proceedings

Abstract

First Laboratory Measurements Of A Super-Resolved Compressive Instrument In The Medium Infrared †

Donatella Guzzi[1*], Tiziano Bianchi[3], Marco Corti[4], Sara Francés González[2], Cinzia Lastri[1], Enrico Magli[3], Vanni Nardino[1], Christophe Pache[5], Lorenzo Palombi[1], Diego Valsesia[3] and Valentina Raimondi[1]

[1] IFAC-CNR, Sesto Fiorentino, Italy; d.guzzi@ifac.cnr.it
[2] IPMS – Fraunhofer Institut, Dresden, Germany; sara.frances-gonzalez@ipms.fraunhofer.de
[3] Politecnico di Torino – DET, Torino, Italy; enrico.magli@polito.it
[4] SAITEC srl Firenze, Italy; marco.corti@saitecsrl.com; marco.corti@saitecsrl.com
[5] CSEM, Centre Suisse d'Electronique et Microtechnique, Neuchâtel, Switzerland; christophe.pache@csem.ch
* Correspondence: d.guzzi@ifac.cnr.it; Tel.: +390555226301
† Presented at the AITA 2025, Kobe (Japan), and 15-09/09/2025.

Abstract: In the framework of the SURPRISE EU project, Compressive Sensing paradigm was applied for the development of a laboratory demonstrator with improved spatial sampling operating from visible up to Medium InfraRed (MIR). The demonstrator, which utilizes a commercial Digital Micromirror Device modified by replacing its front window with one transparent up to MIR, has 10 bands in the VIS-NIR range and 2 bands in the MIR range, showing a super resolution factor up to 32. Measurements performed in the MIR spectral range using hot sources as targets, show that CS is effective in reconstructing super-resolved hot targets.

Keywords: Compressive sensing, Super Resolution, Medium infrared, Hot spot

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

Compressive Sensing (CS) paradigm [1, 2] allows the reconstruction of an image using fewer samples than in a classical approach, allowing the acquisition of a compressed image in a single step. Basically, a CS instrument is composed by a light modulation element (Spatial Light Modulator - SLM) and a single pixel detector on which the light is concentrated through a lens [3]. Each acquisition (measurement) is given by the product - element by element - between each element of the encoding binary pattern applied to the modulator and the corresponding element of the image focused on it, and the subsequent integration carried out by the condenser on the single-pixel detector. Based on its sparseness, the initial image can be reconstructed by making a number of measurements equal to or less than half of the pixels of the image to be reconstructed [4]. In the framework of the EU project "Super-resolved compressive instrument in the visible and medium infrared for earth observation applications" we have explored the application of the Compressive Sensing (CS) paradigm for the development of a CS-based instrument operating across the visible (VIS), Near InfraRed (NIR) and Medium InfraRed (MIR) spectral ranges with a focus on improving spatial sampling performance. During the project we designed and constructed a laboratory demonstrator utilizing a commercial Digital Micromirror Device (DMD) as a central element for implementing a CS architecture. The DMD was modified by replacing its standard front window with one transparent across the entire spectral range from visible to medium infrared. The laboratory demonstrator operates with 10 spectral bands in the VIS-NIR range and 2 spectral bands in the MIR range, enabling CS-based super-resolved acquisitions with resolution enhancement factors of up to 32. Initially, we will present the results from measurements performed in the MIR spectral range using, as targets, small hot sources with an emissivity of 0.75 and maximum temperature of 843°C. The experimental results demonstrate that CS is effective in reconstructing super-resolved hot targets.

2. Materials and Methods

The SURPRISE demonstrator was conceived as a whiskbroom spectral imager with two channels in the MWIR (3 – 5 micron) and 10 channels in the VIS-NIR (400-900 nm) spectral range. The scene is scanned along two axes by means of a scanning system. The fore-optics provides the image of the observed portion (target) of the scene on the image plane field stop at which a SLM (a reworked DMD DLP7000 by Texas Instrument) is placed. The image captured in the instrument's Instantaneous Field Of View (IFOV) corresponds to a 'macropixel' on the SLM. Spectral splitting is applied after the SLM-based coding stage by means of dichroic mirrors and is followed by the spatial integration stage implemented by the condensers. The signal is further spectrally filtered (or dispersed by the spectrometer for the VIS-NIR channels) and finally acquired in spectral bands of interest by suitable detectors. The demonstrator is completed with an additional block constituted by a high resolution camera which will be used for alignment and validation purposes. The main characteristics selected of the demonstrator are listed in the following table.

Table 1. Selected parameters for the laboratory setup of the SURPRISE demonstrator.

Optical parameters for the laboratory setup of SURPRISE demonstrator	
Parameter	**Value**
Target dimensions (mm)	30 x 30
Target to lens distance (mm)	6346
Collection optics focal length (mm)	350.0
Collection optics focal ratio (F/#)	4.605
FOV (degrees)	0.2708 x 0.2708
SLM type	DMD DLP®7000
Micromirrors pitch (μm)	13.68 x 13.68
DMD area of interest (macropixel)	128 x 128 micromirrors (binned 4 x 4)
Maximum nominal super-resolution	32 x 32
Image (macropixel) side on DMD (mm)	1.751 (13.68 μm x 128 pixels)
Lens to image distance (mm)	370.4
Image dimensions (side) on DMD (mm)	1.751 x 1.751
Image diameter on MWIR detectors (mm)	< 1.0
Image dimensions (side) on VIS-NIR channel fiber entrance plane (mm)	< 1 (ensquared energy > 95%)

It is worth to note that none of the DMD models from Texas Instruments (TI) is compatible with the required large spectral range for the demonstrator's operation. Thus, DMD DLP7000 was reworked by replacing the original borosilicate window with an uncoated window presenting a high transmittance over the VIS-NIR and MIR spectrum [5]. Moreover, The DMD is tilted 45° around z-axis (named z-axis the direction of incidence of the rays on the DMD). Such configuration allows the optical elements to be disposed on the same horizontal plane. The need for mounting the DMD rotated is due to the fact that the DMD micromirrors of DLP®7000 have the tilt axis along their diagonal. As a consequence, a generic multi-target scene has to be scanned along a couple of orthonormal axes lying parallel to the diamond sides, i.e. tilted 45° with respect to the plane on which the demonstrator lies. The following figure shows the demonstrator scheme, the target bench with a target use for acquisition in VIS-NIR spectral range and the target used for measurements in the MIR spectral range.

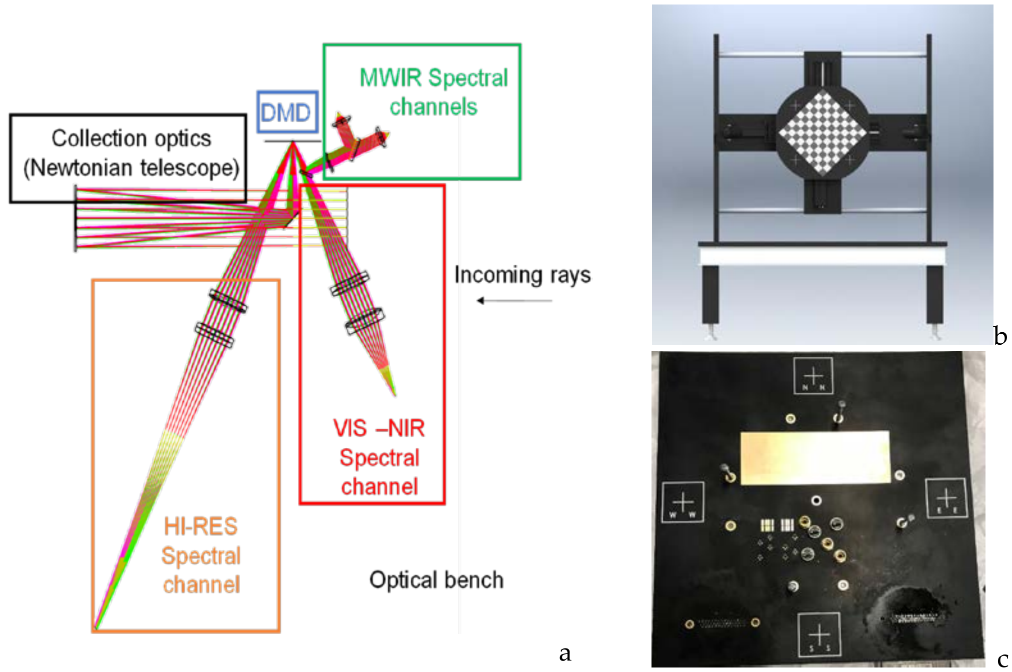

Figure 1. a) Scheme of labortaory demostrator, b)Target scanning system and c)Target used for mesuements in MIR spectral range

Figure 2 shows the infrared image of the MIR target acquired by using a thermal camera. The yellow-marked area corresponds to a macropixel acquired by the demonstrator. The macropixel contains six MIR sources.

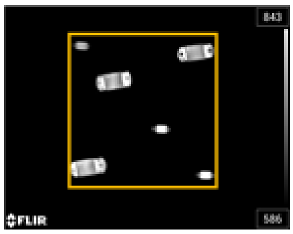

Figure 2. Infrared image of the target that shows the number of IR sources on the target

The MIR sources are IR lamps with emissivity equal to 0.75 and a maximum temperature – measured with a thermocamera - of 843°C. Two different levels of SNR were implemented on the MIR channels: Channel#1 at 3.3. µm featured a higher noise level (electronics parameters were not optimised) whereas Channel#2 @4.0 µm featured a very good SNR. The SNR was evaluated on the super-resolved macropixel image reconstructed (without CS) by applying a sequence of subsequent, single pixel ON masking for the two MWIR channels, with SR ranging from 4x4 to 32x32. Results are reported in table 1.

Table 2. SNR evaluated for different SR values ranging from 4x4 to 32x32.

SNR	SR 4x4	SR 8x8	ST 16X16	SR 32X32
Channel #1	8	5	1.4	<1
Channel #2	70	30	14	2.5

For what concern CS acquisition two methods were used for reconstructing images: the classical TV method and the ISTA-Net method which is based on machine learning paradigm [6].

3. Results

Figure 3 shows that CS reconstruction works well at reconstructing the targets. It can be clearly seen that there is a denoising effect achieved by the ISTA-Net and TV methods.

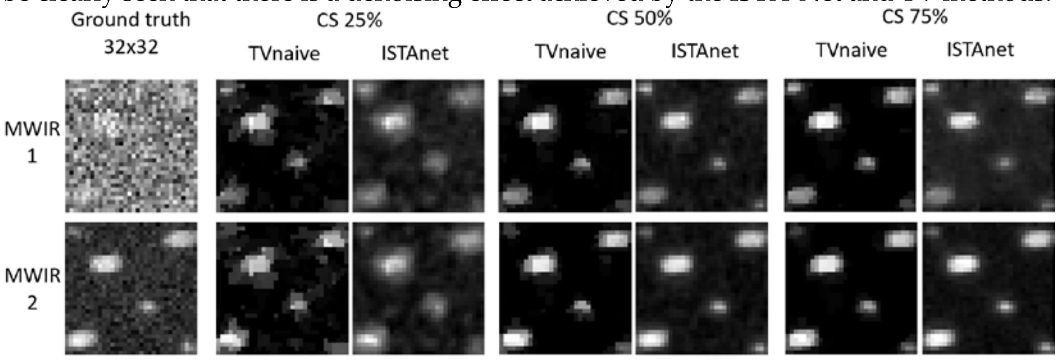

Figure 3. Infrared image of the target that shows the number of IR sources on the target and CS reconstruction of the spatially super-resolved image of a macro-pixel, for the two MWIR channels and SR equal to 32x32.

The reconstruction quality is generally good for the TV method while for ISTA-Net method the performance is worse. In particular, ISTA-net method passes all tests at CR of 50% and 75% for all SR factors, it and passes the test at CR of 25% for the 16x16 and 32x32 SR factors. Performed measurements show a denoising effect, which tends to provide reconstructions that are "cleaner" than the ground truth images at CR equal to 50% and higher, was observed in the case of low-SNR MWIR channel by applying the ISTA-Net and TV methods.

4.Conclusions

The SURPRISE demonstrator was successfully tested in all spectral channels from VIS-NIR to MIR. For what concern the MIR target, the reconstruction quality is generally good for the TV method while for ISTA-Net method the performance is generally worse. In general MIR measurements show a denoising effect, which tends to tends to reduce the graininess of the reconstructed image.

References

1. Candes, E.J.; Wakin, M. An introduction to compressive sampling. *IEEE Signal Processing Magazine* **2008**, 21-30.
2. Donoho, D. L. Compressed sensing. *IEEE Transactions on information theory* **2006**, *52.4*, 1289-1306.
3. Duarte, M.F.; Davenport, M.A.; Takhar, D.; Laska, J.N.; Sun, T.; Kelly, K.F.; Baraniuk, R.G. Single-Pixel Imaging via Compressive Sampling. *IEEE Signal Processing Magazine* **2008**, *25*, 83–91, doi:10.1109/MSP.2007.914730.
4. Candes, E.; Romberg, J. Sparsity and incoherence in compressive sampling. *Inverse problems* ***2007,*** *23.3,* 969.
5. Borque Gallego G.; Giriens L.; Ummel A.; Roulet J.C.; Guzzi D.: Raimondi V.; Pache C. Front-window replacement and performance characterization of a commercial digital micro-mirror device for use in the infrared spectrum, In Proceedings of International Conference on Space Optics — ICSO 2022, Dubrovnik, Croatia (3-7 October 2022) https://doi.org/10.1117/12.2691450.
6. E. Magli, et al., Compressive imaging and deep learning based image reconstruction methods in the "SURPRISE" EU project, in Proceedings of the European Workshop on On-Board Data Processing (OBDP2021), Online Event, 06/2021.

Funding: This research was funded by the European Union's Horizon 2020 research and innovation program under Grant Agreement No 870390.

Conflicts of Interest: The authors declare no conflicts of interest.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.