A COMPARISON OF FOUR SPECTROMETERS AND THEIR EFFECT ON THE SIMILARITY OF SPECTRAL LIBRARIES

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ABSTRACT:

Spectral measurements taken by different spectrometers could be very different for the same objects that can cause difficulties to compare those to each other. This paper is focusing on comparing and evaluating the spectral signatures of four commercially available hyperspectral spectrometers (FieldSpec (FS) and TerraSpec (TS) from the company ASD, HandySpecVIS (HSvis), HandySpecVIS/NIR (HSvnir) from the company Tec5). As reference the free spectral library of United States Geological Survey (USGS) was also considered. The main aim of the investigation was to figure out how spectral signatures from different sources could be corrected before comparing them to each other. According the equipment differences the technical (illumination, viewing angle, arrangement) and radiometrical parameters (resolution and ranges) varied from spectrometer to spectrometer, but a device dependent intercalibration was possible to carry out. The importance of spectral libraries and well documented white reference measurements will be also discussed and the comparison of more spectroradiometers will be initiated.

1. INTRODUCTION

1.1 Motivation

Considering its equipment the hyperspectral technology shows a very complex picture. While multispectral geodata have mostly been produced by satellites hyperspectral data have typically been captured by airborne, terrestrial or laboratory measurements. One spectrometer for one spectral library could provide a reliable uniform dataset. Measurements taken by other spectrometers at other places could be very different for the same objects causing difficulties to compare them (Price 1994, Milton et al. 2006).
One of the weaknesses of a multi source hyperspectral database is its multiplicity caused by inconsistent spectral measurements.

This paper focuses on comparing and evaluating the functionality of four commercially available hyperspectral spectrometers (FieldSpec and TerraSpec from Analytical Spectral Devices (ASD), HandySpecVIS, HandySpecVIS/NIR from Tec5) and their usability in field- and laboratory measurements. It was not intended to select one all-in-one spectrometer based on applicability or spectral properties. Depending on research aim and target specifications must be decided which spectrometer is the most suitable for an investigation. Special attention was paid to white reference measurements because corrections had to be carried out before comparing them. The measurement devices were tested on different targets like minerals of diverse origins and vegetation. After introducing a special white-

reference correction the curves were converted and compared by classical comparing methods like Spectral Angle Mapper (SAM), Binary Encoding (BE) and Spectral Feature Fitting (SFF).

The results indicated that the correction and the comparison of the curves were effective when white references of the spectrometers were well known and documented. Based on the concept comparing different spectral libraries of the same targets is very complex and requires special attention and accuracy but it can work properly when the measured white references are given for conversion.

With the result of this investigation it was intended to support specialists in geology, agriculture and other environment oriented disciplines who are planning to compare different spectral libraries or spectrometers (Price 1998, Castro-Esau et al. 2006).

2. METHODS

In this investigation four targets were measured by four spectro(radio)meters with different white references which strongly modified the spectral curves. White reference was taken with Spectralon® (Labsphere, 2009) and device coupled white references (Tec5). Methods for comparing spectra used in this work are widely employed in hyperspectral image classification (Leone & Sommer, 2000) but less common in analyses of one-point measurements or comparing spectrometers. In this paper, three different methods were applied to compare spectral features within a hyperspectral data set (Aspinall et al., 2002).

Binary Encoding (BE): It is a classification method that encodes the data and reference spectra into 0-s and 1-s based on whether a band falls below or above the spectrum mean. An exclusive ´OR´ function is then used to compare each encoded reference spectrum with the encoded data spectra and classify the dataset (Mazer et al. 1988). Each pixel is classified to the material with the greatest number of bands that match above a

minimum match threshold. Another important algorithm, the Continuum Removal, normalizes reflectance spectra to allow comparison of individual absorption features from a common baseline (Clark et al. 1987, Kruse et al. 1993a). A convex hull that is fitted to the spectrum describes the continuum. Lastly, straight-line segments connect local spectra maxima to define the convex hull, the first and last spectral data values being on the hull by definition.

Spectral Angle Mapper (SAM): It matches pixel spectra to reference spectra using a measure of spectral similarity based on the angle between the spectra treated as vectors in an n-dimensional space with dimensionality (n) equal to the number of image bands. Smaller angles represent closer matches. The angle between each pixel and all reference spectra can be mapped, and pixels assigned to the material for which the spectral angle is smallest and within a defined limiting angle (Kruse et al. 1993b). When used on calibrated reflectance data, the SAM is relatively insensitive to effects of illumination because the angle between vectors is measured rather than the length of the vector. Because it uses only the ´direction´ of the spectra, and not their ´length´, the method is insensitive to the unknown gain factor. All possible illuminations are treated equally. Poorly illuminated pixels will fall closer to the origin. The ´color´ of a material is defined by the direction of its unit vector. The length of the vector relates only to how fully the pixel is illuminated. The SAM algorithm generalizes this geometric interpretation. It determines the similarity of an unknown spectrum to a reference spectrum.

Spectral Feature Fitting (SFF): It uses least squares methods to compare the fit of image spectra to selected reference spectra (Crowley & Clark, 1992). Reference spectra are scaled to match the image spectra after continuum removal from both data sets. The method measures absorption feature depth which is related to material abundance. A relatively simple form of this method, called Spectral Feature Fitting, enables the user to specify a

range of wavelengths within which a unique absorption feature exists for the chosen target. The pixel spectra are then compared to the target spectrum using two measurements: the depth of the feature is compared to the depth of the feature in the target; and, the shape of the feature is compared to the shape of the feature in the target (using a least-squares technique).

The following materials were measured: Augite (inosilicate), Chlorite (phyllosilicate), Siderite (carbonate) and Hieracium pilosella (pioneer vegetation). The geological samples belong to the geological collection of the Martin Luther University Halle-Wittenberg, Germany (MLU). The vegetation material originates from the PhenoSpec Experimental Project managed by the Department of Remote Sensing and Cartography at the MLU (http://www.geo.uni-halle.de/geofern/). In Fig.1 are the main steps followed during the investigation. Abbreviations were introduced and used in the next paragraphs. FS stands for FieldSpec Pro FR (350-2500 nm), TS for TerraSpec (350-2500 nm), HSvnir for HandySpecVIS/NIR (400-1690 nm) and HSvis HandySpecVIS (400-1100 nm).

| Spectrometers (FS, TS, HSvnir, HSvis) |
| Spectral Signatures of Four Targets (Augite, Chlorite, Siderite, Hp) |
| Comparison (three methods: SAM, SFF, BE) |
| Similarity Matrix (Nearest Spectrum Matrix (NSM)) |
| Decision Logic Based on NSM |
| Binary Operations Arithmetic Operations |
| Statistical Results |
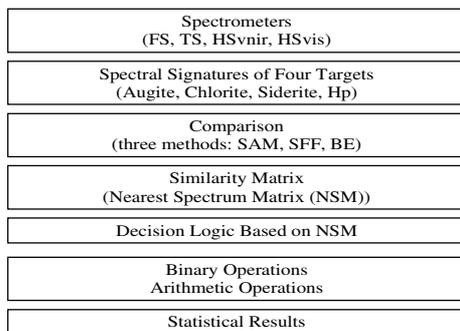
Figure 1. Workflow followed in this spectrometer test

The Similarity Matrix will be explained within the results. In Fig. 1 only the main concept of the investigation can be seen, some parts of the concept will be discussed in Fig. 2.

3. RESULTS

To ensure a transparent working concept, the three-step work flow scheme was developed and employed in this research depicted in Figure 2. It can be seen that reflectance spectra originating from different devices (Step 1) and different targets are integrated into one database. Before they were added to a spectral library, they had been analysed by a modular processing logic (Step 2). The statistical methods used in spectral pre-processing tool are known (BE, SAM, SFF) and are changeable due to modularity. The novel processing logic manages the outputs of the statistics. At the end, the best matched spectra will be separated and summarised in a comparison table (Step 3).
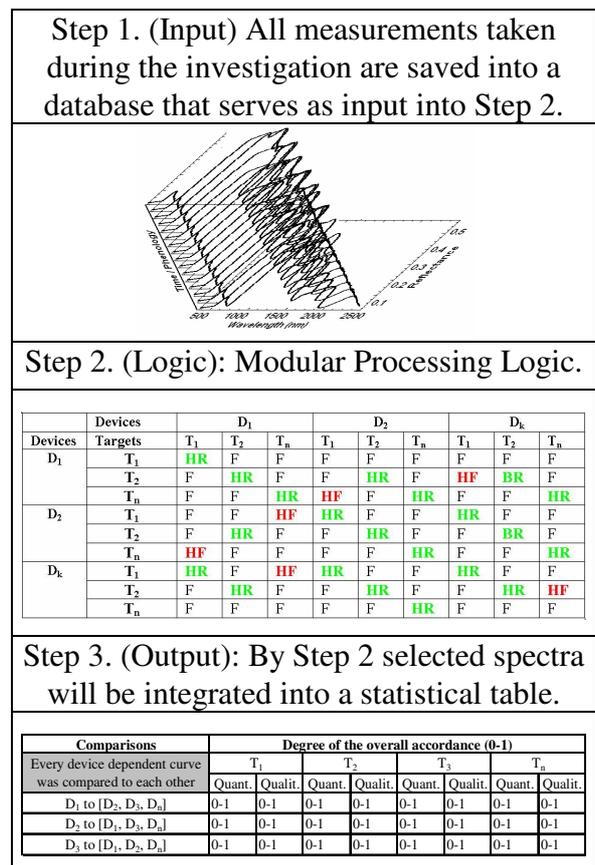
Figure 2. Illustration of the workflow for evaluating and comparing spectra for spectral libraries. Abbreviations: T=Targets, D=Devices, HR=Highest Right, HF=Highest False, F=False.

The Similarity Matrix or Nearest Spectrum Matrix (NSM) in the Modular Processing Logic is a statistics table that demonstrates which spectrum matches with which spectrum at the highest level. Best matched has two alternatives (Highest Right=HR and Highest False=HF) and means that between the spectral signatures must be at least one spectrum which matches with almost all remaining spectra at the highest coincidence level (HR). If this is not the case, it might be found that one sample measured by a given spectrometer could best match with another sample measured by another spectrometer or by the same one (HF). All spectra are compared to all spectra in order to preserve separability.

After having calculated BE, SAM and SFF, one score value was created from the simple arithmetic sum of BE, SAM and SFF. List of scores were then evaluated to see ranking between matches to determine first and second highest matches.

From the NSM you can derive diverse information on spectra. Fig. 2 demonstrates how this matrix works and how to draw conclusions. For instance, the sample S_1 should match (theoretical) every S_1 from different devices (D_1, D_2, D_n) but it is normally not the case when spectrometers work with different spectral resolution and the spectral characteristics of the samples are located in the entire spectrum. If after resampling, the spectral sampling of the spectrometers and the most important spectral characteristics of the targets remain still recognisable then the results are comparable.

After introducing a special white-reference correction (see Eq.1: Correction Operator) and a similarity matrix (NSM) the curves were converted and compared by classical comparing methods like Spectral Angle Mapper (SAM), Binary Encoding (BE) and Spectral Feature Fitting (SFF). When spectra with different spectral ranges were compared both spectra were sampled after the simpler one because the spectrometers used in the investigation had different spectral resolution and spectral sampling algorithm.

The white reference correction is a very important part of comparing spectra. Every spectrometer had its own white reference and the reflectance curves were calculated based on the device-dependent white reference measurements. The results were compared to each other after the logic of Fig.2. The main intension of the investigation was also to enhance the comparability of the curves of the spectrometers. When all the white reference values were substituted by one ´master´ white reference and the curves were recalculated, the similarity of the signatures became higher. In Tab.1 can be seen how the overall accordance changed when the spectral resolution changed and white reference correction was carried out. In Tab.1 the overall accordance was normalized and set between 0 and 1. After correcting white reference values and recalculating the curves the changes were not overall significant. Major changes were found when HSvnir was recalculated (see Tab.1 and Fig.3).

Comparisons	Overall accordance (0-1)			
Every device dependent curve was compared to each other	Augite	Chlorite	Siderite	Hp
	Quant.	Quant.	Quant.	Quant.
FS to [TS,USGS,HSvnir,HSvis]	0,50	0,75	0,75	1
TS to [FS,USGS,Hsvnir,HSvis]	0,50	1	0,75	0,50
USGS to [FS,TS,HSvnir,HSvis]	0,50	0,75	0,75	n.d.
HSvnir to [FS,TS,USGS,HSvis]	0,25	1	0,75	1
CorrHSvnir to [FS,TS,USGS,HSvis]	1	1	1	1
HSvis to [FS,TS,USGS,Hsvnir]	0	1	0	0,50

n.d. = no data

Table 1. Results of the comparisons for the targets

The correction was calculated after the Eq. 1.

$$RC_{HSVNIR} \cdot \frac{WRRC_{HSVNIR}}{WRRC_{TS}} = CorrRC_{HSVNIR} \qquad (1)$$

RC_{HSVNIR}=Reflectance Curve of HandySpecVIS/NIR
$WRRC_{HSVNIR}$=White Reference Reflectance Curve of HandySpecVIS/NIR
$WRRC_{TS}$=White Reference Reflectance Curve of TerraSpec
$CorrRC_{HSVNIR}$=Corrected Reflectance Curve of HandySpecVIS/NIR
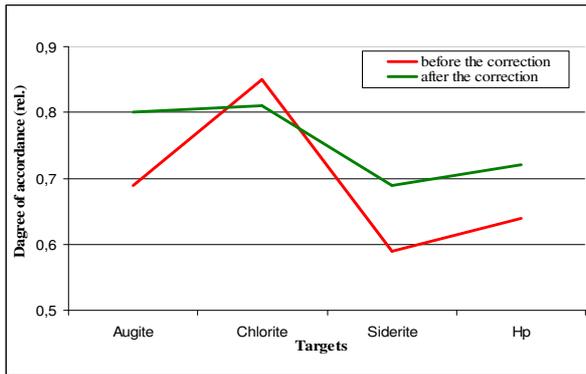
Figure 3. White reference correction for HSvnir.

After white reference correction (the same white reference in every case) the overall accordance increased by c. 10 % (see Tab. 1 and Fig. 3).

2. DISCUSSION UND CONCLUSIONS

The highest changes after white reference correction was found for HSvnir (see Tab. 1). HSvnir has a spectral resolution of 400-1690 mm which lies in the middle range according to the spectrometers compared here. This positive change means more than just a statistical correction or a mathematical operation. The spectral characteristics of the materials are as important as the technical properties of the devices because the absorption peaks are not linearly distributed but after chemical components localized. It is important to emphasize that the absolute results of this investigation is valid for these four materials measured by these four spectro(radio)meters. As a general conclusion of this paper the following statements are of use.

Comparability of curves and devices: For the similarity of the curves the absorption peaks to be compared are probable more important then the minimum spectrum intersected by the considered spectrometers. The similarity of the curves is multiple influenced when spectrometers have different spectral resolutions and ranges and targets originated from different materials with different spectral characteristics.

Post-correction: When spectra are originated from different sources and comparison must be done then post-correction is very advisable because differences introduced by device or illumination could be partially or entirely corrected. Post correction is possible when white reference raw values are known and well documented.

Spectral libraries: There are many spectral libraries available worldwide and the database is growing. It is sometimes very difficult and time-consuming or inaccurate to use them for scientific aims or comparisons. The standardization of spectral libraries and documentations is very reasonable when hyperspectral satellites will be lunched and spectra from different sources for the same materials will be captured and compared. But before going global local initiatives must be started and completed for comparing terrestrial field spectro(radio)meters (Jung et. al 2009).

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