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Hyperspectral LWIR measurements with imaging diffraction grating spectrometer and uncooled thermal camera

Abstract

This paper demonstrates how to perform hyperspectral infrared measurements with uncooled thermal camera and imaging spectrometer. Such thermal cameras are sensitive to wavelengths in the range of 7 – 14 µm (LWIR). There is a description of a diffraction grating based spectrometer with Czerny-Turner optical configuration. To perform hyperspectral acquisition of thermograms it is required to have the camera synchronized with spectrometer, so that recorded frames correspond to known wavelengths. For this purpose the dedicated software was developed and it is also described in this paper, with its operation algorithm. There is a problem of thermal camera drift, and this paper proposes the solution to deal with it. Moreover a description how to obtain transmission plot and exemplary results is presented with the description of measurement rig. In addition, noise related issues are covered and discussed.

Keywords: hyperspectral, spectrometer, diffraction grating, thermal camera.

1. Introduction

Typical uncooled thermal cameras are sensitive to all wavelengths covering the range of 7,5 – 14 µm (LWIR). There are also available specialized thermal cameras capable of performing hyperspectral acquisition of thermograms. It is possible, however, to use typical thermal camera and imaging spectrometer to acquire thermograms for chosen wavelengths. What is more, this approach enables to measure spectral characteristics of different samples, and it is comprehensively described in this paper.

2. Imaging spectrometer

An imaging spectrometer enables scene observation for the chosen wavelength. It is possible to use different models from different manufacturers (e.g. Telops HyperCam, which uses Michelson interferometer [1]), provided the capability of working in the desired spectral range of infrared radiation. The authors provide demonstration in this paper using Newport Oriel Cornerstone MS260i with two switchable diffraction gratings (Fig. 1). Its input F/# is F/3.9 with the input and exit focal lengths equal to 220 and 257 mm respectively [2].

Fig. 1. Newport Oriel Cornerstone MS260i imaging spectrometer [2]

The only available diffraction grating that works in LWIR spectral range for this model of spectrometer is Newport 74182. It has a 75 l/mm line density and has a peak efficiency of 80% at the 7 µm blaze wavelength. It's primary wavelength region covers wavelengths from 4.5 to 20 µm (22.4 µm is the MS260i's upper wavelength mechanical limit for this grating assembly). The best spectral resolution that is possible with this grating is 3.95 nm [2].

As it may be seen in Fig. 1, there are two micrometer slits with adjustable width and height. The optical configuration of this spectrometer is Czerny-Turner – shown in Fig. 2.

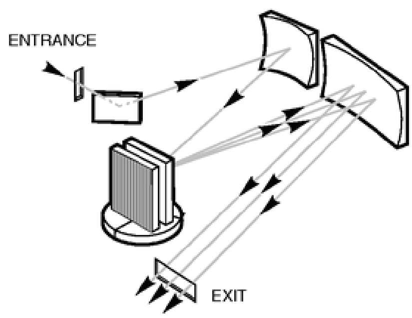

Fig. 2. Czerny-Turner optical configuration of the spectrometer [2]

The principle of the spectrometer operation relies on rotating the diffraction grating to obtain desired wavelength, for which the image may be recorded. In this case, the ruled reflective diffraction grating with 75 grooves per 1 mm density is used (it corresponds to the grating constant d = 13.3 µm) – Fig. 3.

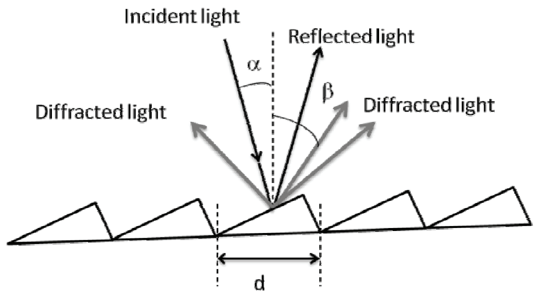

Fig. 3. Ruled reflective diffraction grating [3]

The fundamental grating equation (1) describes the relation between the incident (α) and diffractive (β) angles together with the grating constant d and the wavelength λ.

$$n\lambda = d(\sin\alpha + \sin\beta) \quad (1)$$

where n is the diffraction order [3].

3. Measurement system

3.1. Software

An important part of the system is PC application written in C++. The main task of this application is to control the spectrometer and simultaneously acquire images from a thermal camera. The requirements for the software are as follows:
- connecting with the thermal camera and spectrometer,
- setting the spectrometer to the desired wavelengths,

- capturing several thermal images from the camera,
- temporal averaging of acquired images to reduce noise,
- saving averaged images to file.

This is done according to the following algorithm (Fig. 4), where the measurement is done in the spectral range from “start λ” to “stop λ” with the increment “step λ”.

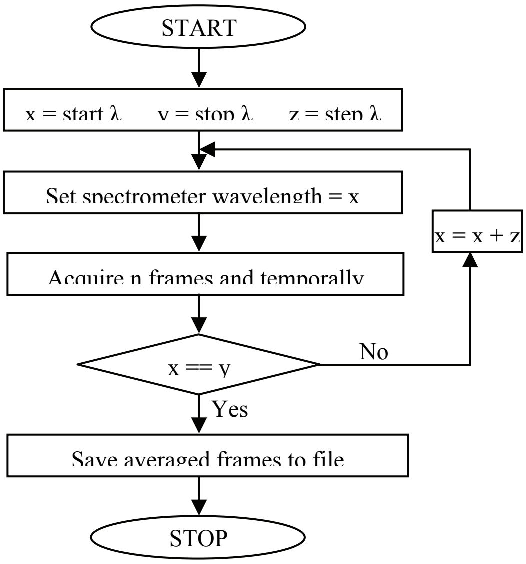

Fig. 4. Developed software operation algorithm

When the application is started it connects to the camera with use of the API functions provided by the camera manufacturer. By pressing “Save” or “Save as” button, the current settings of the application can be saved into project file. By pressing “Settings” button a window with available options shows up.

The “Thermal buffer type” combo box enables selecting the temperature data format of the image frames to be saved. The default format is 16-bit raw values format. The “Grate number” option enables to select the diffraction grating of the spectrometer. In case of this paper, it should be the second grating, which covers the LWIR spectral range.

The “Start wavelength” parameter is the wavelength that is to be set when “Start capturing” button from main window is pressed. The “Wavelength step” parameter is the increment of the wavelength to be introduced after the frames are recorded for current wavelength. The “Number of frames to average” parameter is the number of thermal frames to be captured for a given wavelength position. Depending on Average and Median options for each pixel of the frames captured for a given wavelength average or median values are calculated and written into frame which is to be saved in MATLAB format. If neither Average nor Median options are chosen then each frame captured for a given wavelength is saved.

The “NUC interval” parameter defines how many frames should be recorded before the camera performs the non-uniformity correction (NUC) using the built-in shutter mechanism. If the value of the parameter is zero then the shutter is disabled. This is an important setting which takes control of the shutter mechanism otherwise functioning automatically. Without this control the shutter could interrupt the process of frame acquisition, because when it is controlled by the camera, it may be activated e.g. every minute.

In main window when “Start button” is pressed, the spectrometer is set at start wavelength position and the frames from the camera are being captured and visualized in an additional window. When “Record button” is pressed then the frames with average or median values are saved for wavelength positions changing with given step starting from start wavelength position.

3.2. Hardware

The set-up of the measurement rig is shown in Fig. 5.

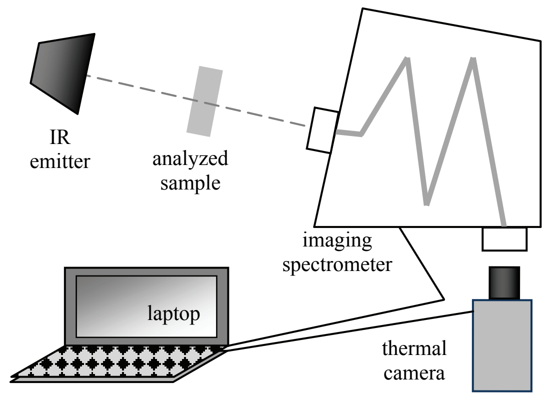

Fig. 5. The set-up of the measurement rig

IR emitter is the blackbody area source Fluke 4181 precision infrared calibrator set to 250°C. The spectral characteristics of the target surface (diameter 152.4 mm) emissivity value is in the range from 0.92 to 0.98 [4]. Its temporal stability is ± 0.20°C at 200°C, and spatial uniformity for a 12.7 cm diameter disc at the centre of target is ± 0.50°C at 250°C [4].

The thermal camera is Jenoptik VarioCam HiRes. It has uncooled microbolometer detector sensitive to LWIR spectral range (7.5 to 14 µm).

4. Exemplary measurement results

The performed measurement was to determine the spectral transmittance of a synthetic, plastic-like material consisting of two thin (0.5 mm) layers. This material is translucent for visible light but for IR its transmission factor is strongly dependent on the wavelength.

The measurement rig was set-up in a way that the thermal camera could observe one part of the IR emitter directly through the spectrometer (❶) and the other part additionally through the measured sample (❷), as shown in Fig. 6. The focus was set to the edge of the sample to have sharp distinction between those two zones.

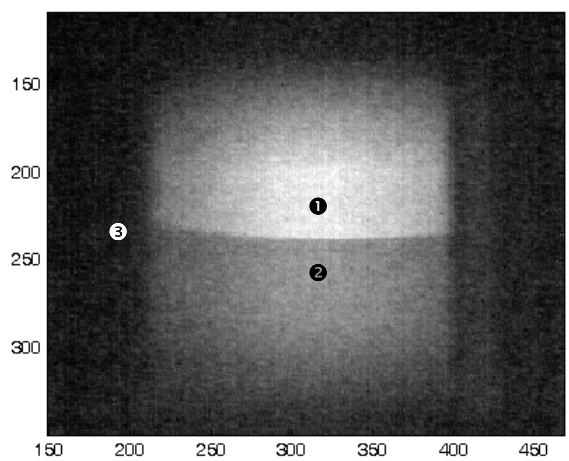

Fig. 6. Exemplary thermal image showing the IR emitter directly (❶) and through the measured sample (❷). There is also background area shown (❸)

In such a configuration the developed software provided images acquired in a range from 7.5 to 14 µm with 50 nm step. For each step (lasting for about 3 seconds) 25 frames were temporally averaged to reduce the noise 5 times (square root of 25) [5]. This enabled showing in the Fig. 7 plots of two chosen points signal versus the wavelength – the upper one (❶) for IR source response and the lower one (❷) for the response of IR source through the sample.

The whole measurement took about 6.5 minutes (3 seconds times 130 steps). This time was long enough to have the influence of camera thermal drift on recorded signal values. Thermal drift in a microbolometer camera is a common problem resulting from heating of the focal plane array from the surrounding electronics and camera interior. During normal operation thermal camera periodically (about once per minute) interrupts the measurement for about one second to update the values of thermal drift correction factors – it is done automatically with the built in shutter. In case of this measurement, however, the shutter was disabled to avoid those interruptions. Hence it was necessary to measure the influence of this thermal drift – it was done by measuring the background signal (❸ - Fig. 6).

In Fig. 7 this drift was compensated by subtracting the background plot (❸ - Fig. 8) from both of the plots (❶ and ❷). This background plot of the captured image corresponds to a border area independent on the spectrometer adjustment and measured sample – it was influenced solely by the camera thermal drift. In fact this background plot is wavelength-independent, it was recorded in the time domain. However a wavelength scale was introduced in Fig. 10 to provide coherency with Fig. 9 - signal levels for each wavelength in Fig. 9 were acquired in different time instants and were affected differently by the camera thermal drift.

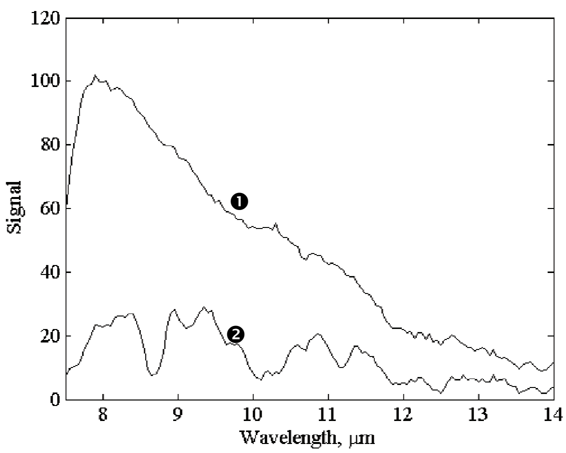

Fig. 7. The exemplary measurement results for examined sample

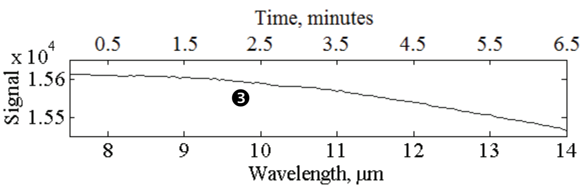

Fig. 8. Camera thermal drift signal measured for the background area in time domain

It was found out that if the camera performed NUC periodically, it affected the measured characteristics. Hence it was decided to disable the NUC for the period of whole measurement and later on perform the above mentioned subtraction of background plot. This way there are no discontinuities in the plots. In addition, to further lower noise levels, every plot was created not from one pixel but from spatially averaged nine pixels (3×3 block) – such operation only reduces noise in measured spectrum.

To obtain the transmittance characteristics of the examined sample, it was necessary to divide plot ❷ by plot ❶. This way Fig. 9 was obtained – it reveals that the measured sample transmittance varies in the range of about 0.1 – 0.5 across the LWIR spectral range. This characteristics resembles the polystyrol's one, but it is not 100% equal. For comparison, the same sample was measured with Perkin Elmer FT-IR System Spectrum GX spectroscope (Fig. 10) - one layer was measured, hence the result was squared to provide compatibility with Fig. 9.

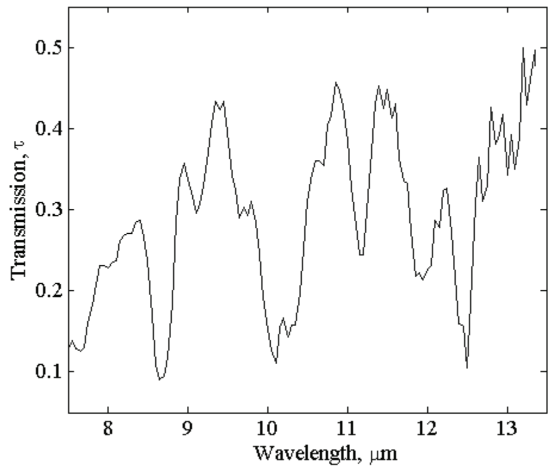

Fig. 9. The transmittance characteristics measured for examined sample (two layers) with thermal camera and MS260i imaging spectrometer

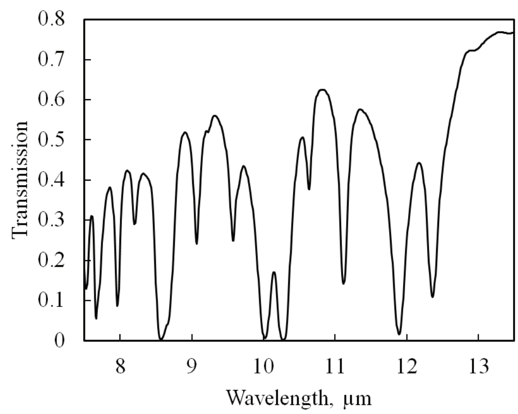

Fig. 10. The transmittance characteristics measured for examined sample with Perkin Elmer FT-IR System Spectrum GX spectroscope (one layer was measured, hence the result was squared to provide compatibility with Fig. 9)

5. Conclusions

This paper demonstrated that an imaging diffraction grating spectrometer may be coupled with uncooled thermal camera to carry on hyperspectral measurements. It is advised to use special software for synchronization of spectrometer wavelength setting with thermal camera image acquisition. In addition temporal image averaging should be used to reduce the amount of noise. For the same purpose if plots are done, an averaged block of 3×3 pixels should be used instead of single pixel.

6. References

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