ROBUST SYSTEM FOR HYPERSPECTRAL IMAGING IN THE LWIR SPECTRAL REGION WITH UNCOOLED THERMAL DETECTOR

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ABSTRACT

The paper describes a robust detection system based on long wave infrared cameras and hyperspectral optics. System was developed for a remote detection of the volatile substances, as well as for low-cost hyperspectral detection based on uncooled microbolometric sensors. The paper describes overall construction challenges and achieved performance and typical characteristics of the system.

Index Terms**—**hyperspectral sensing, thermal cameras, LWIR, uncooled microbolometer sensor, NESR

1. INTRODUCTION

Hyperspectral robust detection system (RODES) was developed by the Institute of Plasma Physics of the Czech Academy of Sciences AV ČR v.v.i., TOPTEC and by company APPLIC s.r.o. Main goal of the RODES system is high quality hyperspectral detection in longwave infrared spectral bands (LWIR) using uncooled detectors. The hyperspectral imaging extends spatial information of the common imaging with the spectral information about measured scenes. The hyperspectral classification methods can detect a material information from the spectral and spatial information of the scene, surveil for selected dangerous substances or monitor the health of plants in the agricultural sector.

Signal from hyperspectrally imaged scene is divided or filtered into tens to thousands narrow spectral bands so the energy detected by the sensor is proportionately lowered. Thus the imager must have high signal-to-noise ratio (SNR) and high information gain in the optical, mechanical and software parts of the system. It leads to a requirement for a more complex optical systems and more sensitive, low noise detectors (focal plane array, FPA) compared to thermal imaging systems.

Imaging in the LWIR spectral range is commonly used for thermal imaging in range -40 to 200 °C and is widely spread across all of the industries due to decrease of prices in recent years. Nowadays, the price of uncooled FPA sensors with resolution of 640×480 pix is around 2000 €, although additional costs must be counted in for a smart readout electronics behind the sensor and optics. The mass produced consumer FPA from FLIR or Lynred have resolution from 80×60 to 160×120 and can be used as the extension of mobile phones [1,2]. Hyperspectral requirements for FPA (high detectivity resp. high SNR) is where the cryo-cooled FPA dominates, but they are ten times more expensive compared to uncooled FPA.

It motivated the development of several interesting systems with uncooled FPA such as LWIR-HS (SPECIM) [3], TIRCIS [4], CRISP [5]. They are generally based on slit imaging spectrometers, compressive sensing (computational imaging) methods, interferometers or tunable filters. Our system uses a classical slit imaging spectrometer approach and focuses on specific applications where it could reach a higher SNR, but at the expense of speed and resolution.

2. OVERALL CHARACTERISTICS

Hyperspectral system RODES (Fig. 1.) use several features to reach high SNR and application performance, which are:

- fast optical system (f/1),
- minimal number of optical elements,
- external reference for nonuniformity correction,
- internal reference for thermal drift correction,
- minimizing overall size,
- modular conception,
- improved mechanical toughness.

Hyperspectral system RODES is using an integrated scanning mirror for imaging like a pushbroom camera. Image of the scene, reflected from the mirror, is projected by a telecentric lens onto an internal slit. Slit is then reimaged through a dispersing optical system on the FPA sensor [6]. The whole optical system has only six optical elements, which improve overall efficiency but reduces tolerance for stray-light and system misalignment.

Image from the FPA sensor is processed on board the IRCA3 infrared camera. The system-on-chip (SoC) Zynq module from Xilinx with ARM processor and field programmable gate array (FPGA) [7,8] is used for image processing. Processed images are sent via Ethernet to the controlling PC or can be stored in internal memory.

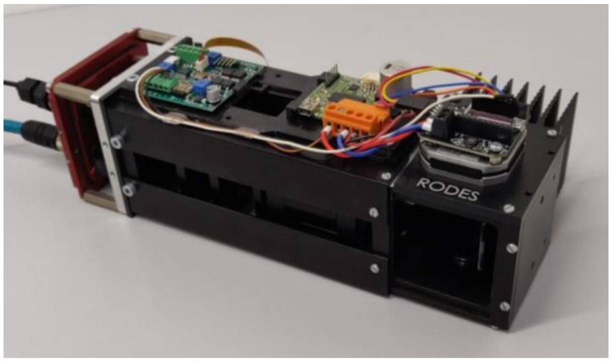

Fig. 1. The main part of the hyperspectral system RODES. From the left: infrared camera IRCA3, optical system, scanning mirror.

The whole system is built in a robust mechanical body with silentblocks and shock absorbers to protect sensitive optics (Fig. 2.) for the purpose of a field use and a system reliability. Also various additional features were made, such as the built in battery power system, two axis rotator with infinity number of rotation and wireless connection. Whole system uses standard Ethernet to transfer image data and the USB bus for communication and control. The Pelco-D protocol is used for compatibility with surveillance application. The system could be powered and charged from 24 V power bus to ease installation in industrial systems.

3. HYPERSPECTRAL IMAGE PROCESSING

Whole hyperspectral system RODES is controlled by a PC software application that covers all basic functions for hyperspectral data acquisition as well as a simple hyperspectral classification. It also provides an individual control of each part of the system.

Imaging sequence starts with measurement of a calibration image by rotating the scanning mirror onto the internal black body, followed by continuous scanning of the scene. A mean of the ten frames is acquired for each mirror position (Fig. 3). Then it is corrected using calibration image and divided into specific areas (Fig. 4). Main area A contains the spectral information about scene, area B is used for alignment or focus and area C is used for drift correction. After all corrections [9,10] and averaging are applied the result of measured spectral information for the slice of the scene are stored in a hyperspectral cube.

Fig. 2. The RODES system in the durable body with a pan-tilt system.

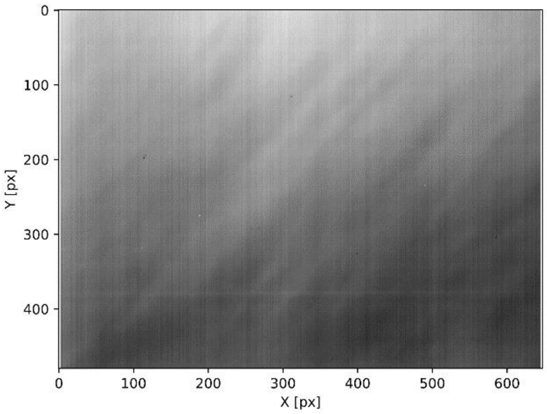

Fig. 3. Uncorrected frame produced by the FPA (size 640×480 pix).

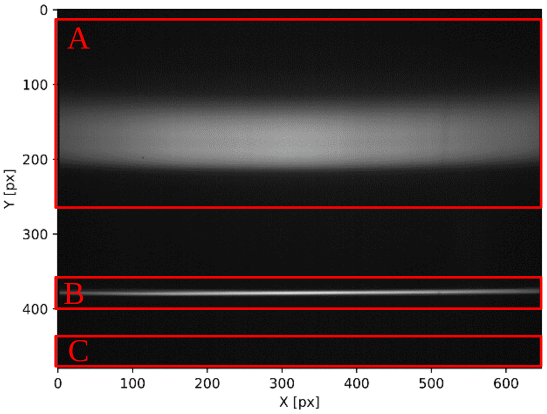

Fig. 4. Corrected image from the sensor (size 640×480 pix). (A) first order diffracted spectra, (B) zero order (slit image), (C) blank sensor area for thermal drift correction.

The SNR respectively the Noise-Equivalent Spectral Radiance (NESR) is affected by the effective size of area A. Analysis shown that the optimal effective area is 600×80 pix (Fig. 5.), which is quite small as the system could be configured with multiple slits or coded apertures. The single slit configuration reaches an average NESR of 100 mW/m^{2}srμm. The spectral layout across the sensor is on Fig. 6. showing distortion by smile up to 3 pix. An average NESR for the wavelengths in the range 8 to 11 μm is shown on Fig. 7., illustrating effective spectral sensitivity of the system. One pixel represents a spectral band of 40 nm (depending on used grating). The spectral resolution is controlled by an interchangeable slit, which could be up to 10 pix, i.e. 400 nm, wide. Such configuration is used for low spectral resolution with advantage of a higher SNR. Typical slit width is ~5 pix resulting in resolution of 20 cm^{-1}.

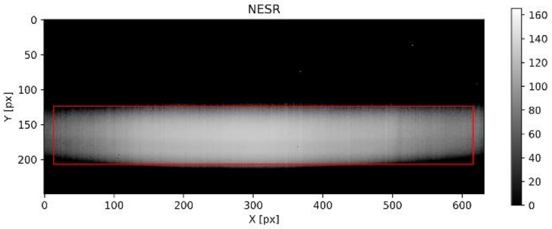

Fig. 5. Spatial representation of computed NESR (mW/m^{2}srμm) over the sensors area A. Selected effective area is marked in red rectangle and the rest of the image is marked by zeros due to high noise.

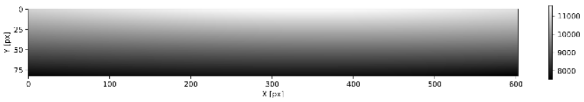

Fig. 6. Representation of wavelength (nm) layout in the effective sensor area.

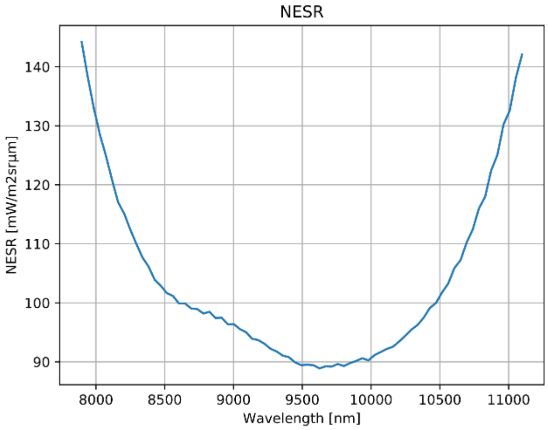

Fig. 7. Average NESR for wavelength range of 7.5 to 11.5 μm

The controlling application (Fig. 8.) for RODES system can be configured to measure selected regions of interest, and provide basic data processing support and hyperspectral detection functions. It also provides control over every system component. It is used for flexible configuration of the scene scanning process (FOV, scanning step, averaging, calibration, sequencing) and data processing (raw output, radiance data, thermal data, chemical fits).

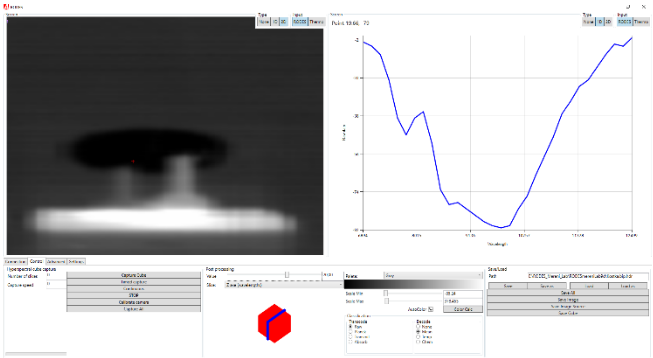

Fig. 8. Screen capture of control application of the RODES system

4. CONCLUSION

The paper presented developed hyperspectral detection system in the LWIR spectral range and some rationales for its design. System is based on uncooled bolometric sensors, which reduce the price, but also exhibits low sensitivity compared to cryo-cooled sensors. The noise merit NESR was reduced to ~100 mW/m^{2}srμm thanks to specific application, design optimization and spatial and thermal correction. It is better than what is typical for uncooled hyperspectral systems (~300), but still lacking behind systems with cooled detectors (<30) [11,12]. Price for this performance is a limited scene acquisition rate.

Several extensions, such as an internal battery power source, high durability cover box and pan-tilt device were developed for the hyperspectral system RODES, as well as user friendly control SW application. Future development of the RODES system is aiming on a better utilization of the FPA and on a high precision hyperspectral detection with neural networks

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