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Exploring the Potential of Compressive Sensing Payloads for Earth Observation from Geostationary Platforms: An Instrumental Concept for Fire Monitoring †

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Abstract: Earth observation (EO) payload performances in the infrared spectral region from geostationary platforms are often limited by spatial resolution. In this paper, we investigate an instrumental concept leveraging a compressive sensing paradigm and super-resolution architecture to implement an EO payload from a geostationary platform aimed at the monitoring of wildfires with a nominal spatial sampling distance of 500 m. The core device of the instrument is a European-technology-based micromirror array under study for space applications. Besides payload specifications and working principles, the main critical aspects and the expected impact on EO applications are discussed.

Keywords: compressive sensing; super-resolution; earth observation; optical payload; spatial light modulator; medium infrared; fire detection

1. Introduction

Earth observation (EO) data have become ever more vital to our understanding of our planet and to monitor risks. However, applications are still limited by two main factors: revisit time and spatial resolution. In particular, EO payloads in the infrared spectral region from geostationary platforms typically have a spatial resolution limited to some kilometers, but with a frequent revisit time that is crucial for monitoring rapidly changing events like wildfires.

The EU-funded H2020 SURPRISE project—acronym for "Super-resolved compressive instrument in the visible and medium infrared for earth observation applications"—has investigated the potential of the compressive sensing (CS) paradigm for the development of a CS-based payload working in the in the visible (VIS), near-infrared (NIR), short-wavelength infrared (SWIR), and medium infrared (MIR) spectral ranges from geostationary platforms with enhanced performance in terms of at-ground spatial sampling, onboard processing, and encryption capabilities. The study included the design and construction of a laboratory demonstrator that used a commercial digital micromirror device (DMD) as the core element to implement a CS architecture [1,2]. The laboratory demonstrator, which had 10 spectral bands in the VIS-NIR and 2 spectral bands in the MIR, was exploited to investigate in detail the capabilities of the CS-based instrumentation to improve the performance of a EO payload working in these spectral regions and to outline a roadmap for the development of a CS-based payload for earth observation from a geostationary platform.

In this paper, we present the instrumental concept of an EO payload from geostationary platform—based on the CS paradigm and implementing a super-resolution architecture—specifically conceived for the monitoring of wildfires with a nominal spatial sampling of 500 m and a revisit time from some hours at a global scale to some minutes at a regional scale.

2. CS-Based Instrument Concept

The idea behind the concept of a CS-based EO payload is a single-pixel camera [3]. Figure 1 shows the working principle of a single-pixel camera: the image generated by the collection optics is modulated at the image plane by a spatial light modulator (SLM)—acting as a modulation mask—and the signal transmitted through the SLM is integrated by an optical condenser and focused on a single-element detector. A set of measurements—each corresponding to a different modulation mask applied to the image—is used to reconstruct the original image using suitable CS reconstruction algorithms [4,5].

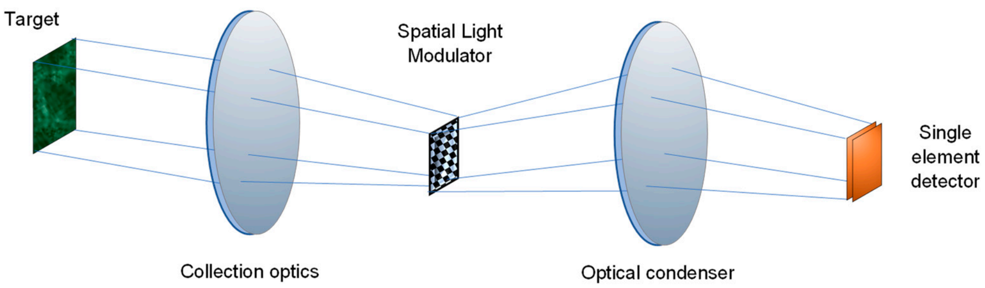

Figure 1. Working principle of a CS-based single-pixel camera.

In a CS-based instrument, the image can be efficiently reconstructed from a number of measurements smaller than the corresponding number of reconstructed image pixels. According to CS theory, a detector with a number of pixels equal to n can be substituted with a single-pixel camera that executes $p \times n$ measurements, where p usually ranges from 0.1 to 0.5. The quality of the reconstructed image depends on the value of p. A CS-based system performs an inherently compressed acquisition, merging the acquisition and the compression steps in a single step. As a consequence, a data compression board—typically used to reduce the amount of data to be stored or transmitted—is not needed any longer since the data are acquired compressed natively. The use of a modulation mask applied to the image plane for each measurement also paves the way to native encryption.

3. Instrument Requirements and Payload Architecture

Table 1 reports the main observational and spectral requirements for a CS-based payload for wildfires monitoring from geostationary platform.

Table 1. Main requirements for a geostationary CS payload for fire monitoring.

Parameter	Value
Orbit type	Geostationary
Orbit altitude	35,786 Km
Acquisition mode	Whiskbroom, Step-Stare
Spectral range	0.4–0.9 μm (VIS) [1.6, 2.2] μm (SWIR) [3.74] (MWIR2)
Number of spectral bands (minimum)	4 bands in the VIS; 2 in the SWIR; 1 in the MWIR
Spatial sampling (nominal)	500 m
Instrument footprint	16 Km × 16 Km

It is worth noting that a payload operating from a geostationary orbit offers the additional advantage of an almost-still-Earth scenario, which is particularly suitable for the compressive sensing acquisition mode since the latter requires the acquisition of a series of measurements of the (almost same) target (the target is meant as the area corresponding to the instrument footprint) in order to obtain the final image reconstructed. The acquisition of the entire scene—at a global, regional, or local scale—is achieved by using a bidimensional scan mirror mechanism (E-W and N-S directions). The time required for the stabilization after each microstep of the scan mirror (settling time) is the driving factor in the estimate of the time required for the acquisition of a full scene. Preliminary estimates yield a revisit time of some hours at a synoptic scale and a few minutes at local–regional scale.

According to the requirements shown in Table 1, the instrument should cover a very wide spectral range, from the VIS up to 4 μm. In order to achieve a nominal spatial sampling of at least 500 m, a pupil diameter of about 350 mm is required, which in turn needs a large pointing mirror, due to a working inclination of 45° with respect to the Nadir.

Figure 2 shows the basic architecture of the EO payload concept that fulfil the requirement of operation in a wide spectral range from VIS to MIR. A MicroMirror Array (MMA) consisting of a 32 × 32 matrix of 16 μm pitch micromirrors is used as the SLM. The instrument relies on a single common collimator positioned after the SLM before the spectral splitting stage between the MWIR channel (MWIR 2) and the VIS-SWIR channels. The spectral splitting is achieved by using dichroic filters. The detection system is configured as a single-element detector based on photovoltaic (PV) silicon detectors for the VIS and NIR bands (from 0.4 μm to 1.0 μm), while HgCdTe PV detectors are used for the SWIR/MIR bands.

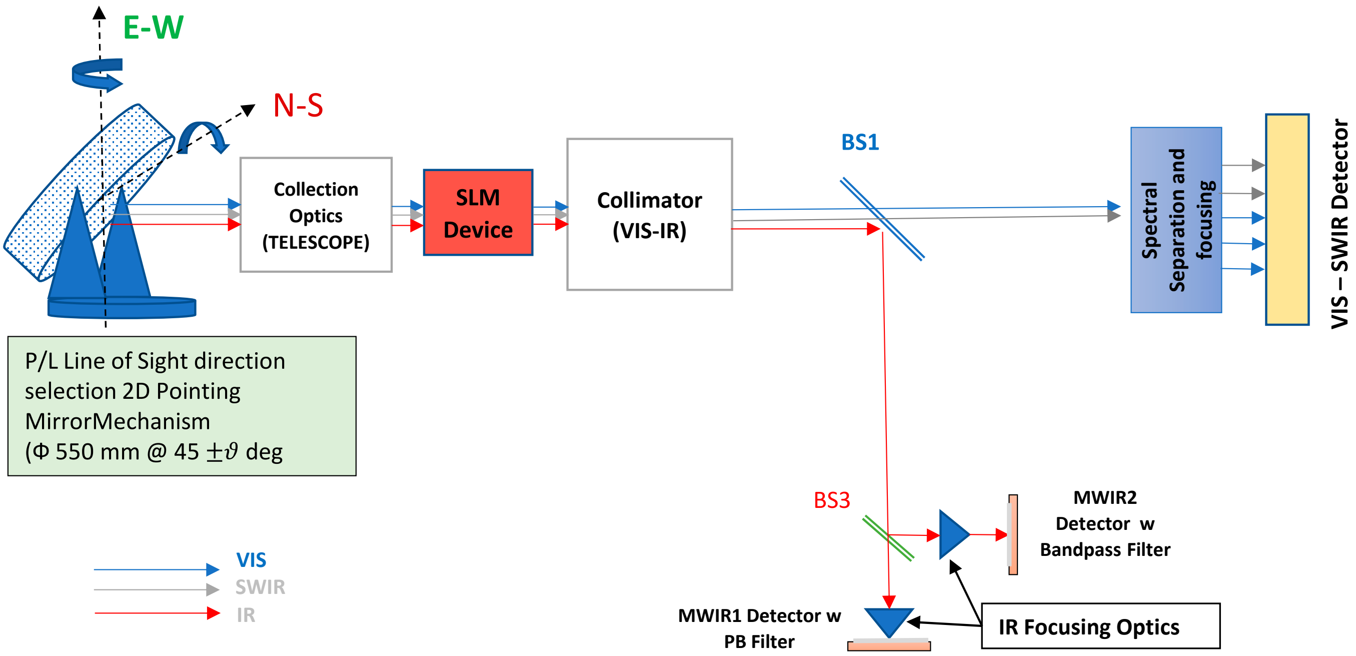

Figure 2. CS-based EO payload concept for whiskbroom operation from a geostationary platform.

4. Conclusions

CS-based architectures for EO payloads from geostationary platforms can provide interesting features useful for enhancing their performances in terms of spatial sampling, compression, and encryption features. Here, we present a concept of a CS-based EO payload operating from a geostationary platform for fire monitoring with a spatial sampling of 500 m and frequent revisit time, from some hours at a synoptic scale to a few minutes at a local–regional scale. Next steps include outlining a development roadmap to identify the most critical aspects, solutions available, and possible technological development needed.

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