Practical training in hyperspectral satellite image analysis

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Abstract:

Hyperspectral remote sensing holds the promise of providing inspection agencies such as the IAEA the capability of chemical analysis, at standoff distances, of rocks, ores and other stockpiles that are impossible to differentiate with high-resolution panchromatic satellite imagery. The Canadian Safeguards Support Program (CSSP) has been investigating hyperspectral methods and applications for nuclear safeguards since 2001. In 2004, we began a series of practical, hands-on training workshops in hyperspectral image analysis for image analysts. Rather than provide an intensive academic treatment of the subject available elsewhere, these workshops provide a very short, focussed introduction to hyperspectral satellite imagery of most relevance to the Agency.

The workshops assume limited advance knowledge of hyperspectral science, but some basic experience with ENVI™, a commercial image processing software package commonly used for hyperspectral analysis. After a brief discussion of hyperspectral remote sensing, the characteristics of the American HYPERION satellite currently providing hyperspectral imagery, and an overview of hyperspectral methods, participants are led through data preparation (removal of instrument artefacts) and atmospheric correction, prior to actual image analysis. A proprietary pre-processing software 'Wizard' insert for ENVI™ written for the CSSP is provided to automate most of the data preparation. After a discussion of matching analysis tools and techniques with the question at hand, selected ENVI™ image analysis tools are presented. Participants use standard ENVI™ tools and the provided Wizard to analyze actual HYPERION imagery of a safeguards relevant site. A training manual with step-by-step instructions is supplied to the participants for future reference.

Our workshops have been successful in giving participants some practical experience, and providing enough experience, confidence and resource material with which to begin to perform hyperspectral analyses in support of inspection activities.

Keywords: remote sensing; hyperspectral; satellite; imagery; training; analysis

1. Introduction

Since 2000 the IAEA have applied satellite image analysis in their nuclear safeguards monitoring program. Specialized image analysts primarily interpret high spatial resolution imagery from sensors such as Quickbird or IKONOS for signs of activity at nuclear facilities and mines, based on visual cues such as vehicle tracks, configuration and changes in structures including buildings, ore and rock piles, and roads. Other sensors such as LANDSAT or ASTER also offer thermal information that is used to detect features such as warm water discharges from nuclear plants.

With the launch of an Earth Observation satellite EO-1 HYPERION in late 2000, a third class of satellite-based image data became available. The hyperspectral capabilities of HYPERION offer detailed spectral information in the visible and shortwave infrared (wavelengths in the range 400-2500 nm). The strength of hyperspectral is its potential for remote chemical characterization of rocks, ores and other stockpiles that would otherwise be impossible to differentiate using standard spatial interpretive methods.

In 2001 the Canadian Safeguards Support Program (CSSP) began to investigate the utility of hyperspectral in safeguards applications, and engaged Borstad Associates Ltd. to conduct a series of case study analyses. In 2004 a hyperspectral training workshop was offered for the first time to the IAEA Satellite Image Analysis Unit (SIAU) analysts, and in response to their feedback the workshop was repeated in 2005 and 2006, with updates each year to include additional topics as well as new developments in data processing.

2. Course development

By 2003 a number of courses were already being offered by universities and other educational institutions on hyperspectral imaging and image interpretation, and in fact members of the SIAU had participated in such workshop before receiving our training. This prior workshop provided a good theoretical background, but there was interest in additional focussed, hands-on training. Our course was therefore structured around the processing and analysis of EO-1 HYPERION imagery, since this is currently the only available open source of satellite-based hyperspectral imagery. Software and training datasets were developed directly from the safeguards case studies performed in the preceding two years, and so were of direct relevance to the participants. Techniques introduced during the course also focussed on those most applicable to safeguards analyses. It should be noted that the same processing and analysis techniques discussed here are applicable also to hyperspectral imagery obtained from airborne platforms or hand-held devices.

The 2004 course was considered by participants to be highly successful and a “refresher” course was held the next year. Since the majority of 2005 attendees were repeat participants from 2004, the introductory portion of the course was minimized, and some new and updated techniques were included, including a customized image pre-processing software “wizard” that sped up much of the tedious process of image correction required to make the imagery ready for analysis. In addition, a step-by-step guide was distributed to participants to assist with analyses undertaken after completion of the workshop. By the end of the 2005 workshop participants had performed all of the processing steps and analytical techniques then in routine use at Borstad Associates, and in the time between the 2005 and 2006 workshops, SIAU analysts performed successful hyperspectral analyses as part of their regular duties.

In 2006 all of the workshop participants were new or recent additions to the SIAU and so had varying degrees of previous experience with image analysis. The workshop was therefore restructured to include more theoretical background than the previous two years, though due to increasingly streamlined preprocessing, there was sufficient time to introduce all of the analytical techniques from the 2005 workshop. In addition, a new module was presented that allows analysts to visualize both hyperspectral imagery (or derived maps) and the more traditional high spatial resolution imagery as overlays, so bridging the two technologies and enabling analysts to benefit from their simultaneous interpretation.

3. Setup and Software

The workshops were structured as hands-on sessions, with each participant or pair of participants at a workstation. Following brief explanatory lectures, participants were guided through test datasets to gain experience performing each preprocessing and analytical step.

Image processing and analysis software was based on ITT ENVI version 3.2 in 2004, progressing to version 4.2 and 4.3 in 2006 as new versions were released. Although other commercial image processing software is available, ENVI is well suited to hyperspectral and is in common use in the remote sensing community. The workshops and step-by-step guide were not intended as ENVI training, but identified those tools most useful for hyperspectral analysis, and most importantly assisted participants in the selection of analytical algorithms appropriate to the scenarios likely to be encountered in safeguards-related analyses. New features available with updated versions of ENVI were introduced in the 2005 and 2006 workshops as appropriate, including new atmospheric correction algorithms and multi-resolution overlays as described above. As well, participants were alerted to potential problem areas and unresolved software “bugs” encountered during our own experience. ENVI software was supplemented with custom routines developed by Borstad Associates

Ltd, notably the preprocessing software wizard that automated much of the initial correction required with HYPERION imagery.

4. Course content

For analysts experienced in working with panchromatic or multispectral imagery, the concepts and interpretive techniques employed in spectral analysis are often unfamiliar, so the introductory session to the course in all three years reviewed the nature of hyperspectral imagery and analysis. A sample explanatory slide is illustrated in Figure 1.

The second workshop session in each year was devoted to image artefact correction. Unlike panchromatic or multispectral, hyperspectral satellite technology is still relatively new, and so the at-source preprocessing tends to be incomplete, and the imagery provided by the supplier requires considerable preparation to remove small but important instrument errors. In the first year of the workshop, artefact removal was performed “manually” – that is, using a collection of standard image processing tools available with ENVI, but in 2005 and 2006 much of this time-consuming process was accomplished using a custom software wizard designed specifically to remove artefacts from HYPERION imagery and to format it for ENVI analysis.

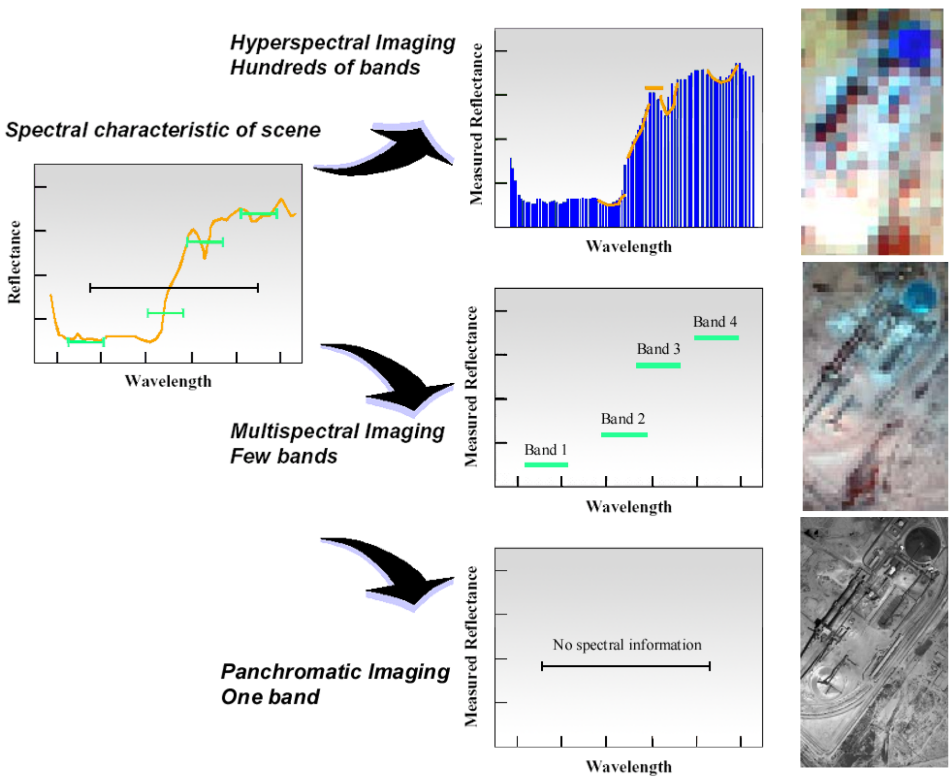

Figure 1: Introduction to hyperspectral imaging

The third workshop session covered atmospheric correction. Because hyperspectral analysis frequently involves the identification of unknown materials present in an image, the image spectra must be comparable to reference spectra of known materials from field or lab measurements, and hence must be corrected to remove the very large spectral signal due to the earth’s atmosphere. Figure 2 illustrates the magnitude of the correction. Workshop participants were introduced to and obtained practical experience with both theoretical (model-based) and empirical methods of atmospheric correction. Decision-making as to the need for atmospheric correction on a case-by-case basis was also discussed.

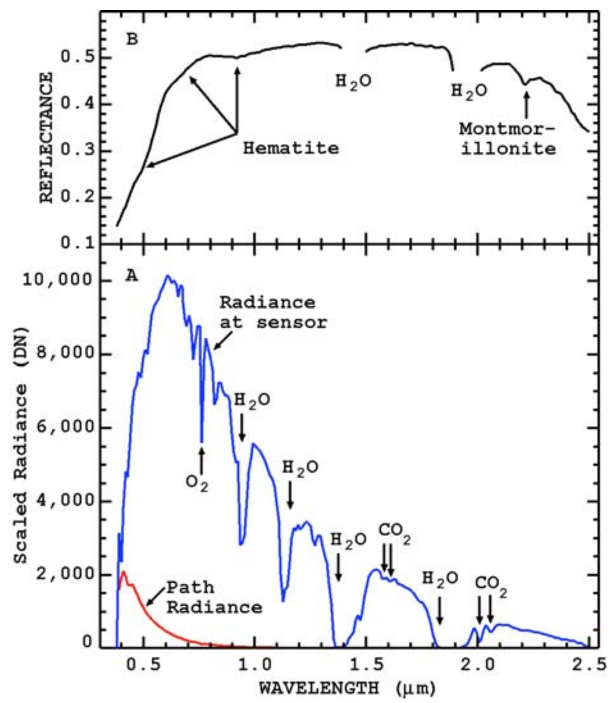

Figure 2: Comparison of uncorrected (lower) and atmospherically corrected (upper) spectra for the same material (*speclab.cr.usgs.gov/PAPERS.calibration.tutorial/).*

If your question is...	**The recommended algorithm to use is...**
Is the material at location *x* found elsewhere in the scene? Or, is material "A" found anywhere in the scene?	Supervised classification
What are the relationships among this user-defined set of materials found in the scene?	Spectral Analyst
What are the relationships among all of the pixels in the scene?	Unsupervised classification

Table 1: Selection of analytical algorithms.

About half of the overall workshop schedule was devoted to the selection and application of analytical techniques. The three most useful techniques are listed in Table 1, along with typical safeguards situations in which each would be used. A case study for each was presented, and participants were guided through the analyses during the workshop. Figure 3 illustrates one of these case studies in which phosphate ore and the refined fertilizer product was mapped at Al Qaim, Iraq. Lab spectra for these two materials were used to locate them in a HYPERION scene over Al Qaim. In 2004 this analysis was performed "manually" using individual tools available in ENVI 3.2. In 2005 and 2006, using more recent ENVI 4.1 and 4.2 participants were introduced to the "Spectral Hourglass Wizard" that automates much of the analysis, thereby reducing overall processing times. Figure 4 illustrates the application of ENVI's Spectral Analyst to determine the similarities among materials in a HYPERION scene without necessarily identifying them. In this exercise, the operational relationships between excavations and rock and ore piles at Ranger Mine, Australia were inferred from their spectral similarities. The rock from three different excavation sites at the same pit was traced to various locations around the mine.

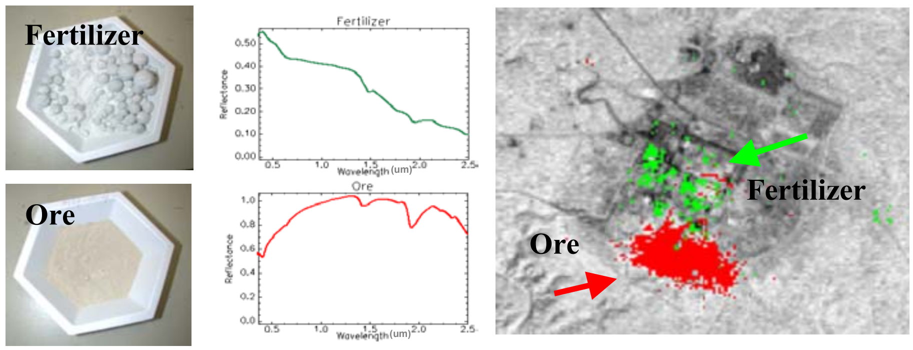

Figure 3: Case study of supervised classification at Al Qaim, Iraq.

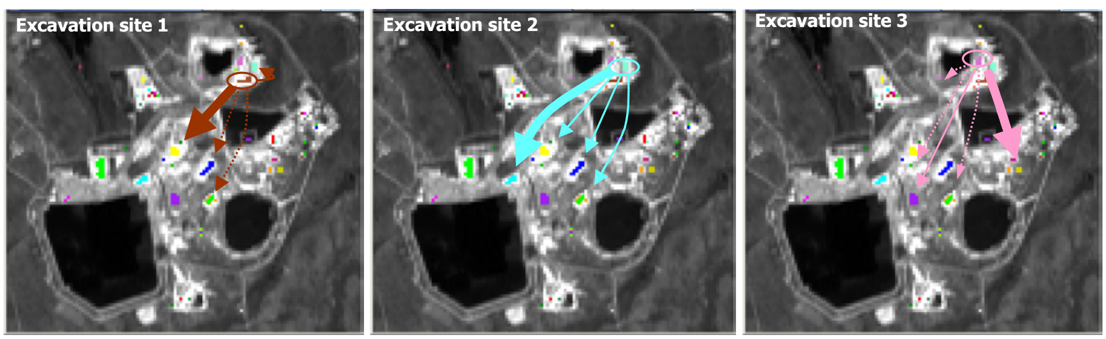

Figure 4: Spectral Analyst case study at Ranger Mine, Australia.

In 2006, new techniques were also introduced, showing SIAU analysts how the geochemistry determined from hyperspectral data can be interpreted in light of high-resolution panchromatic imagery of the same area, or conversely, how activities observed from high resolution imagery can be interpreted in terms of the geochemistry.

5. Course feedback

The final session in each year was a summary and evaluation session in which participants were tested on their understanding of the material and the potential safeguards applications of the technology, as well as providing feedback on the workshop and suggestions for future training. The feedback from participants in each year was extremely positive. The interactive format with hands-on practice was appreciated, as was the balanced presentation showing both the strengths of the technology and potential for error. The perceived level of difficulty of the material varied with the background experience of the participants, but the overall level of understanding was high as was the recognition of potential safeguards applications. The compilation of a written guide in 2005 was well received, both during the workshop and as a future reference. Participants who attended in both 2004 and 2005 appreciated the timesavings achieved with the introduction of processing software wizards.

Participants also demonstrated their understanding by pinpointing areas for potential technological improvement that are currently recognized within the remote sensing community, including the need for improved atmospheric correction algorithms and for specialized spectral libraries more relevant to safeguards applications. All requested ongoing training in the form of repeat or annual refresher workshops for new and existing staff.

6. Conclusion

Our workshops have been successful in providing participants with enough practical experience, confidence and resource material with which to begin to perform hyperspectral analyses in support of inspection activities. The annual format permits analysts to be kept informed of new developments in this young technology. The interactive nature of the workshops and feedback from participants has enabled us over the 3 years to respond to their needs by incorporating new workshop modules and by developing automated software routines to improve processing times.

HYPERION is now in extended mission, having fulfilled its original goal as a technology demonstration. Several countries are now planning new hyperspectral sensors with higher resolution and better signal-to-noise, scheduled for launch in the next 3 to 5 years. With these new sensors, hyperspectral remote sensing is expected to make the transition from research to operational mode, significantly increasing data coverage and availability. Providing training for agencies such as the IAEA will ensure that they are fully prepared to take advantage of this emerging technology.