Optical multi-spectral images: processing and applications

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The last time

- What means “Optical Remote Sensing”
- The history of a success: from Bievre Valley to the entire World
- The electromagnetic spectrum

- Some applications
- The optical measurement and the signal components

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The last time

- Spatial features discrimination

- Radiometric resolution
- The spectral resolution: from panchromatic to hyperspectral
- The evolution of optical sensors:
  - Very high resolution multi-spectral
  - High/medium resolution multi-spectral
  - High/medium resolution hyperspectral
  - Multi-spectral wide swath for global coverage
Figure 2.1.1 Classification of Sensor

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And today…

Wiskbroom and pushbroom instruments

From the acquisition to the radiance
• Data reformatting and geometric correction
• Conversion to radiance
• Correction of radiometric artifacts: destriping

From the radiance to the surfaces reflectance
• The effects of the atmosphere
• Atmospheric correction and reflectance calculation
• Reflectance of surfaces

Applications
• Classification: basic concepts, techniques and examples
• Vegetation indexes: why, technique, examples
Pushbroom or along track sensors

The sensor is composed by lines of detectors oriented normal to the flight path. The scene is scanned by the lines while the spacecraft advances following its orbit.

For each spectral band corresponds a line of detectors.
Wiskbroom or across track sensors

The radiance is addressed toward a small line of detectors by a rotating mirror which sweeps the scene along the line transversing to the orbit direction.
1 - Mainframe
2 - Aperture Sunshade
3 - Scan Mirror
4 - Primary Mirror
5 - Secondary Mirror
6 - Prime Focal Plane
7 - Hybrid Preamplifiers
8 - Calibration Shutter
9 - Black Body
10 - Relay Optics Assembly
11 - Radiative Cooler
12 - Circuit Card Assemblies
13 - Earth Shield
14 - Electronics Module
15 - Power Supplies
16 - Thermal Control Louvers
17 - Full Aperture Calibrator Assembly
Spot5 HRG camera

Copyright SPOT, from http://spot5.cnes.fr
Data reformatting and geometric correction

The data reformatting processing aims to organize the information coming from the detectors in order to reproduce the real scenario.

Geometric correction is undertaken to avoid geometric distortions from a distorted image, and is achieved by establishing the relationship between the image coordinate system and the geographic coordinate system.

Conversion to radiance (i)

This step aims to calculated the physical radiances reaching the sensor starting from the digital numbers (DN) associated to the levels of signal captured by the electro/optic transducers.

The formula used:

\[ L_{\lambda} = \text{Gain} \times \text{DN} + \text{Bias} \]

Also expressed as

\[ L_{\lambda} = \left( \frac{(L_{\lambda \text{MAX}} - L_{\lambda \text{MIN}})}{(\text{DN}_{\text{MAX}} - \text{DN}_{\text{MIN}})} \right) \times (\text{DN} - \text{DN}_{\text{MIN}}) + L_{\lambda \text{MIN}} \]

\( L_{\lambda \text{MAX}} \) corresponds to the max quantized DN (\( \text{DN}_{\text{MAX}} \))

\( L_{\lambda \text{MIN}} \) corresponds to the min quantized DN (\( \text{DN}_{\text{MIN}} \))

Considering values at 8 bit:

\( \text{DN}_{\text{MAX}} = 255 \)

\( \text{DN}_{\text{MIN}} = 0 \) or 1 (according to the considered standard)

Conversion to radiance (ii)

Values calculated during the satellite life

Table 11.2 ETM+ Spectral Radiance Range
watts/(meter squared * ster * µm)

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Before July 1, 2000</th>
<th>After July 1, 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Gain</td>
<td>High Gain</td>
</tr>
<tr>
<td></td>
<td>LMIN</td>
<td>LMAX</td>
</tr>
<tr>
<td>1</td>
<td>-6.2</td>
<td>297.5</td>
</tr>
<tr>
<td>2</td>
<td>-6.0</td>
<td>303.4</td>
</tr>
<tr>
<td>3</td>
<td>-4.5</td>
<td>235.5</td>
</tr>
<tr>
<td>4</td>
<td>-4.5</td>
<td>235.0</td>
</tr>
<tr>
<td>5</td>
<td>-1.0</td>
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<td>6</td>
<td>0.0</td>
<td>17.04</td>
</tr>
<tr>
<td>7</td>
<td>-0.35</td>
<td>16.60</td>
</tr>
<tr>
<td>8</td>
<td>-5.0</td>
<td>244.00</td>
</tr>
</tbody>
</table>
Correction of radiometric artifacts: destriping

The stripes problem
Its source can be traced to individual detectors that are miscalibrated with respect to one another. It means that illuminating the array with the same radiance, the transducers provide different quantized values.

The application of the calibration coefficients (gain and bias) could in some cases delete this noise.

But in many cases an additional processing is required in order to compensate the residual stripes effect.

Solution
• Spatial filtering
• Histogram matching using the recalibration formula
• Advanced filtering
Some examples

More than 30 years of hard work against the stripes!

Landsat MSS

Hyperion band 1

MOS-B band 12

CHRIS band 1
Destriping using spatial filters

- Low pass filter
  - Very wide
  - Not very tall

- High pass filter
  - Very wide
  - Very short

- Immagine combinata
  - Depurata da stripes

• http://isis.astrogeology.usgs.gov/IsisWorkshop/Lessons/Destripe/
Destriping based on advanced filtering

Since two years also the Tor Vergata PhD Programme has given an important contribution to the solution for the stripes noise.

A tool to destripe the optical images of CHRIS Proba-1 has been developed and tested in several cases.

The algorithm is based on the low pass filtering in the spatial frequency domain.

PRINCIPAL STEPS:
- Calculation of the radiance average of each column (each detector)
- FFT over the averages
- Low-pass filtering step
- Estimation of the parameters for the equalization
- Correction
Examples of correction

Lybian desert

**Before destriping**  **After destriping**
Examples of correction

No more stripes in our campus

Frascati/Tor Vergata

Before destriping

After destriping
Examples of correction

And also no more stripes in USA… but nor really…

Tampa bay (USA)
The components of the signal

1. Radiance scattered by the atmosphere to the sensor
2. Radiance coming from adjacent targets
3. Radiance reflected by the target illuminated by direct + diffuse irradiance
4. Radiance reflected by the target illuminated by multiple scattering

THE ATMOSPHERE CONTRIBUTION PLAYS AN IMPORTANT ROLE IN THE RADIANCE CAPTURED BY THE SENSOR
The atmospheric scattering

It is due to the gasses present in the atmosphere

It depends by:
• $\lambda$ of radiation
• amount and type of molecules of gas
• length of the path

1. Scattering of Rayleigh
2. Scattering of Mie
3. No selective
The Rayleigh scattering

Molecules $\ll \lambda$ of radiation

Presence of powder, N2, O2

It is prevalent for short $\lambda$ and in the highest layers of the atmosphere

And more…
• It tends to decrease if $\lambda$ increases, it is predominant in the blue with respect to the red $\lambda$
• During the day prevails in the blue visible
• During the sunset and the sunrise the blue is totally scattered, in fact the sky appears more yellow and red
• The presence of dust and powder can enhance the effect
Mie Scattering

Molecules $\approx \lambda$ of radiation

Presence of powder and water vapor

It produce effects for larger $\lambda$ with respect to the Rayleygh but it is less depended to the $\lambda$

It is present on the lowest part of the atmosphere
No selective

Molecules >> $\lambda$ of radiation

Presence of large dust or powder, little drops of water

The scattering is the same for all $\lambda$

Presence of clouds, fog, large amounts of aerosols

White optical effects
Atmospheric absorption

Photons absorbed by molecules of gases

Strong dependence to the $\lambda$ of radiation

Gasses like $\text{CO}_2$ and $\text{O}_3$

$\text{O}_3$ absorbs for lower $\lambda$, for this reason the UV rays do not burn the human beings
Atmospheric correction: the problem

What does it do?
The goal of Atmospheric Correction is to completely remove the absorption and the scattering effects of the Earth’s atmosphere to allow conversion of the image data to a primary physical parameters: reflectance.

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\[ L_{\text{tot}} = L_{\text{path}} + L_{\text{target}} + L_{\text{adj}} \]

But why more processing?
- Better discrimination of surfaces and materials
- Comparison among images of different dates and angles
- Vegetation indexes retrieval
- Comparison among spectral information coming from different sensors or ground instruments
- Fine classification
Atmospheric correction: the goal

Our purpose is to compensate the atmospheric noise in order to calculate the reflectance.

The flux of energy which illuminated a surface $\Phi(\lambda) \text{ W} \mu\text{m}^{-1}$ can be divided in three main components:

$$\Phi(\lambda) = r\lambda + t\lambda + a\lambda \quad \Rightarrow \quad \alpha(\lambda) + \rho(\lambda) + \tau(\lambda) = 1$$

- $r\lambda$: reflected component
- $t\lambda$: transmitted component
- $a\lambda$: absorbed component

They depend on the physical and chemical properties of the target.
What is the reflectance?

- It describes the reflective properties of target and surfaces in function of the $\lambda$
- It is indicated with a number between 0 and 1 or between 0% and 100%

SURFACES
**Mirror like**: energy in the angle of illumination = energy in the angle of reflection

**Perfect diffusive**: energy measured under every angle of view does not change
Surfaces

Figure 2.1 Four examples of surface reflectance: (a) Lambertian reflectance (b) non-Lambertian (directional) reflectance (c) specular (mirror-like) reflectance (d) retro-reflection peak (hotspot).

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From the radiance to the reflectance

Landsat 7 multispectral channels 30 m of spatial resolution

Radiances simulated for a conifer forest, changing different water vapor content
Examples of reflectance signatures

Figure 1.9.1 Spectral reflectance of vegetation, soil and water

Figure 1.9.4 Spectral reflectance of rocks and minerals

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Atmospheric correction: methodologies

EMPIRICAL
Is based on the knowledge of the radiometric and reflective properties of predefined areas or targets inside the image.
- **Areas:** the histogram of corrupted areas is matched to the histogram of clean areas
- **Targets:** the analysis performed using well defined spectral control points allows the correction of the whole image.

Simple methods, very fast, not much processing, mostly used
In some cases not good correction, the correction can not be absolute, a priori knowledge

ATMOSPHERIC MODELING
The atmospheric properties are estimated or obtained by external sensors. The radiative quantities (irradiance, transmittance and scattering) are simulated by the use of a model and used during the correction.

Very effective methods, good correction
Expensive, in some case difficult, difficulties on the retrieval of atmospheric parameters
Esempio: Immagini corrette atmosfericamente

Bosco denso

CHRIS Proba 2007

Correzione atmosferica applicata

Immagine originale di radianza TOA
Esempio: Immagini corrette atmosfericamente

Asfalto
Parcheggio policlinico TV

Correzione atmosferica applicata

Immagine originale di radianza TOA

CHRIS Proba 2007
The classification processing (i)

Definition
Multispectral classification is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criteria.
From ERDAS field guide

The classed could be associated to real features on the ground (asphalt, vegetation, bare soil,...) or simply because they appear different according a specific criteria.

Pattern recognition
Is the science (and art) of finding meaningful patterns in data (using spectral or spatial information), which can be extracted through classification.
From ERDAS field guide
The classification processing (ii)

Training Phase
It is possible to instruct the system to identify patterns in the images

*Supervised training*
Several training patterns are submitted to the system and it uses these example to build the knowledge

*Unsupervised training*
Is more computer-automated. Some statistical information are provided to the system which organizes the knowledge in order to identify a certain number of pattern according to the information

Classifying phase
All the image are processed and the pixel are divided in classes using a pre-defined rule
The classification processing (iii)

**Decision rule** is a mathematical algorithm that, using data contained in the signature, performs the actual sorting of pixels into distinct class values.

**Parametric rules:** there is a statistical characterization of the information contained in the signatures
- Minimum distance
- Mahalanobis distance
- Maximum Likelihood/Bayesian rule

**Non parametric rules:** not based on the statistics, definition of intervals (spaces) related to the decision
- Parallelepiped
Non parametric rule: parallelepiped

- $\mu_{B2} = \text{mean of Band B, class 2}$
- $\mu_{B2} = \text{mean of Band B, class 2}$
- $\mu_{A2} = \text{mean of Band A, class 2}$

$\bullet$ = pixels in class 1
$\triangle$ = pixels in class 2
$\diamond$ = pixels in class 3
$?$ = unclassified pixels

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Production of land cover maps

Highway asphalt
Road asphalt
Residential
Bare soil-arable land
Unclassified
Clouds (withe)
Commercial-Industrial
Vegetated areas
Forest
Very high resolution land cover

Bare Soil
Asphalt
Vegetation
Urban Fabrics (white)

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The importance of vegetation monitoring

Remote sensing has proven a powerful "tool" for assessing the identity, characteristics, and growth potential of most kinds of vegetative matter at several levels (from biomes to individual plants)
Vegetation indexes and maps

Analysis of the reflective properties in several spectral bands can be carried out to monitor the status, the development, the density and the productive potentiality of vegetated areas and cultivated fields.

Spectral bands are properly combined to produce indexes related to the vegetation condition:
- **NDVI**
  \[ \text{NDVI} = \frac{\text{NIR} - \text{red}}{\text{NIR} + \text{red}} \]
- **LAI**
- **FAPAR**

For this kind of analysis sensors at medium and low resolution wide swath are used (MODIS, AVHRR, MERIS, SPOT Vegetation,…).
Examples

Monitoring of productive areas in Italy using MERIS processed with the FAPAR algorithm

Red areas agricultural high photosynthetic fields
Yellow areas low photosynthetic activity

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And now you...

http://www.disp.uniroma2.it/geoinformazione/