



White-reference based post-correction method for multi-source spectral libraries

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Summary: This paper focuses on an easy-to-use post-correction method of spectral ground-truth signatures. This method was developed and applied within this experiment. The following spectrometers were used: FieldSpec (FS) and TerraSpec (TS) from Analytical Spectral Devices, Inc and HandySpec^{VIS/NIR} (HS) from the German company Tec5 AG. As a fourth “virtual spectrometer”, the free spectral library of the United States Geological Survey (USGS) was included. Spectral measurements taken by different spectrometers for the same objects can cause difficulties when comparisons are made between ground-truth spectra. The instrumental differences, the technical parameters (spectral resolution and ranges, illumination sources, arrangement, viewing angle) vary from spectrometer to spectrometer, but a white-reference dependent post-correction could work and enhance the similarity between spectra. By the post-correction method a positive change of over 10% was achieved which is considered as significant for most spectral library users. The importance of spectral libraries is growing and the intercomparability of them is still a challenge. The post-correction method is a practical tool for building and using multi-source ground-truth spectral libraries.

Zusammenfassung: *Weißabgleich-basierte Post-Korrekturmethode für Spektralbibliotheken.* Das Ziel der Arbeit ist die Entwicklung einer anwendbaren Post-Korrekturmethode für spektrale Feld- und Labormessungen. Diese Methode wurde innerhalb eines Spektrometervergleichs entwickelt und getestet. Folgende Spektrometer wurden verwendet: FieldSpec (FS) und TerraSpec (TS) von Analytical Spectral Devices, Inc und HandySpec^{VIS/NIR} (HS) der deutschen Firma tec5 AG. Als viertes virtuelles Spektrometer wurde die frei verfügbare Spektralbibliothek des United States Geological Survey (USGS) verwendet. Spektrale Messungen mit verschiedenen Spektrometern zeigen für gleiche Messobjekte Unterschiede im Spektroskopsignal. Die instrumentellen Unterschiede basieren auf technischen Parametern (spektrale Auflösung und Spektralbereiche, Lichtquellen, Arrangement, Betrachtungswinkel). Die auf einem Weißabgleich basierende Post-Korrektur kann zur Verringerung externer Fehler beitragen. Durch die Post-Korrekturmethode kann eine positive Veränderung der spektralen Ähnlichkeit von über 10% erreicht werden. Die Bedeutung von Spektralbibliotheken wächst, die Vergleichbarkeit ist aber immer noch eine Herausforderung. Die Post-Korrekturmethode ist ein praktisches Werkzeug für die Erstellung und Nutzung von spektralen Bibliotheken.

1 Introduction

In hyperspectral remote sensing high-resolution spectral signatures are essential for object identification. The spectral information can originate from many sources and are usually stored in spectral libraries. From point measurements to pixel based imaging systems numerous techniques and methods are available for use. These facts challenge both the prima-

ry data producers and the data archivists but most importantly the high-end data users (MILTON et al. 2006). Even now practical questions are still of high importance and need to be discussed before going into more complex levels. However, to discuss the whole data chain would go beyond the capabilities of this paper. For this case a reduced but highly focused aim is advisable. This reduction leads to the very first level of the spatial data scale, the

ground truth. It is well known that the most common way to capture spectral ground truth is to use a hand-held field spectrometer. This device can virtually provide a uniform dataset for the same target in a very short time. However, measurements taken by other spectrometers for the same object could be different, which could strongly affect spectral identification (PRICE 1994, 1998, CASTRO-ESAU et al 2006). Recent tendencies have shown that the number of field spectrometer providers is growing and in some segments of the market prices have decreased. This phenomenon will be more noticeable when new hyperspectral satellites will be in orbit and ground truth data will be required. Experience from practice has shown that using external spectral libraries often led to disappointments. Development is needed for new methods that can improve the spectral similarity between “quasi-identical” samples. In this paper a simple and easy-to-use post-correction approach will be presented which can help users synchronize multi-source ground-truth spectra. Special attention was paid to the white-reference measurements, because the proposed post-correction method works with white panel raw data. Three commercially available hyperspectral spectrometers and the free USGS spectral library were included in the experiment. It was not our intention to create a ranking system among the spectrometers. Decisions regarding which spectrometer is the most suitable for an application should depend on research aims and target specifications.

2 Materials and Methods

Three spectrometers, FieldSpec and TerraSpec from Analytical Spectral Devices (ASD 2010) and HandySpec^{VIS/NIR} from Tec5 (Tec5 2010) were included in this experiment. The following abbreviations are used in this paper. FS stands for FieldSpec Pro FR (350–2500 nm), TS for TerraSpec (350–2500 nm), HS for HandySpec^{VIS/NIR} (400–1690 nm) and USGS for the USGS spectral library sample (400–2500 nm). To enhance the spectral comparability, the same mineral sample was scanned by all spectrometers. As test material chlorite was selected. Chlorite with a size of 5 × 5 cm

was an ideal mineral for a spectrometric test because it is durable and shows absorption peaks and stand-alone features throughout the spectrum of 400–2500 nm. This consideration is of high importance for a spectrometer with a sensing capability of up to 1690 nm (HS, for instance). The mineral sample was courtesy of the geological collection of the Martin Luther University Halle-Wittenberg, Germany (MLU).

Due to influencing factors (changing atmospheric conditions, seasonal and diurnal changes etc.) the laboratory seemed to be the most stable and suitable place for this experiment. The illumination parameters, human factors and other technical parameters were not predetermined, because every spectrometer has its own source of illumination and white reference panel in practice. Two white reference panels were from Labsphere® (Labsphere 2010) and the third one was a device coupled material from Tec5. The white panel for the USGS spectrum was not known. However, white reference panels can considerably modify the spectral reflectance curves. The white reference measurements were separately taken by every spectrometer and were used as a reference for the chlorite sample.

Each spectral sampling was repeated four times over the same target and saved separately. For the evaluation the repeats were averaged. Before reflectance values were generated the raw data or digital counts were also archived. MILTON et al. (2009) wrote that reflectance data will remain a convenient way to represent the energy interactions occurring at the surface, and they have value in generic spectral libraries (MILTON et al. 2009). This approach was highly accepted and followed in this work and used for further analyses. It is important to note at this point that the quantity acquired by the used spectrometers was the reflectance factor. The term reflectance factor was used, whereby the ratio of the radiant flux is reflected by a target to that reflected into the same reflected-beam geometry by an ideal and diffuse standard surface, irradiated under the same conditions (NICODEMUS et al. 1997). The normalized reflectance factors were calculated and analyzed.

The analyzed spectral products varied in spectral resolution and ranges; this phenome-

non was able to be statistically solved by spectral resampling. This process was necessary when HS was compared to all other spectra or when USGS to FS, TS and HS. FS and TS had the same spectral resolution. The above mentioned circumstances are very typical for multi-source spectral libraries and were treated as reality factors.

Before applying the white-reference post-correction method, the reflectance factor curves were compared by hyperspectral mapping methods like Spectral Angle Mapper (SAM), Spectral Feature Fitting (SFF) and Binary Encoding (BE). Methods for comparing spectra used in this work are widely used in hyperspectral image classification (LEONE & SOMMER 2000, ASPINALL et al. 2002) but less common in analyses of single-point measurements or spectral libraries. The statistic was generated in the ENVI 4.4 software environment (ENVI 2010). The three comparison methods will be described in the following section.

Spectral Angle Mapper (SAM): It matches spectra to reference them 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 spectral channels. Smaller angles represent closer matches. The angle between each spectra and all reference spectra can be mapped and 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 changes, because the angle between vectors is measured rather than the length of the vector. It determines the similarity of an unknown spectrum to a reference spectrum.

Spectral Feature Fitting (SFF): It uses the “least squares method” to compare the fit spectra to selected reference spectra (CROWLEY & CLARK 1992). The method measures absorption-feature depth which is related to material abundance. It enables the user to specify a range of wavelengths, within which a unique absorption feature exists for the chosen target.

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 spectral value in a band falls below or above the overall average of spectrum. 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 spectrum is classified to the material with the greatest number of channels that match above a minimum-match threshold (CLARK et al. 1987, KRUSE et al. 1993a).

In Fig. 1 can be seen how the four-source spectra of chlorite take place within the 400–

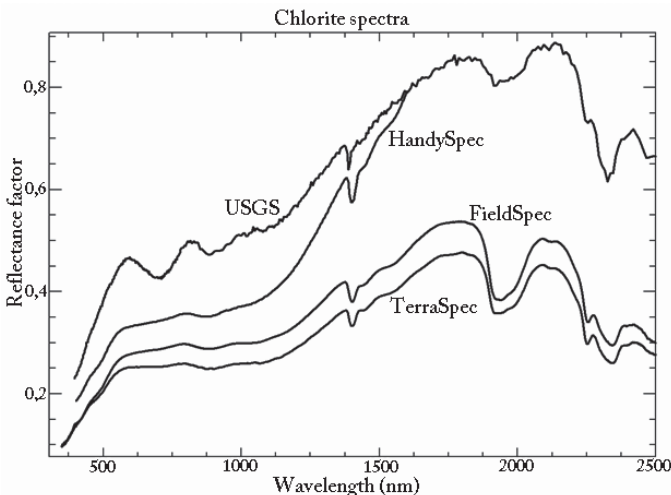


Fig. 1: Reflectance factor curves of chlorite created by four different spectrometers.

2500 nm spectral range. The HandySpec (HS) spectrometer works only up to 1690 nm and shows significant divergence over 1000 nm. The other chlorite spectra vary also both in intensity and resolution, but remain more stable compared to HandySpec (HS). The chlorite sample from USGS spectral library shows distinctions in the visible spectrum, which means that it appears to have had a different colour compared to the sample measured by TS and FS.

For the USGS chlorite sample, only the reflectance factors were available without knowing anything about the white panel properties. This is common for most spectral libraries. However, the supplementary sample information is well documented in the available online database (USGS 2010).

The post-correction method

Special attention was paid to the reflectance factor curve of HS. For HS the white panel raw data was known and could be well processed. For a post-correction a master spectrum is needed to define which one serves as the reference. In this case the white panel raw data of TS was chosen for HS. The FS (FieldSpec) and TS (TerraSpec) spectra were very similar (see Fig. 1) and post-correction was not necessary.

Why to use TS as reference? On the one hand there were technical similarities between TS and HS because both of them had internal illumination that ensured a higher similarity between spectra taken from the same samples. On the other hand, TS was a new device with an up-to-date calibration file.

In Fig. 2 the applied methods and main processing paths are depicted. To generate a post-correction curve it is necessary to know the white panel raw data, because the normalized spectra mask the original properties of the reference surface.

The white reference post-correction is significant when ground-truth spectra are to be compared. Once both white reference raw values and a master spectrometer with known white reference raw values are given, the correction curve can be calculated. The post-correction of HS was carried out by Eq. (1). ORC_{HS} stands for Original Reflectance Curve of HS, $WRRD_{HS}$ for White Reference Raw Data of HS, $WRRD_{TS}$ for White Reference Raw Data of TS and CRC_{HS} for Corrected Reflectance Curve of HS.

$$ORC_{HS} \cdot \frac{WRRD_{HS}}{WRRD_{TS}} = CRC_{HS} \quad (1)$$

The changes implied by the post-correction method can visually be observed in Fig. 3. The 'correction curve' was calculated from

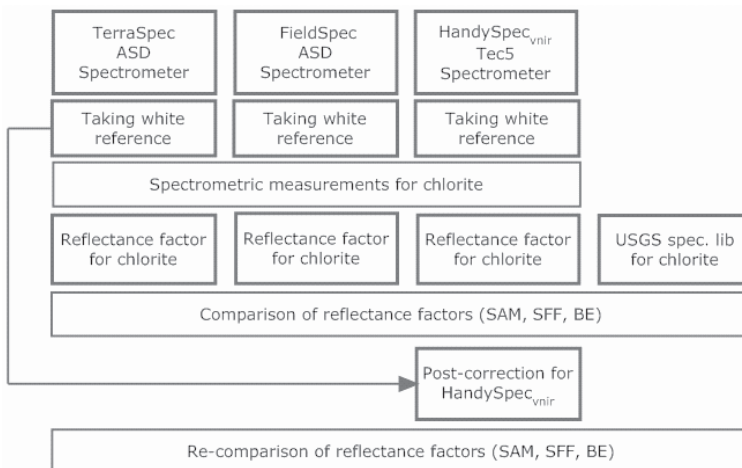


Fig. 2: The workflow and processing paths.

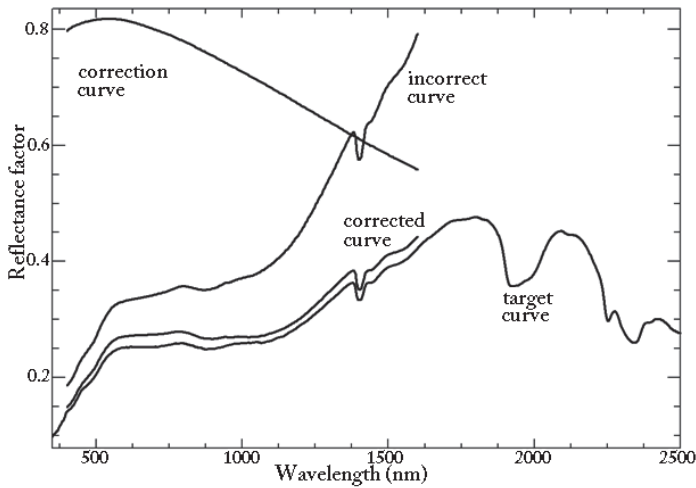


Fig. 3: Changes caused by post-correction.

($WRRD_{HS}/WRRD_{TS}$), the ‘incorrect curve’ represents ORC_{HS} and the ‘corrected curve’ is virtually CRC_{HS} . The ‘target curve’ is the sample reflectance factor curve (chlorite) of the master, in this case TS. The HS has no sensing capabilities above 1700 nm, this is the reason why the ‘correction curve’ and the ‘corrected curve’ end at 1700 nm.

3 Summary and Outlook

Reflectance factors of different devices for the same target were compared and, if necessary, post-corrected (see Eq. (1), Fig. 1 and 3). The statistics table Tab. 1 shows the comparison results. Each spectrometer was compared to

the other and relative similarity values were calculated. The matches were set between 0 and 1. The column ‘rel.similarity’ stands for an averaged value calculated from SAM, SFF and BE.

For the average values an increase of 6% (between bc: FS to HS and ac: FS to HS) and 5% (between bc: TS to HS and ac: TS to HS) was registered. These values (as it can be seen in Tab. 1) depend very much on methods. If considering SAM for changes, the values increased by 11% (SAM between bc: FS to HS and ac: FS to HS) and by 13% (SAM between bc: TS to HS and ac: TS to HS). These changes are significant when multi-source ground-truth signatures should be synchronized. SFF shows also considerable changes, but not as

Tab. 1: Comparison results before and after the correction.

Comparison	Comparison methods			
	rel. similarity	SAM	SFF	BE
before correction (bc)				
FS to TS	0,94	0,97	0,85	0,99
FS to USGS	0,75	0,88	0,48	0,88
FS to HS	0,89	0,85	0,84	0,99
TS to USGS	0,86	0,95	0,67	0,96
TS to HS	0,92	0,85	0,91	1,00
USGS to HS	0,86	0,86	0,75	0,97
after correction (ac)				
FS to HScorrected	0,95	0,96	0,93	0,98
TS to HScorrected	0,97	0,98	0,92	0,99

frequent as SAM, and BE can be regarded as inconsequential for the correction. These results show the strengths and robustness of the comparison methods, too, and focus our attention on the SAM.

Via the post-correction method, it was possible to produce a positive change of over 10%, which is very promising. From a practical point of view, the similarity between two spectra was increased by over 10%, which is significant when spectral libraries have to be synchronized.

The results indicated that the post-correction of the curves was effective when the raw reflectance values were known and well documented. The spectral characteristics of the reference materials are as important as the technical properties of the devices. It is important to emphasize that the numerical results of this investigation are only valid for those materials measured by these 3+1 spectrometers. But in general, the following conclusions can be drawn:

- When reflectance spectra originate from different sources and a comparison must be executed, then post-correction is very advisable and a helpful tool. Systematic differences (see Fig. 3) introduced by device, reference panels or other time-resistance factors are able to be corrected. Post correction is possible when white reference raw values are available and well documented.
- There are many spectral libraries available worldwide and the database is growing. It is often very difficult, time-consuming and inaccurate to use them for scientific aims or comparisons. The standardization of spectral libraries is reasonable when hyperspectral satellites will be launched and spectra from different sources for the same targets will be compiled and evaluated. Before going global, local initiatives must be started and completed for comparing field spectro(radio)imeters. Reference panels used in practice have different chemical components, working-properties and spectral-properties. The spectral responses given by reference panels effect the ultimate results of the measurement, which can also be corrected.

With the results of this investigation it is concluded that it is advisable to support special-

ists in agriculture, geology, geography and other environment-related experts who intend to use or build multi-source ground-truth spectral libraries.

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