MR-*i* – OVERVIEW AND FIRST RESULTS OF THE ABB HIGH SPEED HYPERSPECTRAL IMAGING SPECTRORADIOMETER

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ABSTRACT

With more than 35 years of innovation in spectroscopy, ABB presents its most recent addition to the proven MR product line. This instrument, called MR-i, is a fast imaging Fourier Transform spectroradiometer. It generates spectral data cubes in the MWIR and LWIR and is designed to acquire the spectral signature of various scenes with high temporal, spatial and spectral resolution. MR-i features the MR series 4 ports FTIR architecture enhanced for imaging spectroradiometry. Its architecture is modular and can be configured to support several applications and measurement scenarios for improved performances and extended hyperspectral imaging capabilities. An overview of the new MR-i design and capabilities will be presented as well as the current product development status.

***Index Terms* —** FTS, Hyperspectral, imaging spectrometer, Fourier, FT-IR, Remote Sensing

1. INTRODUCTION

From scientific research to deployable operational solutions, Fourier-Transform Infra-red (FT-IR) spectroradiometry is a very well suited technology for the development and enhancement of various military applications. For the defence, FT-IR spectroradiometry techniques include military targets IR signature characterization, development of advanced camouflage techniques, aircraft engine's plumes monitoring, meteorological sounding and atmospheric composition analysis such as monitoring of gaseous emanations applied for the detection and identification of chemical threats (chemical warfare agents and toxic industrial compounds).

The MR-i instrument is a fast imaging Fourier Transform spectroradiometer that generates spectral data cubes in the MWIR and LWIR. It is designed to acquire the spectral signature of various scenes with high temporal, spatial and spectral resolution. Its architecture is modular and can be configured to support several applications and measurement scenarios.

The MR-i is user configurable; each detection module and the telescope can be replaced by the user without any needs for alignment. The four ports FTIR configuration of MR-i also brings the option for dual-input optical subtraction operation.

2. THE MR-*i* PLATFORM

Imaging FT-IR spectrometers have the capability of generating 3D images composed of multiple spectrums associated with every pixel of the mapped scene (Figure 1). That data allows for accurate spatial characterization of target's signature by resolving spatially the essential characteristics of the observed scenes. The captured data are now further exploited by combining the spectral and spatial information of the scene.

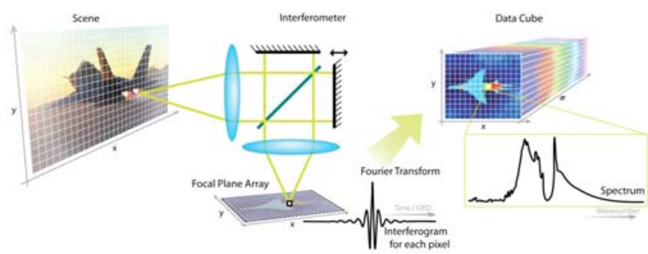

Figure 1: Schematized imaging Fourier transform spectrometer

The MR product line is a series of fast non-imaging Fourier transform spectro-radiometers designed for research in the field of infrared target characterizations and chemical vapour detection. The MR series instruments are appreciated and widely used for infrared target characterization applications. Based on the success of the MR series, the MR-i is designed to preserve the same key features offered by the MR with the addition of imaging capabilities:

- The MR-i supports a broad spectral range from about 0.7 μm to 20 μm. This characteristic allows the end-user to combine or change optional detection module to make measurements over a desired spectral sub-range without having to change the optical head of the spectrometer. Optical path difference is adjustable in order to let the users select the appropriate spectral resolution for their applications.

reference such as a cooled plate in the second input port to enhance the contrast and improve the sensitivity.

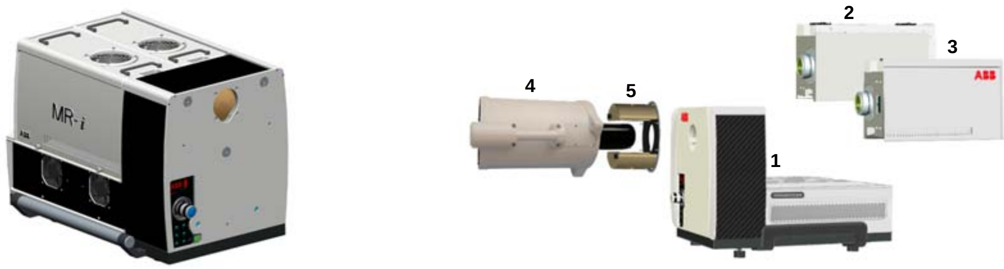

Figure 2: MR-i instrument: 1) MR-i Spectroradiometer, 2) Camera/detector module A, 3) Camera/detector module B, 4) Input telescope, 5) Radiometric calibration sources

- The MR-i is designed to achieve high measurement rates. Rapid measurements allow the observation of fast targets such as in-flight jet fighter aircrafts or of short-lived or transient events (flares, explosions, burn phases). It also makes the instrument less sensitive to external vibrations and to motion of the target within the instantaneous field of view (scene jitters) which is a source of noise in the measurement. The acquisition scheme is optimized and the detector matrices support fast data cube rates. Up to 88 data cubes per second are provided at a resolution of 32 cm-1 in the MWIR atmospheric window (3 – 5 µm) for 32x32 pixels window.

- The interferometer of MR-i takes advantage of the heritage of the interferometer used in the ABB Bomem MR series. The interferometer is based on a V-shaped scan arm onto which are mounted two cube corner retro reflectors. The scan arm has a simple friction-less mechanism; it is robust and not subject to wear. It also supports operation in dual input and dual output mode (see Figure 3). No dichroic filter is required for separating the signal into two detector channels; the dual output FTIR generates two distinct output ports, each port is served by its own detector. This provides a good overlap of the spectral range between both detectors. Having two distinct output ports also opens up some interesting detector configuration possibilities. For instance, one output port can be populated with a LWIR camera while the other is populated with a MWIR camera in order to increase the spectral range coverage. Another possibility is to populate each output port with the same type of camera but each set with different gains. With such combination it becomes possible to observe bright scene elements such as exhaust plumes with one camera while observing fainter elements such as the sky with the other camera and ensuring a good measurement dynamic range while avoiding saturation. With two input ports it becomes possible to perform automatic background removal by optical subtraction [3]; one input is directed at the target of interest and the second input points at the background. It is also possible to put a cold

- The architecture of the instrument is flexible and modular. The input optics can be changed to support different spatial resolutions. The detection modules can be changed by the user to support different detector configurations. The instrument is field deployable, under the same conditions as the MR series. Thermal control, heat evacuation and protection against the direct Sun are implemented. The instrument can interface to a tripod, a tracker mount and various vehicles.

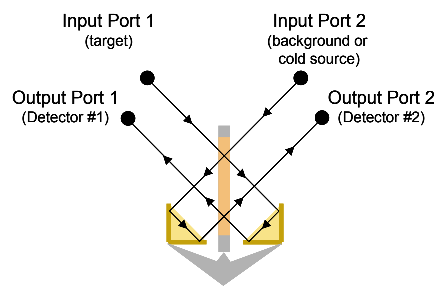

Figure 3: Schematized dual input and dual output interferometer

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3. PERFORMANCES

The MR-i instrument equipped with a MWIR detection module, and a wide angle FOV telescope has been tested in laboratory and some results are presented in the following section.

5.1. Cube rate / frame rate

The cube rate has been evaluated for different resolutions, for a 3 – 5.5 µm spectral range and 64 x 64 pixels images. Results are provided in the left part of Table 1. Note that a data cube is composed of a certain amount of frames that essentially depends on the spectral resolution (Figure 1).

The MR-i cameras can also be used as a very fast infrared camera from 3 – 5.5 µm (1.3 – 5.5 µm extended). In that case, the scan arm is locked at a predefined position, and the signal is integrated over the whole band, or on the spectral band defined by an optical filter that can be placed in the optical path of the instrument. Several values of the frame rate are given in the right part of Table 1, for different window sizes.

Table 1: Cube rate and frame rate

Spectral resolution	**Cube rate at 64 x 64 pixels**
0.6	3.1
1	5
2	9.6
4	17.5
8	30.3
16	45.4
32	60.6

Window size	**Frame rate (Hz)**
64 × 64	26710
128 × 128	9164
160 × 160	6237
200 × 200	4293
256 × 320	2187

5.2. Imaging capabilities

An important feature of the instrument is the optical imaging aspect. MR-i provides not only the spectral distribution of the incoming scene, but also the spatial information. Spatial resolution and iFOV depends essentially on the input telescope and detector pixel size, since the FOV also depends on the number of pixels in the images. Figure 4 illustrates an image of the MR-i integrated over the 3 – 5.5 µm spectral range, when the instrument was aimed at a torch plume in front of a 200˚C blackbody (circular part). The darker part around the circular blackbody is the ambient temperature background. The right image illustrates the uncalibrated spectra corresponding to the selected pixels of the left image (three crosses). The upper left cross is the hot blackbody around 200˚C, the cross at the center of the image is over the torch plume (high intensity dashed spectra), and the bottom right cross is the ambient temperature (background around 20˚C).

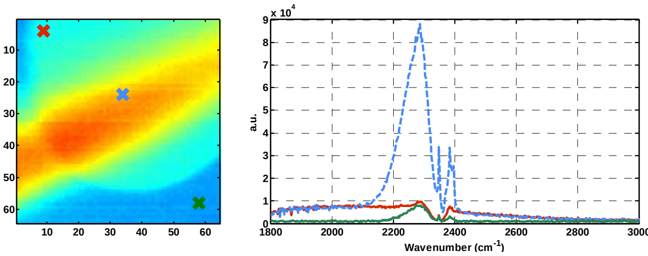

Figure 4: left – IR image of a torch plume in front of a 200˚C blackbody, right – Spectra corresponding to the selected pixels on the left image.

5.3. Radiometric performances

The radiometric performances of the MR-i equipped with a MWIR detection module are characterized in Noise Equivalent Spectral Radiance (NESR), which is the standard deviation of the radiance calibrated measurements over a certain number of acquisitions. The NESR measurement have been performed on about 30 data cubes, and converted to one second of observation time, for a 35˚C scene. Results will be provided at the presentation.

4. IN FIELD RESULTS

In order to evaluate the behaviour, functionality and performances of the instrument, the MR-i has been tested on a tracking mount at a customer facility. A first measurement campaign was performed with a Beechcraft Baron aircraft and several results are presented in this paper.

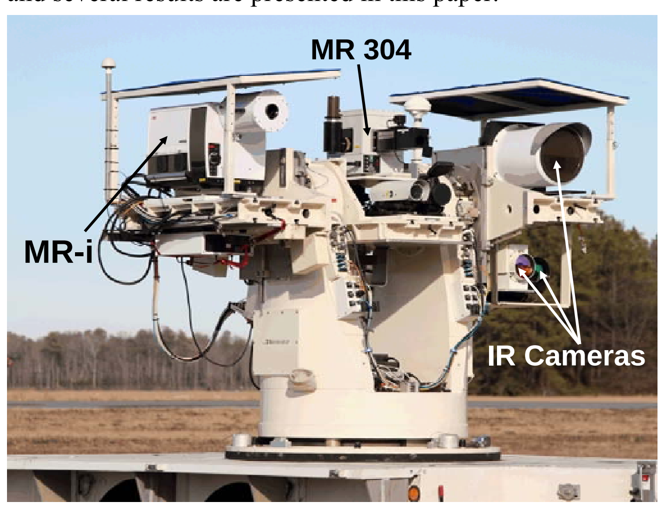

Figure 5: Tracking Mount, left - MR-I, center - MR 304, right – IR cameras

The instrument was mounted on a tracker that was locked on the aircraft position via a GPS system. The tracker was equipped with a MWIR MR-i, a standard ABB Bomem MR304 (MWIR and LWIR detectors) and three panchromatic cameras (see Figure 5). All the instruments were synchronized via a common trigger system.

The MR-i was set at 64×64 pixels window size and at 4 cm^{-1} of spectral resolution (17.5 cubes per second). A 3 – 5.5 µm optical band pass filter was set in the optical path. The MR-i was equipped with the medium Field Of View telescope with internal blackbodies in order to perform radiometric calibration after each measurement. The MR-i real time processing interface enables to program an automatic measurement sequence. Thus, as soon as the aircraft was at the desired angle to be recorded in the FOV of the instrument, the MR-i (and all other cameras) was triggered and 250 data cubes were recorded followed by blackbody calibration measurements.

Even if the MR-i was subject to important accelerations because it was not centered in the tracker, it behaved perfectly and no frames or cubes were missed during acquisitions or even during repositioning of the tracker.

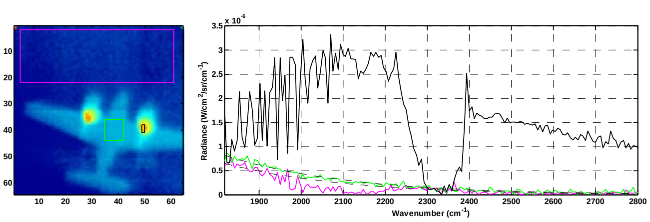

Figure 6: Left – Mean of 3 images of the Beechcraft Baron; Right – spectra associated to the selected areas of the left image

Measurements have been performed under very cloudy meteorological conditions; however, several measurement results were acquired and are shown in Figure 6. The left image is the mean of three subsequent calibrated images of the aircraft integrated over the 1900 to 2200 cm^{-1} spectral band (4.5 to 5.2 µm). It displays the logarithm value of the calibrated radiance in order to distinguish weak contrasts (aircraft and sky) as well as high temperatures (piston engines). The right part illustrates the mean spectra associated with the areas selected in the left image. The magenta square in the top of the image is a part of the sky, and its corresponding spectrum is at the bottom of the right figure (in magenta as well). A fit with a Planck function indicates that the sky apparent temperature was around 8˚C. The green square in the middle of the image is a part of the aircraft fuselage. The corresponding spectrum is in green in the left-side graph. Its apparent temperature is around 15˚C, which is confirmed with the IR panchromatic camera of the client. The upper spectrum, in black, corresponds to the hot piston engines of the aircraft, and the blue spike and red spike clearly appear in the spectrum on both sides of the CO_2 absorption near 2400 cm^{-1} and 2225 cm^{-1} respectively.

5.4. Specifications

The following section gives an overview of the MR-i performances, for different configurations.

Table 2: MR-i specifications

Parameter	MR-i
Spectral range	Limited by detector(s) within 0.7 – 20 µm
Number of detectors	Up to two (2-D arrays, 1-D array or single-pixel)
IFOV	1.2, 0.48, 0.13 mrad per pixel
Number of pixels	up to 256 × 256 pixels
MPD	±1 cm or less
Spectral resolution	0.6 cm^{-1} or more
Cube rate	Up to 88 cubes / s
NESR	Depending on spectral range and setting. Peak NESR for 16 cm^{-1} resolution, 1 sec measurement. 300 K scene 3 – 5 µm: NESR < 1×10^{-4} $W/m^2/sr/cm^{-1}$ 8 – 13 µm: NESR < 4×10^{-4} $W/m^2/sr/cm^{-1}$ Single pixel: NESR 3.6×10^{-6} $W/m^2/sr/cm^{-1}$
Dimensions	62 cm × 50 cm × 45 cm^3
Mass	40 kg (minimal configuration)
Input power	110 or 220 V AC. Optional DC input.
Temperature	Operating Temperature: -20°C to 40°C
Main options	3 – 5 µm camera (extendable to 1.3 µm) 8 – 13 µm camera 8 – 14+ µm line scanner Other detector options Cold source for 2nd input port Selection of input telescope Optical subtraction input optics Internal radiometric calibration source GPS receiver

5. CONCLUSION

MR-i is a FT-IR imaging spectroradiometer developed by ABB with a design based on the MR Series product lines spectroradiometers. The robustness of the MR series proven design, the dual-cameras configuration, the sensitivity, the extended dynamic range, the fast scanning data acquisition rate makes MR-i a highly versatile instrument. MR-i is suited to future upgrades. Its capabilities can easily be extended with add-on modules, and latest camera developments. Behaviour, functionality and performances of the MR-i have been tested during a test campaign at a customer facility. The MR-i was on a tracking mount and aimed at a Beechcraft Baron aircraft. This campaign demonstrated the ability of the instrument to operate on a tracking mount and its capacity to acquire spectral datacube of a fast moving target. The results presented in the current paper are for a MWIR configuration. A LWIR (8 – 13 µm) configuration and dual-band MWIR-LWIR configuration also exist. The two output ports of the MR-i can be populated with any combination of MWIR and LWIR camera. A dual output system is the equivalent of having two perfectly co-aligned and synchronised imaging spectrometers inside a single box.

11. REFERENCES

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