleyball pit while it is being raked, and Figure 6(c) shows the gravel upon which the gray tarp was placed.

cover a small region of the image and so the sensors’ non-uniformity can not be quantified. Similar vicarious calibration approaches which have used large dry lake beds (instead of and in addition to large uniform tarps) have been applied to several space-based and aerial-based sensors in the past, including Landsat 4-7, SPOT, AVIRIS, MODIS, MASTER, and CHRIS.11–13

5. FUTURE WORK AND CONCLUSIONS

As discussed there are several tasks which can be performed with the large targets collected during SHARE 2012. At this time the basic analysis of the data needed to extract useful image chips and perform quick-check calculations have been completed. Orthorectification of the images needs to be performed before further analysis is conducted. A new spectral unmixing validation approach also needs to be looked at with the ortho-rectified data which may make it possible to know with better accuracy the true abundances of mixed pixels along the straight edges between the large targets. Additional uniformity of the white and gray tarps needs to also be completed. Conversion of the ground-truth relative reflectance data must also be converted to absolute reflectance by removing any spectralon panel spectral effects.

Ground-truth datasets like Indian Pines and Cuprite AVIRIS images are needed for algorithm development and validation. The SHARE 2012 dataset contains many different types of targets and materials for many different tests, algorithms, experiments, etc. Here focus was on the large targets deployed in the volleyball pit and on the gravel parking lot within the Avon, NY, park. Three tarps were deployed (black, white, and grey). The spectral and physical properties of each of these tarps have been discussed. The black and white tarp were originally planned to be used for a novel spectral unmixing validation algorithm, but have been determined to also be useful for other applications including vicarious radiometric

Proc. of SPIE Vol. 8743 87430G-7
Figure 7. Figure 7(a) shows RGB image of small HSI chip extracted from SpecTIR SHARE 2012 data, Figure 7(b) shows the four ROIs user defined pure pixels, Figure 7(c) shows the three EMs extracted using SMACC not including the shade EM, and Figure 7(d) shows the pixel distribution for the RGB HSI chip with 450nm (axis labeled as 34), 550nm (axis labeled as 56), and 750nm (axis labeled as 77).
calibration, MTF calculation, atmospheric adjacency effects, and several others. As soon as possible all of this data will be made available to the scientific community, at which point it becomes up to the many users what they can do with such targets.

REFERENCES