An Analysis Task Comparison of Uncorrected vs. Geo-registered Airborne Hyperspectral Imagery
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ABSTRACT
Geo-registration is the task of assigning geospatial coordinates to the pixels of an image and placing them in a geographic coordinate system. However, the process of geo-registration can impair the quality of the image. This paper studies this topic by applying a comparison methodology to uncorrected and geo-registered airborne hyperspectral images obtained from the RIT SHARE 2012 data set. The uncorrected image was analyzed directly as collected by the sensor without being treated, while the geo-registered image was corrected using the nearest neighbor resampling approach. A comparison of performance was done for the analysis tasks of spectral unmixing and subpixel target detection, which can represent a measure of utility. The comparison demonstrates that the geo-registration process can affect the utility of hyperspectral imagery to a limited extent.

Keywords: hyperspectral image; geo-registration; performance comparison; unmixing; subpixel target detection

1. INTRODUCTION
Geo-registration can be an essential step in remote sensing image analysis. The RIT SHARE 2012 data collection provided a set of remote sensing data and accompanying ground truth for several different ground experiments\(^1,2\). These data provide a good test for the study of the impact of georegistration on an analysis task. In remote sensing, it is generally recognized that every pixel (even at the one meter scale of these data) is a mixture of multiple materials or cover types of interest. Thus one application for the analysis of hyperspectral imagery is that of unmixing which is defined as the process that separates the pixel spectra from a hyperspectral image into a collection of constituent spectra, or signatures, called endmembers and their proportions within a pixel\(^3\). Similarly, the limited spatial resolution but large number of spectral channels also leads to the application of subpixel target detection, which refers to the ability to detect the spatially unsolved material or target using the target spectral information\(^4\). With the help of these two applications, the quality of hyperspectral image can be studied.

This paper provides a comparison in terms of spectral unmixing and subpixel target detection performance between geo-corrected imagery and uncorrected imagery. The acquisition and processing of these images are presented as below.

1.1 Airborne Imagery
As part of a comprehensive data collection in September 2012, aircraft equipped with multiple sensors flew over the area of Avon, NY, executing an experiment referred to as the “SpecTIR Hyperspectral Airborne Experiment”. Many different kinds of data were collected including high-resolution visible, infrared, hyperspectral and lidar imagery. High resolution imagery were acquired by RIT’s “Wildfire Airborne Sensor Program” (WASP) sensor, which includes four cameras capable of capturing color imagery in the visible region (400-700 nm) of the spectrum, as well as the short-wave infrared (1100-1700 nm), mid-wave (3000-5000 nm), and long-wave (8000-9200 nm) regions of the spectrum. The color (RGB) image from this sensor is 4000*4000 pixels and has a resolution of approximately 4 inches (0.1m) from a height of 2000 feet above level. This image provides a high-resolution image suitable for visual identification of the targets and other test objects in the scene. The main source of data for this research was hyperspectral imagery acquired with SpecTIR, LLC’s ProSpecTIR-VS sensor. This sensor collected imagery with 360 bands ranging from 400 to 2450 nm with a spatial resolution of 1 meter for this collection. These images were made available in both radiance and reflectance formats.
Figure 1 presents RGB composites of the uncorrected and geo-registered HSI data. It is obvious that the uncorrected image has distortions in the spatial layout of the imager. Reasons for this can include aircraft movement or buffeting from winds during the image acquisition process. Also, in this uncorrected format, the airborne image acquired from the sensor does not include with map coordinates for each pixel. Analysis can be performed on uncorrected imagery like this, but then for the information to be used in an application, one usually needs to apply geo-correction to be able to map each pixel to a known geographic coordinate.

![Uncorrected Image](image1.png) ![Corrected Image](image2.png)

Fig. 1 Uncorrected and Geo-corrected reflectance images of the test scene.

Geo-correction of imagery is defined as associating each pixel in an image with locations in physical space and resampling to a regular grid in that space. In other words, it defines the relationship between rows and columns of the hyperspectral image in a raster map and a ground XY-coordinate. Geographic Lookup Table (GLT) files can bridge the two coordinate systems together. A GLT file contains the ground map location for every pixel of the image. There are two bands in GLT: sample numbers and line numbers of the georeferenced image. With a GLT file, nearest neighbor algorithm can be applied to geo-correct the image. This process is illustrated as shown in Fig. 2, where dashed black lines and black dots represent input pixels and red solid lines and red plus signs represent output pixels. The grey arrows indicate how output values are determined. The values at the pixel locations in the uncorrected image are moved accordingly to the geo-corrected image. They now form a spatial relationship that reflects their true orientation on the ground and in a proper map coordinate system.

![Fig. 2 The Nearest neighbor resampling.](image3.png)
1.2 Objective
The objective of this research is to investigate if the results of the applications of spectral unmixing and subpixel object
detection to an uncorrected image and geo-registered image remain the same.

2. BACKGROUND AND PREVIOUS WORK

As mentioned above, automated algorithms (instead of the visual interpretation) are most commonly used for the
analysis of hyperspectral images. Aside from the spectral unmixing and subpixel target detection applications that are
used in this work, there are many other applications for hyperspectral imagery including classification, material
identification, etc. While a topic of much discussion, the area of hyperspectral image quality has received relatively little
attention. However, the question posed in this paper requires some quantitative measure of performance in order to
quantitatively assess the impacts of the geo-registration process.

In the following paragraphs we review of the work aimed at quantifying the utility of hyperspectral images as well as a
previous effort related to the topic of this paper.

2.1 Leachtenauer, et al, 1997

The seminal work in assessing the utility of panchromatic imagery is the paper by Leachtenauer, et al, 1997. The authors
in this paper developed a quantitative relationship between imaging system parameters such as ground sample distance
(GSD), the signal-to-noise ratio (SNR) of sensor and relative edge response (RER). And the numerical scale of 0-9 was
also provided to rate the utility of images. (0 is the lowest level of utility, 9 is the highest level of utility). The General
Image Quality Equation (GIQE) presented a quantitative approach to assess the rating level of a given image. The utility
here is defined in the context of visual interpretation of the imagery and corresponding extensions to multispectral
imagery have focused on visual interpretation as well.

2.2 Stefanou and Kerekes, 2009 and 2010

Stefanou and Kerekes in their papers from 2009 and 2010 (along with references therein) explored the use of application
metrics for hyperspectral image quality, particularly in the context of subpixel object detection. This work demonstrated
a quantifiable approach for metrics associated with machine-processed hyperspectral imagery.

2.3 Kerekes and Goldberg, 2013

Kerekes and Goldberg applied idea that the utility of a hyperspectral image addressed the system effects on two
applications, spectral unmixing and subpixel detection, particularly for the SpecTIR data in SHARE 2012 and in model-
based analyses. For spectral unmixing, it was observed that spectral range was more important for that case than the
spectral resolution or number of bands. For subpixel detection experiment, it showed that the greater value of SNR, the
better results we would get from the system. They presented that all aspects of the imaging system (scene, sensor, and
processing) can result in the impact of utility in a given task.

2.4 Bloechl, et al, 2014

This work was concerned with a methodology and results for the comparison of simulated hyperspectral imagery and
real hyperspectral imagery. The performance of classification, detection and unmixing applications was tested to
compare empirical and simulated images. It was found that several differences exist due to the way the image is
generated. The result demonstrated a quantifiable approach to assess the validity of simulated hyperspectral imagery.

2.5 Casey and Kerekes, 2009

Casey and Kerekes studied in particular the impact on subpixel target detection of misregistration between spectral bands
in hyperspectral imagery. While not the same as geo-correction, the spectral registration of bands naturally occurs during
a geo-correction process and was found to lead to an improvement in performance in some situations.
3. EVALUATION APPROACH

The approach and evaluation criteria are described in this section.

3.1 Geo-registration

The uncorrected original hyperspectral images was geo-registered using the GLT files supplied by SpecTIR and the ENVITM geo-correction routines. Nearest neighbor resampling was used. For both the unmixing and the target detection experiments the atmospherically-compensated reflectance images, as provided by SpecTIR, were used.

3.2 Spectral Unmixing

While there has been considerable research and many spectral unmixing algorithms, our interest here is on the relative performance. Also, the unmixing targets in the experiment were flat fabric panels and the mixing can be reasonably assumed to have been limited to linear area-weighting effects. Thus, a simple unconstrained linear unmixing approach as implemented in ENVITM was used.

3.3 Subpixel Target Detection

For the subpixel detection experiment we selected the Adaptive Coherence Estimator (ACE) detector, which is derived from the Generalized Likelihood Ratio (GLR) approach. The ACE detector is written as:

\[ TACE(x) = \frac{(d^T \Sigma^{-1} x)^2}{(d^T \Sigma^{-1} d)(x^T \Sigma^{-1} x)} \]  

(1)

Where \( d \) is the target spectrum, \( x \) is the pixel spectrum, \( \Sigma \) is the background covariance matrix. In previous research, ACE detector has been found to achieve better performance than other detectors for the application of subpixel detection.

4. RESULTS

Results comparing the unmixing and target detection performance for the uncorrected and geo-registered images are presented in this section.

4.1 Spectral Unmixing Results

In our real test scene, a set of unmixing targets were deployed on an asphalt surface with the objective of quantifying results of spectral unmixing. In Fig.3, two large unmixing targets were placed (left top yellow target and right top blue target). The first target was a 16’ x 16’ square which had a repeating pattern of 2’ x 2’ squares containing three 1’ x 1’ yellow felt squares and one 1’ x 1’ yellow cotton square. Thus, with the 1-meter spatial resolution, the yellow target should contain 75% felt and 25% cotton in each pixel. The second target, measuring 24’ x 24’, consisted of a checkboard-type pattern of alternating blue felt and blue cotton squares, each 1’ x 1’. Hence, each pixel of the blue target should contain around 50% blue cotton and 50% blue felt. In the Fig. 3, there are also six 10’ x 10’ uniform panels which can be seen. These uniform panels consisted of the pure materials used to make up the checkerboards and were deployed for use as in-scene endmembers. The second row from the bottom, from left to right, contains a pink felt and a yellow cotton target. The bottom row, from left to right, contains yellow felt, blue cotton, gold felt and blue felt.
As mentioned above, endmembers are the spectra describing the “pure” target material. In this experiment, the endmember spectra were chosen from the uniform panels containing the ‘pure’ color signature for reference. To ensure the accuracy of experiment, only the centered pixel was selected as referenced spectra. Similarly, for the mixed material checkboard, the surrounding pixels were abandoned. Hence, the number of pixels used in the experiment were 16 and 25 for yellow mixed target and blue mixed target respectively. Since the desired area are two small squares, no difference should be detected within the two specific area with the algorithm of nearest neighbor. In the Fig. 2, we could suppose that the dashed lines are the uncorrected pixels of checkboard and the red lines are the pixels in the georeferenced image. By mapping the red gridding on top of the black dashed line, we can predict that, regardless what the content in the surrounding pixels, as long as selected area in the uncorrected image is only containing checkboard, the unmixing results of both uncorrected image and geo-referenced image will be same.

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<tr>
<th>Table 1. Unmixing Result</th>
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<td>True Fractions</td>
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<td>Uncorrected Image</td>
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<td>Geo-registered Image</td>
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We observe in Table 1 that the geo-correction process has a small impact on the retrieved endmember fractions for both uncorrected and geo-registered image. Comparing with the true fractions, although the slightly overestimated or underestimated results are obtained, the retrieved fractions are still very similar to each other. Hence, as discussed above, not much difference can be obtained in the application of unconstrained linear unmixing for uncorrected vs. geo-registered images.

4.2 Subpixel Target Detection Results
During the SHARE 2012 experiment, two sets of targets, yellow and green, were deployed on an asphalt court and in a nearby grassy area, respectively. The wood targets were 12” x 20”. Thus, each target does not fill a full 1 meter pixel. The aim of this task is to detect as many pixels containing targets while keeping low rate of false alarm. In order to get the optimal result, 50 bands (5-54) were used to detect the targets in this experiment. Using the high-resolution WASP.
image, the precise pixels containing the targets were determined for the geo-registered image with a reasonably high confidence. The ground truth pixel locations for the targets in the uncorrected imagery were more difficult to determine. For this experiment, these locations were found through an iterative process of applying the detection algorithm and discerning the results until a reasonable set of target pixel locations were determined.

ACE was applied to both the uncorrected and geo-corrected images to detect subpixel target using a target spectrum of the reflectance spectral signatures of green and yellow targets obtained from field spectrometer measurements of the targets. The detection statistic images after application of ACE are shown in Figure 4, while Figure 5 presents Receiver Operating Characteristic (ROC) curves.

It can be seen from Figure 5 that the rate of detection for a given false alarm rate is higher for the uncorrected image when considering both the yellow and green targets. It is because that, in the Fig. 1, if the centers of two corrected pixels overlap with a target pixel in uncorrected image, the two pixels in geo-corrected image will both become target after being processed based on nearest neighbor algorithm. As such, compared to the uncorrected image, a greater rate of false alarms was observed in the geo-referenced image.

![Fig. 4 Subpixel detection results for uncorrected and geo-referenced image. (a) Geo-referenced image with green targets. (b) Uncorrected image with green targets. (c) Geo-referenced image with yellow targets. (d) Uncorrected image with yellow targets.](image)
5. CONCLUSIONS

This paper investigates a comparison between uncorrected and geo-corrected images in terms of the applications of spectral unmixing and subpixel target detection. In other words, the impact on hyperspectral imagery after applying geo-registration is studied by comparing the difference of the two images.

The results of the experiment suggest that the ability to detect subpixel target of hyperspectral image processed with geo-correction would be impaired compared to using the uncorrected image, while the retrieved endmember fractions for geometrical mixing targets indicate that not much difference is obtained between uncorrected and geo-registered images and the geo-correction has minimum impact on the application of spectral unmixing.

Overall the general conclusion of this experiment is that the geo-registration process can affect the utility of hyperspectral imagery as measured by unmixing and target detection performance, but that more experiments should be conducted to better confirm this observation.

REFERENCES


