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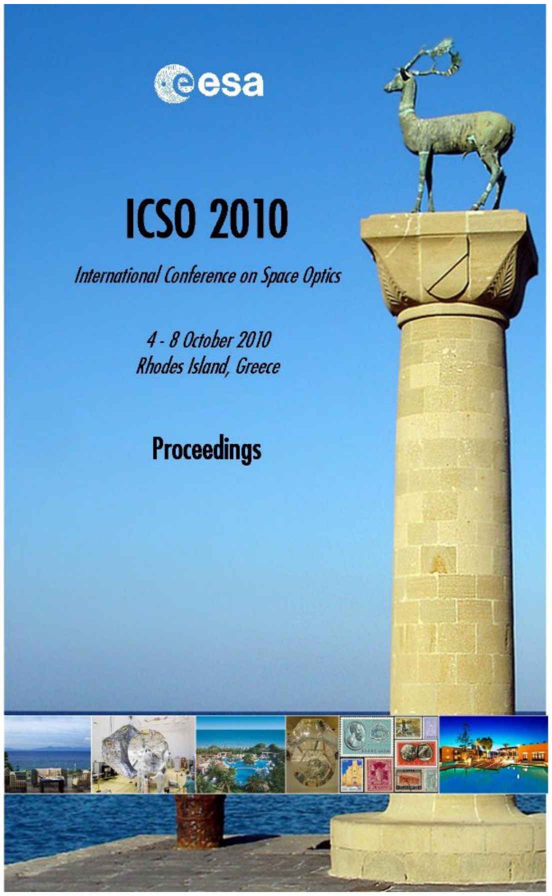

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HIGH THROUGHPUT, COMPACT IMAGING SPECTROMETER

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ABSTRACT

A novel hyperspectral imaging technique based on Fourier Transform analysis applied to a low finesse scanning Fabry-Perot (F-P) interferometer has been demonstrated in the visible and NIR regions. The technique allows the realization of a lightweight and compact instrument yet having high throughput with respect to classical instruments based on dispersive means. Experiments carried out in the visible region have demonstrated hyperspectral imaging capability with a spectral resolution of 2 nm @ 532 nm and an image resolution limited by the CCD (696x512 pixel). In the NIR (0,9-1,7 µm) region a spectral resolution of 8 nm @1064nm and an image resolution limited by the CCD (320x256 pixel) has been obtained. The potentiality in spectroscopic applications like remote gas sensing has been demonstrated as well as accurate thermal imaging capabilities. Unlike classical hyperspectral instruments, based on dispersive means or on tuneable band-pass filters, the efficiency of our F-P based system is very high (about 30% of the photons collected by the objective reach the CCD) allowing much faster and/or better quality hyperspectral images. In the present experiments the speed was by far limited by the acquisition speed of the CCD sensors. Furthermore the device is very compact and is placed between the objective and the CCD of a standard imaging system: in this configuration the field of view of the instrument is only limited by the same objective that in the present system is interchangeable. Because of its roughness, compactness, lightweight and luminous efficiency, the device is a good candidate for airborne or space borne hyperspectral applications.

I. INTRODUCTION

Hyperspectral imaging (HI) is a powerful method of analysis to obtain the spectral composition of the radiation emitted by a subject. A HI device is typically made of a spectrophotometer and an imaging device. The obtained data set is known as “hyperspectral cube” and it is a 3D matrix formed by a 2D image to which is associated the spectral composition of each pixel.

Development of HI devices is growing due to the increasing numbers of applications, for example satellite Earth survey, spectroscopy, colorimetry, thermal imaging and so on. Classical HI devices are usually made by integrating a dispersive means (a prism or a grating) or a tuneable band-pass filter in an optical system. These devices have a good image quality and resolution but also a low efficiency in terms of photon collection. A comprehensive overview on classical HI devices can be found in [3].

When the spectrometer is based on an interferometer instead of a dispersive means there are two features that make this system a faster (or equivalently with higher luminosity) instrument when compared to the others at the same resolution. First, the Felgett or multiplex advantage arises from the fact that there is no spectral scanning and all the spectral components are acquired at the same time. Second, the Jacquinot or throughput advantage originates from the fact that the apertures used in the inteferometetric spectrometers have a larger area than the slits used in dispersive spectrometers, thus enabling higher throughput of radiation. On this basis, novel techniques using Michelson or Sagnac interferometer have been developed with interesting results as described in [4] and [5].

The hyperspectral imaging device developed at INRiM is based on a scanning low finesse Fabry-Perot interferometer [1, 2]. By applying an algorithm based on the Fourier transform (FT) to the interferogram it is possible to obtain the spectral composition of the subject. Here we present the results obtained in the visible region (VIS, 400-720 nm), and in the near infrared (NIR, 900-1700 nm) with a new version of the instrument.

II. HYPERSPECTRAL IMAGING DEVICE

The hyperspectral imaging device is made by a F-P interferometer inserted in a simple optical system formed by a monochromatic camera and a photographic objective (Fig. 1).

Fig. 1. Picture of the hyperspectral imaging device. From the left: the photographic objective, the F-P interferometer and the monochromatic CCD camera.

A. The F-P interferometer

The F-P interferometer is the core of the HI device. It is made of two glass mirrors coated with a thin aluminum layer having a reflectivity around 25%, mounted in an aluminum frame. The distance between mirrors is varied from zero to 40 µm by means of three piezo actuators. During the cavity length scanning a video is captured so the variation of light intensity on each pixel is recorded.
The recorded data are then analyzed to obtain an interferogram from which it is possible to calculate the spectral composition of each pixel by applying a Fourier transform based algorithm. In order to apply the FT it is necessary to know the distance between the mirrors for each frame of the video. This is obtained with a calibration procedure based on the analysis of the interferogram of the pixels when illuminated by a monochromatic light (a laser) as described in [1].

B. The experimental setup

As described before, the HI system is made by a photographic objective, the F-P interferometer and a CCD camera. The simplified layout of the experiment is schematized in Fig. 2.

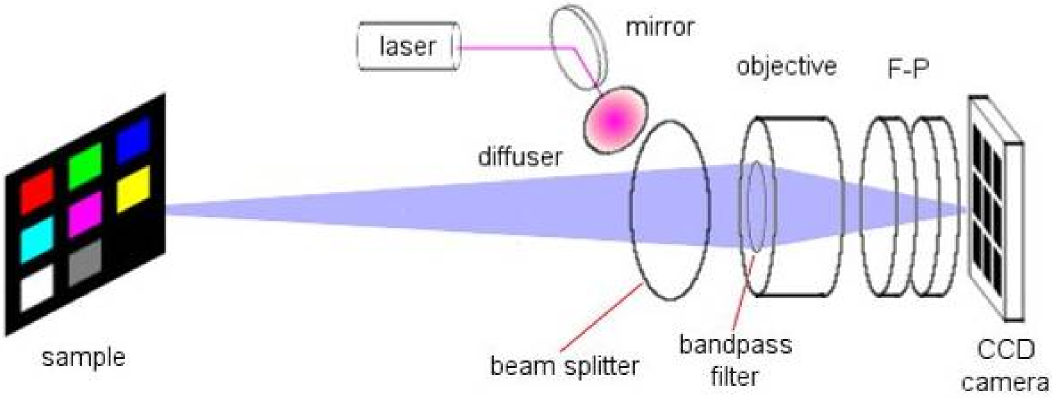

Fig. 2. Schematic layout of the experiment. From the left: the light emitted (or reflected) by the sample is focused on the CCD camera sensor after passing through a beam splitter, the photographic objective an the F-P interferometer. The laser used to calibrate the mirror distance is diffused on the beam splitter just in front of the objective by means of a mirror and a diffuser. (In case of reflected light to the scheme must be added an illuminant for the sample).

This prototype has an important improvement with respect to the previous prototype described in [1] and [2] where, in order to calibrate the mirror distance, the sample is illuminated with a reference laser and from the measured calibration interferogram it is possible to obtain the optical path difference (OPD) of the interferometer. In the present prototype the laser is sent to a diffuser close to the beam splitter in front of the photographic objective.

The calibration procedure is applied for each acquisition. It consists in recording two videos consequently: the first one is the video of the monochromatic source for calibration and the second one is the video of the target to be measured. The video frames of the two videos are triggered in such a way that they are synchronous with the mirror distance scan. Alternatively an area of the image that is not used in the analysis can be shone with the laser light and used for the calibration. In this case a single video is recorded.

Results show that calculation of the spectral distribution is possible even if the reference laser is not on the sample. This is particularly important because it means that it is possible to integrate the reference directly in the hyperspectral imaging device and to realize a more compact instrument. Furthermore, with this prototype is possible to recover the spectrum of a sample at great distances without the need of having the reference on it, simply by changing the photographic objective.

III. RESULTS

Here we present a selection of the results obtained in the VIS and in the NIR spectral regions: analysis of emission spectra in the visible, and analysis of emission (blackbody) and absorption spectra in the infrared, although the same set-up has been also successfully used to measure reflection spectra in the visible.

A. Emission spectral analysis in the visible

In the experimental setup presented, the sample is a 9 coloured square pattern displayed on a 13” LCD with LED backlight. The display is placed normal to the HI system at around 1 m distance from the camera sensor. The emission spectra have been compared with the reference spectra measured with a calibrated spectroradiometer. The spectroradiometer has been placed normal to the display at 2 m distance. Results are shown in Fig. 3

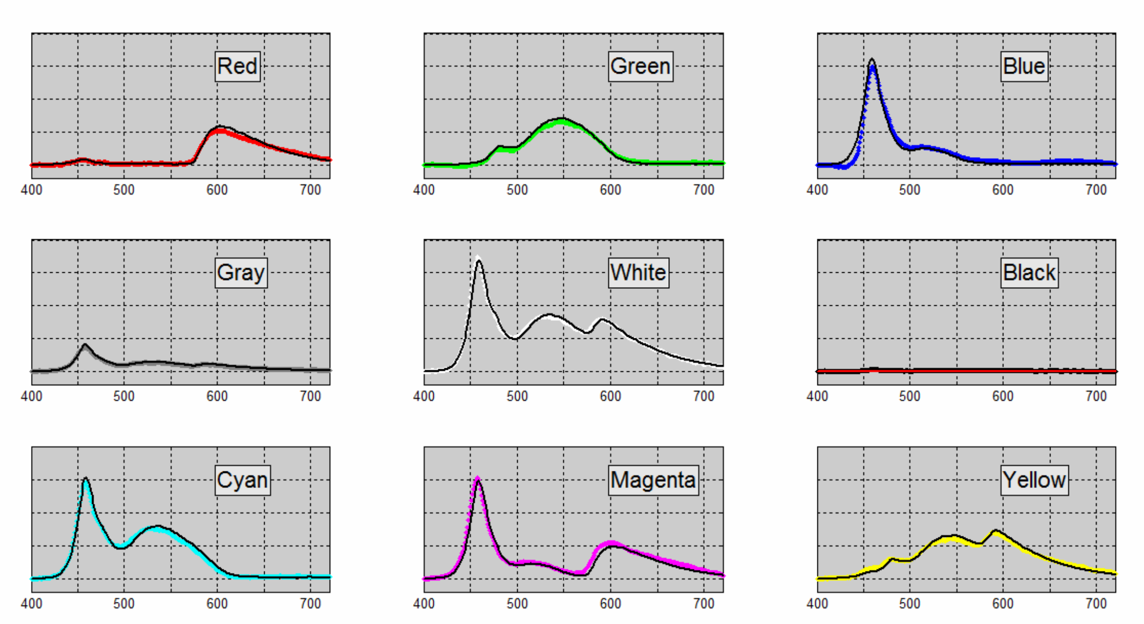

Fig. 3. Emission spectra obtained with the HI device (coloured line) compared with corresponding spectra measured with the calibrated spectroradiometer (black line).

B. Thermal imaging

In this experiment we demonstrate that it is possible to infer the temperature of a body by looking at the shape of the emission spectrum. We have observed a tungsten strip lamp used for radiometer measurements. For each pixel of the image in Fig. 4 (left) we find the emission spectrum (Fig. 4 right) and fit it with the theoretical blackbody curve using the temperature as the fit parameter. In this way we assign a temperature value to each pixel of the image.

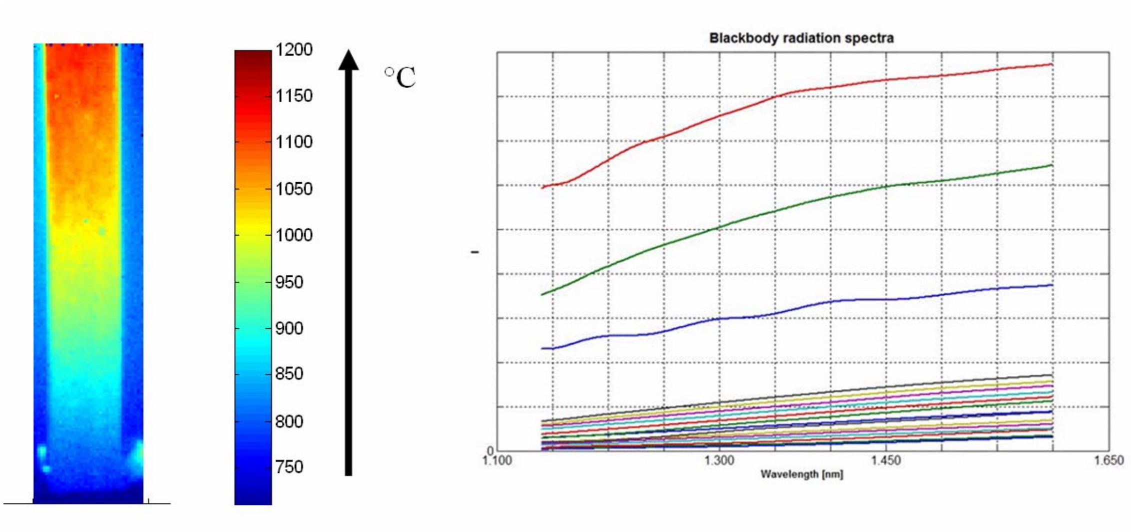

Fig. 4. (Left) Thermal imaging of a tungsten strip lamp obtained with our hyperspectral imaging by fitting the spectrum of each pixel with the theoretical blackbody curve using the temperature as the fit parameter. In the graph at the right some blackbody radiation spectra used for the fit.

C. Atmosphere absorption

Here the experimental set-up is the following. A halogen lamp is used as a blackbody source in the infrared. The lamp was placed at two different distances from the instrument: 3,5 m and 75 m. The absorption of the air in between is observed. In Fig. 5 we can see the two spectra corresponding to the blackbody emission spectrum of the lamp where the absorption bands of the water contained in the air is observed.

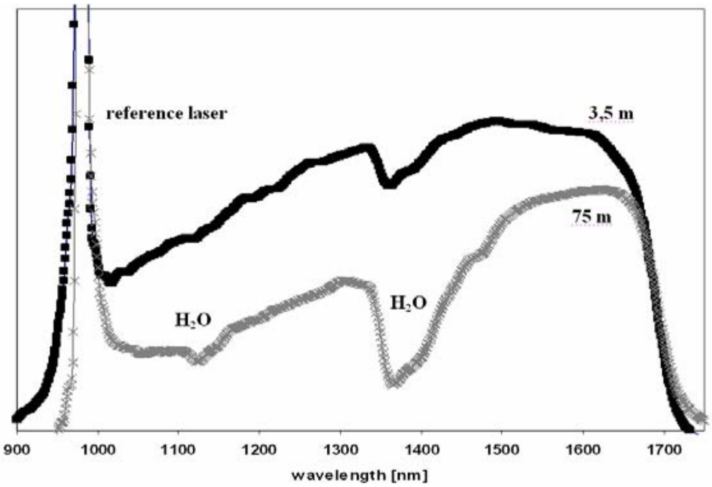

Fig. 5. Absorption spectrum of the atmosphere obtained using as a blackbody source an halogen lamp placed at 3,5 m (black) and at 75 m (gray). Absorption bands of water can be observed. The peak on the left is spurious laser light entering in the image.

D. Solar spectrum

The set-up is similar to the one described in the previous section. Here the blackbody source is the sun. In a first experiment we have observed the sunlight through a cloudy sky. It is evident the strong absorption in the water bands due to the high concentration of water vapor in the atmosphere (gray curve of Fig. 6). In a second experiment we have observed directly the spectrum of the sun surface (black curve of Fig. 6). A metallized mylar sheet has been placed in front of the objective to attenuate the sun light by a 99%.

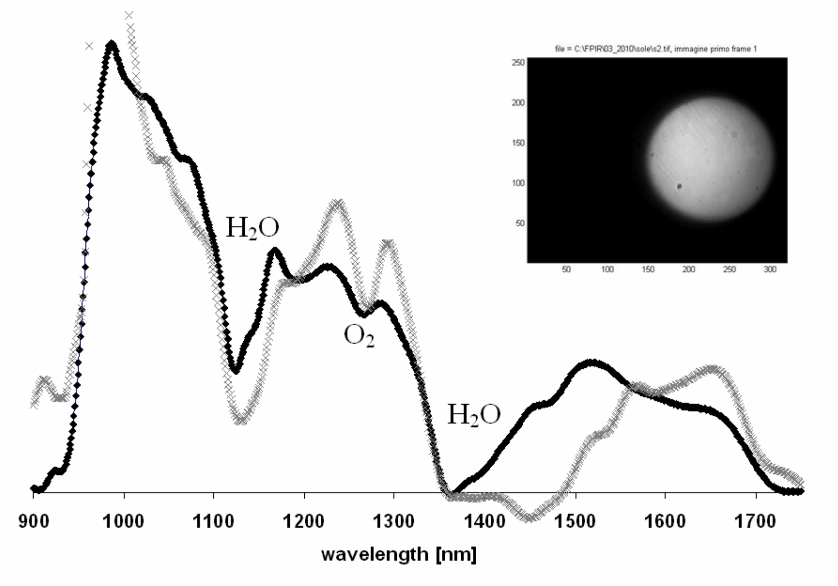

Fig. 6. Spectrum of the sun surface (black) and of the sunlight observed through a cloudy sky (gray). Absorption bands of water and oxygen can be observed. At the upper right corner one of the frames of the video.

IV. CONCLUSIONS

With this new experimental setup we have confirmed the results obtained with the previous prototypes [1, 2] where the reference laser illuminated directly the sample. In this new setup the reference laser shines a diffuser instead of the sample and whose image is not on the image plane. This set-up permits the realization of a self calibrating, compact instrument and allows to observe objects placed far away (astronomic sources). Furthermore we have demonstrated the potentiality of the instrument in the infrared region allowing hyperspectral imaging of gas absorption spectra. Further results can be found in [6].

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