Realization of a UV fisheye hyperspectral camera

Valentina Caricato, Andrea Egidi, Marco Pisani and Massimo Zucco, INRIM
Outline

• Purpose of the instrument
• Required specs
• Hyperspectral technique
• Optical design
• Realization and preliminary tests
Purpose of the instrument

• Purpose of the device is to create a complete spectro-gonioiometric map of the irradiance of the sky in the UV

• The map will be used to correct cosine error typical of commercial UV spectroradiometers

• The target could be acheived with a scanning spectroradiometer, but we prefer to use Hyperspectral Imaing technique because is much faster
Specifications

• Specs
  – Field of view $> \pm 80^\circ$
  – Spatial resolution $\leq 1^\circ$
  – Spectral range 310-400 nm
  – Spectral resolution $\leq 5$ nm
  – Good dynamic range

• The instrument must be compact and transportable to be easily calibrated and operated in the field

UVNet Workshop, Davos 27-28 August 2013
Hyperspectral Imaging

A hyperspectral imaging system (HI) is a combination of imaging device (a digital camera) and a spectrophotometer.

The obtained data set, known as “hyperspectral cube”, is a 3D matrix formed by a 2D image combined with a third dimension that is the spectral composition of each pixel of the image.
Classical hyperspectral devices

- Dispersive (pushbroom)
- Tunable filter (LCTF)
- Michelson interferometer (FTS)
A new concept: from Michelson to F-P resonator used as a two beams interferometer

M. Pisani and M. Zucco, Optics Express, 17 (10), pp.8319-8331, (2009)
• The intensity modulated light signal is captured in a video during the F-P cavity length scanning.

• The spectral composition is calculated by means of a Fourier Transform based algorithm from the interferogram.
The INRIM scanning F-P interferometer

The Fabry-Perot interferometer is made of two glass mirrors mounted in aluminum frames.

The distance between mirrors is varied by means of three piezo actuators.
Device main elements

F-P interferometer

Digital camera for video acquisition

Photographic objective to focus the image on the camera sensor
Emission spectra

Coloured pattern from LCD display with LED backlight
Reflection spectra
Spectral analysis in the visible range
In Vivo Hyperspectral Imaging
Spectroscopy in the IR region: Long distance atmospheric absorption
The F-P cavity in the UV

A new F-P cavity more compact and robust is under construction and will be integrated in the optical system. The new F-P will be based on motor actuators in order to compensate for temperature induced deformations.
Design of the optical system

- A fisheye objective with good efficiency in the 280-400 nm range is required.
- A fisheye objective in the UV is not commercially available, must be designed from scratch.
- A refractive design although possible would be extremely complex.
Catadioptric solution

- A wide angle image can be easily obtained by looking «through» a convex mirror.
- A catadioptric system combines a traditional refractive system with a mirror.

Catadioptric scheme from an early 20th century patent.
Catadioptric solution

- Commercial devices are available but not compliant with UV requirements

Fisheye catadioptric commercial camera from Nanophotonics
Realization of the mirror

The mirror has been realized starting from a glass lens vacuum coated with aluminium protected by a thin layer of \( \text{SiO}_2 \). The reflectivity exceeds 80% in the range of interest.
The objective

The objective is made by UKA optics from quartz lenses coated MgF₂. Is a 25 mm f= 2.8 lens with a transmittivity of 85% from 200 to 300 nm.
Camera selection

- **small transversal size**, because we have to minimize the shadow projected by the camera itself on the spherical mirror in order to scan the maximum portion of the sky above the system;
- **sufficient absolute quantum efficiency** down to 300 nm;
- **high frame rate** in order to acquire a sufficient number of frames in a small time.
Back thinned (or back illuminated) CCD

- The first choice because of its excellent efficiency in the UV.
Hamamatsu back thinned CCD

Quantum efficiency in the UV is excellent, but the speed is at best 1fps

Spectral response (without window)\(^{13}\)

(Typ. \(T_a=25\, ^\circ\text{C}\))

Front-illuminated CCD (UV coated)

Back-thinned CCD

Front-illuminated CCD

Wavelength (nm)

Quantum efficiency (%)
Kodak KAI 4022 CCD

- Scientific CCD with discrete responsivity in the UV (>5% @ 300nm), good dynamic range (16 bit) and speed, excellent spatial resolution (4 Mpixel)
Ascent 4000 camera

• Kodak sensor is integrated in the Ascent 4000 camera with dual 16 bit ADCs
In order to exploit the whole dynamic range of the camera a UV band pass filter is placed in front of the camera.

We have combined a dichroic short pass filter (blue curve) with a coloured glass blue filter (red curve) obtaining a band pass UV filter (yellow curve).
The assembled system
Resolution and sensitivity test

Camera set:
4x4 binning = 512x512 pixel image
Objective aperture f=8
Resolution at zenith

- Angular resolution $<< 1^\circ$
- Angular sensitivity $\approx 4.4$ pixel/deg
Resolution close to the horizon

- Angular resolution < 1°
- Azimuth sensitivity ≈ 4.4 pixel/deg
- Zenith sensitivity ≈ 2.5 pixel/deg
Angle of view

The angle of view has been evaluated theoretically and verified experimentally. Sky coverage exceeds ± 80° as required.

Edge of the mirror ≈ 6.5° above the horizon
Resolution and mapping

- With 4x4 binning the worst resolution exceeds 2pix/deg, so a 8x8 binning could be acceptable for a 1° resolution reducing the number of acquired spectra from 200 k to 50 k
- A complete mapping of the angular coordinate of each pixel will be obtained experimentally
Test in the field
Test of the camera sensitivity in the UV
To be done yet

- Integration of the Fabry-Perot device in the camera
- Spectral characterization
- Angular characterization
- In field measurements and comparison with reference instruments (classical spectrogoniometers)
Thank you!

http://www.inrim.it/res/hyperspectral_imaging/