Recent developments at DLR’s Calibration Home Base

P. Gege, A. Baumgartner, K. Lenhard, T. Schwarzmaier

Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Institut für Methodik der Fernerkundung, Oberpfaffenhofen, 82234 Wessling, Germany

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6700 employees across 33 institutes and facilities at 13 sites.

Recent developments at DLR‘s Calibration Home Base

Overview

- Original concept and set-up
- Realization of geometric, spectral and radiometric measurements
- Results for HySpex
- Recent upgrades
- Equipment for water applications
- Conclusions
DLR’s Calibration Home Base (CHB)

- Funded partly by ESA to establish Calibration Home Base (CHB) for APEX
- Operational since 2007
- Used for geometric, spectral and radiometric measurements
- Available to third parties
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- Designed for hyperspectral line scanners similar to APEX
  - Mass: < 500 kg (sensor + adapter)
  - \(\lambda\)-range: 380–2500 nm
  - Bandwidth: > 1–2 nm

Special features
- Close to airfield
- Suited for bulky and heavy instruments
- Sensor in same position as in aircraft
- Sensor stable on vibrationally isolated bench
Folding mirror concept

1. Pillar bearing instrument + adapter
2. Folding mirror
3. Assembly for geometric measurements
4. Assembly for spectral measurements

5. Sensor ROSIS
6. CHB adapter
Radiometric measurements

1. Frame

2. Small integrating sphere for absolute calibration
   4 lamps, diameter 50 cm, aperture 4 x 20 cm², originally traceable to PTB

3. Large integrating sphere for relative calibration (flatfielding)
   18 lamps, diameter 165 cm, aperture 40 x 55 cm²
Auxiliary measurements

Detector linearity
- Small sphere and neutral density filters

Spectral stray light
- Monochromator
- Small sphere and bandpass filters

Spatial stray light
- From inside FOV: set-up for geometric measurements (LSF)
- From outside FOV: large sphere and reflectance targets

Polarisation
- 3 linear polarisers 0.47 – 2.5 µm
Sensor characterisation uses relative intensity (I) measurements at well defined incident angles $\theta$ and wavelengths $\lambda$:

- Geometric: $I_{x,c}(\theta, \lambda)$ vs. $\theta$
- Spectral: $I_{x,c}(\theta, \lambda)$ vs. $\lambda$

Calibration is the inverse:

- Geometric: $\theta(x, c)$
- Spectral: $\lambda(x, c)$
Set-up for geometric measurements

- Quartz halogen lamp illuminates narrow slit
- Collimator produces nearly parallel light beam
  - divergence $\ll$ IFOV
  - cross section $>\$ sensor aperture
- Folding mirror scans over pixels
Line spread function (LSF)

- LSF(x, c) is the relative response of pixel x and channel c as function of the incident angle
- Derived information
  - Viewing angle relative to reference pixel
  - Angular resolution = IFOV = FWHM
  - Keystone: each pixel has own LSF

![Graph of LSF with FWHM = 0.31 mrad](image-url)
Results for HySpex VNIR-1600

HySpex system mounted in DLR aircraft

1 VNIR camera
2 SWIR camera
3 Navigation system
4 Stabilized platform
Set-up for spectral measurements

- Monochromator scans over wavelength
  - Range: 0.38–2.5 µm
  - Uncertainty: ± 0.1 nm
  - Spectral bandwidth: > 0.1 nm
- Parabolic mirror focusses beam
  - divergence ≥ IFOV
  - cross section > sensor aperture
- Folding mirror selects some pixels
Spectral response function (SRF)

- SRF(x, c) is the relative response of pixel x and channel c as function of wavelength
- Derived information
  - Center wavelength
  - Spectral resolution = FWHM
  - Smile: each pixel has its own SRF
Results for HySpex VNIR-1600

HySpex system mounted in DLR aircraft

1 VNIR camera
2 SWIR camera
3 Navigation system
4 Stabilized platform
Set-up for radiometric measurements

- Sensor is mounted to integrating sphere
  - Large sphere for relative calibration
  - Small sphere for absolute calibration
Radiometric response

- **Relative response** of pixel $x$ are the sensor signals $S(c)$ relative to a reference pixel $x'$ when all pixels are illuminated with the same intensity:
  - $\rho(x, c) = \frac{S(x, c)}{S(x', c)}$

- **Absolute response** is the ratio of the measured signal to the radiance $L$ from a calibrated light source and integration time $t$:
  - $r(x', c) = \frac{S(x', c)}{[t \times L(x', c)]}$

- For pixels not illuminated by the $L$ source:
  - $r(x, c) = r(x', c) / \rho(x, c)$

- **Effects influencing response**
  - Polarization
  - Noise
  - Nonlinearity: $S$ not always proportional to $L$ or $t$
  - Stray light: $S(x, c)$ affected by light from angles and wavelengths outside the ranges of element $(x, c)$
  - Electronics: quantization, smear, memory effects
Results for HySpex VNIR-1600

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At signals < 300 DN additional uncertainty of 5% was assumed based on manufacturer information about non-linearity (worst-case estimate)
Results for HySpex VNIR-1600

Sensitivity to polarization

Nonlinearity

Noise

Stray light
Recent upgrades

**Tunable laser**

*For spectral calibration and stray light measurements*

- Tunable from 410 – 2550 nm
- Spectral linewidth fix at 0.5 – 2.5 nm
- 10 ns pulses @ 10 Hz
- Illumination of instruments via integrating sphere
Recent upgrades

6 precise filter radiometers
For radiometric measurements and monitoring of stability

- Much more stable than lamps
- Temperature stabilized to <0.001 °C during 1 h
- Large dynamic range: 8 decades
Recent upgrades

Radiance Standard RASTA
New radiance standard of CHB

1. Light source: FEL 1000 W halogen lamp
2. Diffuser: Spectralon panel (25 x 25 cm²)
3. Monitoring of stability: 5 filter radiometers
   - Calibration at PTB:
     - FEL lamp: irradiance
     - Spectralon panel: reflectance
     - Complete system: spectral radiance
Recent upgrades

Spectrometer SVC HR-1024i
To calibrate radiance sources against RASTA

- Range: 350 – 2500 nm
  - 512 Si Detectors @ 350 – 1000 nm
  - 256 InGaAs Detectors @ 1000 – 1850 nm
  - 256 Extended InGaAs Detectors @ 1850 – 2500 nm
- Spectral resolution (FWHM)
  - ≤ 3.5 nm @ 350 – 1000 nm
  - ≤ 9.5 nm @ 1000 – 1850 nm
  - ≤ 6.5 nm @ 1850 – 2500 nm
- Field of view
  - 2°, 4°, 8°: lenses
  - 25°: glass fibres with lengths of 1.15 m, 3 m
- Digitization: 16 bit
Equipment for water applications

**Laboratory instruments**
- Varian Cary-1 UV/VIS spectrophotometer (190-900 nm) – *old*
  - Used to measure CDOM absorption
- PerkinElmer Lambda 1050 UV/VIS/NIR spectrophotometer (190-3300 nm) – *new*
  - Used to measure CDOM and phytoplankton absorption
- Horiba Fluoromax-4 fluorescence spectrometer (220-850 nm) – *delivery May 2014*
  - Used to measure CDOM and phytoplankton fluorescence (EEM)

**Field instruments**
- TriOS RAMSES (190-900 nm)
  - Used to measure $L_u$, $E_u$, $E_d$ in air and under water
- Spectra Vista SVC HR-1024i spectrometer (350-2500 nm)
  - Used to measure $L_u$, $E_d$ in air
- Microtops sun photometer and ozonometer
  - Used to derive atmospheric ozone, water vapour and aerosol optical depth
Conclusions

- CHB was designed for airborne imaging spectrometers (line scanners)
  - Fully computer controlled including data evaluation
  - It was used for APEX, ROSIS, HySpex, AISA
  - Cooperation with PTB assures state-of-the-art accuracy and traceability
  - ISO-9001 certified in 2013

- CHB is equipped to measure optical properties
  - Transmission, reflectance, absorption, fluorescence

- Recent upgrades improved
  - Accuracy of radiometric calibration
  - Speed of spectral measurements
  - Dynamic range of stray light measurements

- CHB is partly suited for field spectrometers
  - Radiometric calibration: feasible for radiance in air, but not for irradiance and not in water
  - Spectral characterization: feasible; range and accuracy depends on instrument
  - Geometric characterization: feasible; range depends on instrument
  - Stray light: estimate possible, but no full characterization
  - Linearity: feasible
  - Polarization sensitivity: feasible