PRE-PROCESSING OF DUAL-VIEW FIGOS DATA: TOWARDS OPERATIONAL BRDF RETRIEVAL

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KEY WORDS: Spectral Database, Metadata, Spectral Processing, BRDF

ABSTRACT:

The Bidirectional Reflectance Distribution Function (BRDF) is an inherent property of natural and manmade materials. Its effects depend on the illumination/observation geometry and wavelengths and are apparent in groundbased, airborne and spaceborne imagery. The BRDF is a fundamental quantity from which all other illumination/reflection configurations can be derived. Calibration and validation of hyperspectral images requires knowledge of the BRDF if spectrodirectional effects are to be accounted for. The BRDF can be retrieved from dual-view field goniometer system (FIGOS) data, which is stored in the spectral database SPECCHIO. The retrieval must be precluded by pre-processing steps, which apply transformations on the raw field data and according metadata. SPECCHIO has been updated to support such pre-processing. Intercalibrations of the involved instruments and temporal corrections lead to a network of operations to be applied to the input data. A generalisation of the processing has led to the concept of the Space Processing Chain, allowing the flexible combination of modules to form complex processing flows as required by the goniometer data pre-processing. The newly added support of intercalibration factors in the SPECCHIO data model will be an important asset in future round robin experiments. The Space Chain approach will operationalise the retrieval of BRDF from dual-view FIGOS data and generally increase the usefulness of the SPECCHIO system by the introduction of user configurable processing.

1. INTRODUCTION

The BRDF (Bidirectional Reflectance Distribution Function) is an object inherent property and describes the dependency of an observed reflectance on the wavelength and the illumination and observation geometry (Nicodemus et al., 1977). BRDF effects can be readily identified in airborne and satellite imagery and do hinder the straightforward utilization of such data for subsequent analysis, as identical objects can appear to have differing spectral signatures. The severity of surface specific BRDF effects in airborne imagery is dependant on the field of view (FOV), observation direction and orientation of the flight strip relative to the sun. Effects are most pronounced with large FOVs and flight directions perpendicular to the solar principal plane (Beisl, 2001).
Correction of BRDF effects in imagery requires knowledge of the BRDF of the involved objects to validate or parameterise according algorithms. The acquisition of spectrodirectional in situ data is a part of the calibration and validation (CalVal) activities carried out by the Remote Sensing Laboratories (RSL) (Nieke et al., 2007; Schopfer et al., 2007b).

Table 1 illustrates the possible combinations of conceptual illumination and reflection geometries according to Nicodemus (1977). An isotropic illumination L_i is assumed for these configurations.

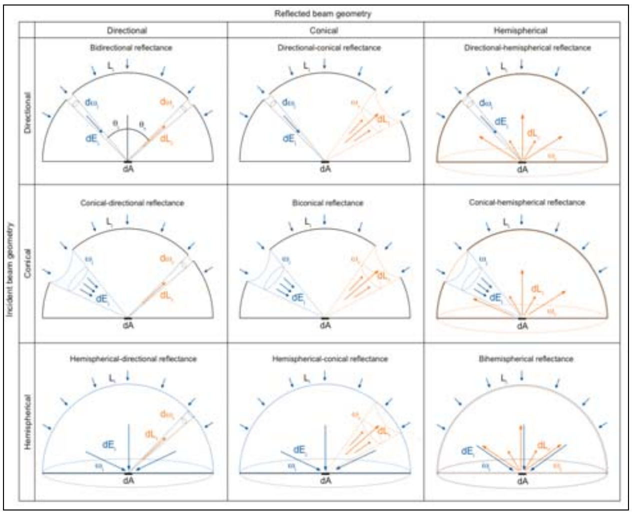

Table 1: Illumination and reflection geometries (adapted from Nicodemus et al. (1977))

From a geometry point of view, the hemispherical conical configuration describes the field case where the incoming radiance originates from the sky (i.e. hemispherical illumination) and the reflected radiance is sampled by an instrument with a finite detector size, i.e. the target with area dA reflects radiance into a solid angle towards the detector.

However, irradiance under field conditions is a mixture of directional and diffuse, non-homogenous, hemispherical components as shown in *Table 2* (Schaepman-Strub et al., 2006).

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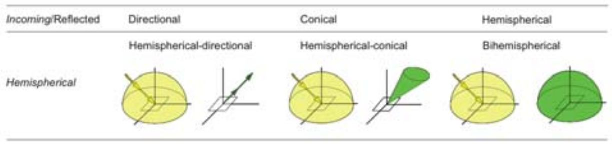


Incoming/Reflected	Directional	Conical	Hemispherical
Hemispherical	Hemispherical-directional	Hemispherical-conical	Bihemispherical

Table 2: Illumination and reflection geometry configurations in the field case (Schaepman-Strub et al., 2006)

The hemispherical conical case (*Table 2*) is the configuration that describes the illumination/reflection geometry under field conditions. Under clear sky conditions most energy is stemming from the direct solar irradiation while a minor part is contributed by the indirect radiation originating from scattering processes in the atmosphere and from adjacent objects. The indirect component is inhomogeneous over the incoming hemisphere: largest values are observed close to the direct irradiance direction and minimum values in the principal plane opposite the sun position. For clarity, we will refer to the hemispherical-conical configuration under field conditions as "Field HCRF" within this paper.

The BRDF is the most fundamental of the configurations shown in Table 1, as all others may be derived from it by integration over the illumination and reflection angles. The provision of accurate, spectral albedo imagery products (e.g. bi-hemispherical reflectance), as is foreseen for the APEX (Airborne Prism Experiment, (Nieke et al., 2005)) processing facility, depends on knowledge of the BRDF of the sampled objects.

It is thus the goal the retrieve the BRDF from empirical data collected under the field conditions, i.e. from Field HCRF data. An according retrieval algorithm has been proposed by Martonchik (1994) and was experimentally applied to dual-view FIGOS (Field Goniometer System) data by Schopfer et al. (2007a).

The BRF (Bidirectional Reflectance Factor) is the BRDF normalized to the reflectance characteristics of an ideal Lambertian reflector ($\mathrm{BRDF}_{\mathrm{Lambert}} = \pi^{-1}$) and is calculated by dividing the BRDF by the factor of π. The BRF is retrieved from field data by iteratively solving the following equation for *R* (Schopfer et al., 2007a):

$$L_r(\theta_r,\theta_0,\phi_r-\phi_0)=\pi^{-1}\cdot R(\theta_r,\theta_0,\phi_r-\phi_0)\cdot E_{dir}(\theta_0)+$$

$$\pi^{-1}\int_0^{\pi/2}\int_0^{2\pi} R(\theta_r,\theta_i,\phi-\phi_i)\cdot L_{diff}^{inc}(\theta_i,\theta_0,\phi_i-\phi_0)\cdot\sin(\theta_i)\cdot\cos(\theta_i)d\theta_i d\phi_i$$

(Eq. 1)

Where

θ_i,θ_r = illumination and view zenith angles
$\phi_{i,r}-\phi_0$ = illumination or view azimuth angle relative to the solar principal plane
$R(\theta_r,\theta_i,\phi-\phi_i)$ = Bidirectional Reflectance Factor (BRF) of the target for the given illumination angles.

Prerequisites of the retrieval are the quantities L_r, E_{dir} and L_{inc_diff}, which should be measured in the field. However, due to the instrumentation used, field data must be subjected to pre-processing before the retrieval can be started.

This paper describes the dual-view FIGOS data acquisition and storage, the generation of metadata and the pre-processing applied prior to a BRDF retrieval in the context of the spectral database SPECCHIO (Hüni et al., 2008), which is used to store the according spectral data and metadata.

2. DATA ACQUISITION AND PREPARATION

2.1 Data Acquisition

Acquisition of spectrodirectional datasets is based on the dual-view FIGOS. Two ASD FieldSpec 3 spectroradiometers (Analytical Spectral Devices Inc., 2007) are mounted on a sledge running along a zenith arc and capture the down-welling (L_{inc_diff}) and up-welling (L_r) radiances (Schopfer et al., 2007a). Due to saturation and pointing problems, the direct illumination E_{dir} is not measured with the upward looking ASD but with an MFR sunphotometer (Yankee Environmental Systems Inc., 2000) that collects the incoming total and diffuse radiance in six narrow spectral bands (central wavelengths: 413, 496, 612, 671, 867, 935 nm) and one broadband channel.

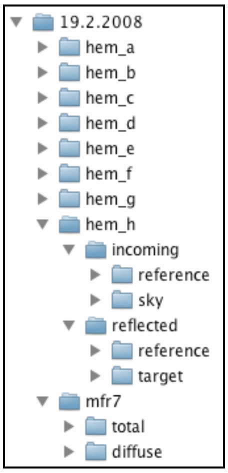
Data collection for one target is usually carried out during one day with varying illumination angles, resulting in several dual-view goniometer data sets.

2.2 Data Structuring

Organised data collection is an important issue and the structuring of the data in a defined way not only helps the acquisition process but also aids subsequent data handling.

The two instruments capturing the incoming and reflected radiances are being controlled by two independent laptops. Thus, these data must be combined into one dataset before loading them into the database. Furthermore, dual-view goniometer data sets must be divided into sky/target and reference panel measurements. The latter are taken according to a predefined sampling protocol and are of importance for (a) conversion of radiances to reflectances and (b) calculations needed during the pre-processing, as will be detailed later on.

A hierarchical structure thus holds the data (ASD and MFR files) for one target and must be set-up and filled accordingly prior to the loading into SPECCHIO (*Figure 1*).



- 19.2.2008
  - hem_a
  - hem_b
  - hem_c
  - hem_d
  - hem_e
  - hem_f
  - hem_g
  - hem_h
    - incoming
      - reference
      - sky
    - reflected
      - reference
      - target
  - mfr7
    - total
    - diffuse

Figure 1: Hierarchical structure holding dual-view goniometer data plus sunphotometer measurements for one target

2.3 Data Storage

Data is stored in the spectral database SPECCHIO (Hüni & Kneubühler, 2007). It is a central repository for spectral data and associated metadata, based on a MySQL relational database. The database is interfaced with a Java application, providing graphical user interfaces for data input, editing, visualising, processing and output. The long-term usability and shareability of the spectral data is supported by metadata, consisting of 34 variables, effectively defining the so-called metadata space (Hüni et al., 2007b).

2.4 Metadata Generation

Among the host of metadata variables that are required to be entered into the database, the following subset is of major importance for the retrieval process and is thus elaborated in greater detail: spatial sampling position, capturing time, illumination and viewing angles.

The SPECCHIO application offers functions for the automated generation of metadata such as the calculation of the sampling/illumination geometry.

The goniometer angles can be calculated based on the temporal sequence of the spectroradiometer files, as the movement of the goniometer is predefined. *Figure 2* shows the sampling points projected onto a 2d Cartesian coordinate system. Sensor zenith angles range from 0° - 75° at 15° intervals and azimuth angles from 0° - 330° with a step size of 30°.

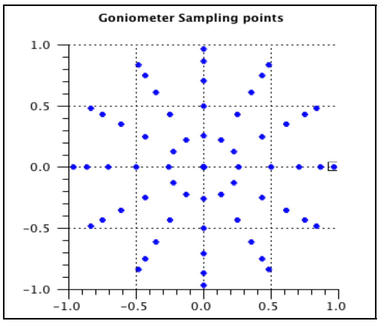


Figure 2: FIGOS sampling point positions

The sun angles can be calculated if the sampling time in UTC and the spatial position in latitude and longitude are given. A UTC timeshift utility enables to correct local time to UTC while the spatial position can be entered manually or directly read from the ASD binary files if a GPS device had been connected to the system during the sampling process.

3. PRE-PROCESSING

The goal of the pre-processing is to produce the input quantities required for the subsequent BRF retrieval. This input data must be contained within one single spectral space, i.e. the number of bands, the central wavelengths and spectral response functions must be the same for all spectral data vectors.

3.1 Dataflow and Processes

The pre-processing includes a number of calculations that are detailed in the following subsections. *Figure 3* shows the dataflow diagram (DFD) of the dual-view FIGOS data pre-processing. Input sources are the spectral database SPECCHIO and, optionally, MODTRAN lookup tables (LUT).

3.1.1 ASD – MFR Intercalibration

The intercalibration is required to make measurements of the involved instruments comparable.

The intercalibration procedure yields intercalibration factors for each MFR band, thus enabling the correction of MFR data with the ASD instrument being taken as the reference.

Calculation of the factors is based on the total irradiance E_{tot} , directly measured by the MFR and indirectly by the ASD. E_{tot_ASD} can be calculated from Spectralon (Labsphere) reference panel readings:

$$E_{tot\_ASD}(\theta_0) = \frac{L_{r\_WR}(0°,\theta_0) \cdot \pi}{R_{WR}(0°,\theta_0)} \qquad \textit{(Eq. 2)}$$

Where

$L_{r\_WR}(0°,\theta_0)$ = Spectralon reflected radiance, measured from nadir for the given illumination zenith angle.

$R_{WR}(0°,\theta_0)$ = Correction factor for the non-lambertian behaviour of the Spectralon panel, obtained from the BRF of the panel for the given zenith angles (Sandmeier et al., 1998; Schopfer, 2008).

E_{tot_ASD} is then convolved to the narrow MFR bands and intercalibration factors are calculated for each channel of the E_{tot_MFR} . These factors are subsequently applied to the E_{dir_MFR} data.

3.1.2 ASD Intercalibration

Intercalibration between the two used ASD instruments is not relying on data captured during the goniometer sampling experiment but based on factors obtained during a laboratory calibration campaign (Schopfer, 2008). The according intercalibration factors are stored as vectors in the SPECCHIO database and can be retrieved by an SQL query with constraints on the involved instrument numbers and the sampling date.

The reference instrument is the downward looking ASD as it is used to capture the Spectralon reflectances that are utilised for the MFR intercalibration. Thus, both MFR and upward looking ASD are tied to the same reference instrument.

3.1.3 E_{dir} Generation

The MFR instrument measures with a temporal frequency that allows the determination of E_{dir} for every sampling position of the goniometer. However, the limited spectral resolution and range of the MFR data is not sufficient for the BRF retrieval that requires E_{dir} to be available with the same number of bands and spectral resolution and range as the incoming and upwelling radiance measurements.

To achieve the transformation of $E_{dir\_MFR\_ic}$ into the spectral space defined by the ASD sensor, $E_{dir\_MFR\_ic}$ must be augmented by E_{dir_ASD}. E_{dir_ASD} is calculated by applying the ratio between E_{dir_MFR} and E_{tot_MFR} to E_{tot_ASD}.

However, the spectral range of the MFR instrument prohibits the calculation of E_{dir} for wavelengths above 1000nm. To overcome this limitation, the utilisation of MODTRAN data is a possible option to estimate the direct irradiance up to 2500nm.

3.1.4 Saturation Detection

The detection and filtering of saturated, upward looking measurements ($L_{inc\_diff\_ic}$) taken around the sun direction is necessary due to (a) incorrect radiance values of these readings due to saturation and (b) interference with the BRF retrieval scheme that requires E_{dir} and L_{inc_diff} to be measured as separate entities.

The filtering thus removes potential direct irradiance components from the upward looking ($L_{inc\_diff\_ic}$) dataset.

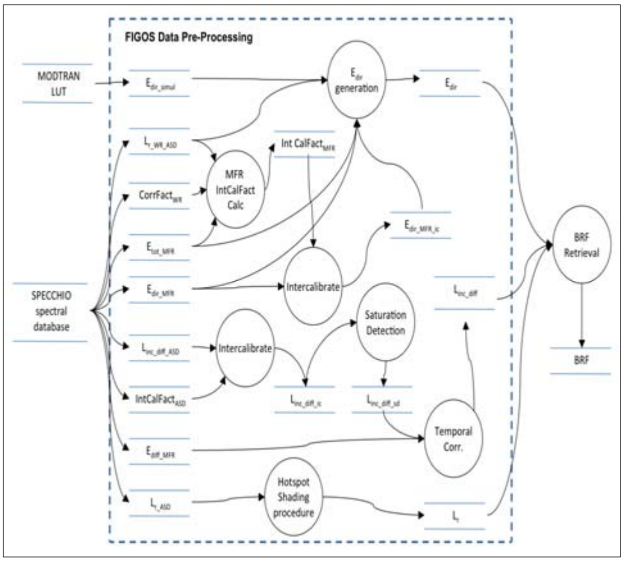


Figure 3: FIGOS Pre-Processing Dataflow Diagram

3.1.5 Temporal Correction

FIGOS data acquisition takes around 20 minutes per hemisphere. During this time the illumination angles and atmospheric conditions are changing. Consequently, the radiance incident upon the target is not constant and the recorded reflected energy is time dependant. This hinders the BRF retrieval as the diffuse, angular irradiance $L_{inc\_diff\_sd}$ is not available for the whole hemisphere for every point in time a target sample is taken. The temporal correction tries to account for changes in the diffuse irradiance by applying ratios derived from the E_{diff_MFR}.

3.1.6 Hotspot Shading

The FIGOS instrument has been built to minimise the hotspot shading by eccentric placement of the zenith arc (Schopfer et al., 2007a). The used fore optic is thus the only part that can produce shading effects (~1cm in diameter). Potentially affected readings can be selected based on the geometry and either be omitted from processing or replaced by interpolated values using the neighbouring samples.

3.2 Optional Pre-Processing Operations

Once the quantities E_{dir}, L_r and L_{inc_diff} have been calculated as outlined in the previous section, further subsequent operations might have to be applied. These may include: (a) removal of noisy bands, e.g. the well-known water vapour absorption wavelengths, (b) spectral dimensionality reduction, e.g. downsampling or (c) sensor convolution. The latter two transformations can both drastically reduce the volume of the data in the spectral domain and could increase the speed of the BRF retrieval considerably.

As the application, configuration and sequence of such transformations is not known a priori, the system must offer freely configurable, user definable processing (Hueni & Tuohy, 2006).

3.3 Generic Considerations

Processing operations are applied to data in a certain order and the according dataflow can be described by a directed graph, as can be observed in *Figure 3*. Such a network consists of processing modules and data sources/sinks. In order to avoid code redundancy and provide the flexibility as defined in 3.2, a generic approach is required that allows the application of modules to spectral data originating from the SPECCHIO database.

A further important requirement is the independence from specific sensors, i.e. processing modules should be applicable to data stemming from differing instruments in terms of number of bands, central wavelengths and spectral response functions.

3.4 Concept of the Space Processing Chain

A solution to the generic, flexible requirements outlined above is given by the concept of the 'Space Processing Chain'. It is based upon the definition of spectral spaces and feature spaces by Landgrebe (1997). The continuous, spectral response of an object is transformed into a discrete space by the sampling instrument. This transformation is defined by the sensor characteristics (Hüni et al., 2007a). Thus, data captured by different instruments are contained by different spaces. A space has a dimensionality equal to the number of bands of the used sensor and the spectra are data vectors contained within this space.

Processing modules are effecting a transformation on a space, i.e. the spectral data vectors of the input space are transformed to an output space. The algorithm of the processing module defines the dimensionality of the resulting space. This is illustrated in *Figure 4* with an input space of dimensionality N being transformed into another discrete space of dimensionality M.

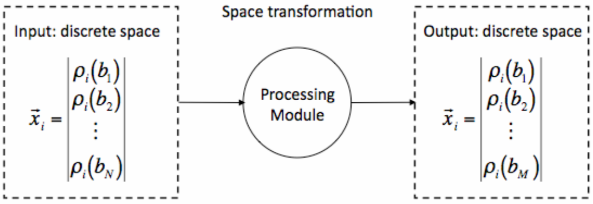


Figure 4: Transformation into a new space by a processing module

The Space Chain concept has been implemented in Java as part of the SPECCHIO application and offers graphical representations of the spaces and processes, thus allowing the user to check the effect of operations on the resulting spaces interactively.

4. DISCUSSION

The complexity of the pre-processing of dual-view FIGOS data prior to BRF retrieval is mainly due to the characteristics of the different instruments involved. Ideally, the irradiance should be measured at the same temporal and spectral resolution and wavelength range as the reflected radiance. Thus, a device that could capture direct and angularly resolved diffuse irradiance at a sampling rate equal to the target reflectance acquisition time would be highly desirable. This would provide a complete angular characterisation of the irradiance distribution for each spectrodirectional target measurement.

The use of several instruments requires intercalibrations. The storage of according intercalibration factors in the spectral database enables the automation of intercalibration. Similarly, the storage of Spectralon characteristics, i.e. factors describing deviations from the ideal Lambertian reflector, allows correcting measurements for these imperfections (Hüni et al., 2008). While Spectralon factors can be considered part of the metadata space of spectral data, the same does not strictly apply to intercalibration factors. The latter are rather metadata of the instruments. However, their storage within a spectral database is important as they can tie spectra to some common reference instrument. Such capability is highly desirable when dealing with campaigns involving many different instruments, e.g. round robin experiments as planned in the Hyper-I-Net project (Nieke et al., 2007).

The concept of the Space Processing Chain is using the SPECCHIO database as data source to build the chain input spaces. All spaces are then held in memory, leaving the original information in the database untouched. Chain outputs are not stored in the SPECCHIO database but can be exported to files or stored in specialised reference databases (Hueni et al., 2008). Due to the flexible and fast processing capabilities of the SPECCHIO Space Chain, reprocessing of original data is far easier than managing products by keeping track of all involved module parameters. It is however foreseen to implement the storage of chain configurations in the database or in configuration files. This will enable users to store and reload typical chain settings.

5. CONCLUSIONS

The automated pre-processing of dual-view FIGOS data is an important step towards an operational BRF retrieval. The utilisation of a database combined with a flexible, configurable processing chain allows dealing with the complex processing needs arising from instrument intercalibrations and differing spectral and temporal resolutions of the field data sets.

The generic, modular approach to processing of spectral data will enable the application of processing components to datasets acquired with different sensors, thus making the system useful for other research groups.

The inclusion of instrument intercalibration data in the database model is enabling the SPECCHIO system to be used in round robin experiments and is an important step towards comparable datasets in multi-instrument campaigns and, ultimately, better data quality.

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