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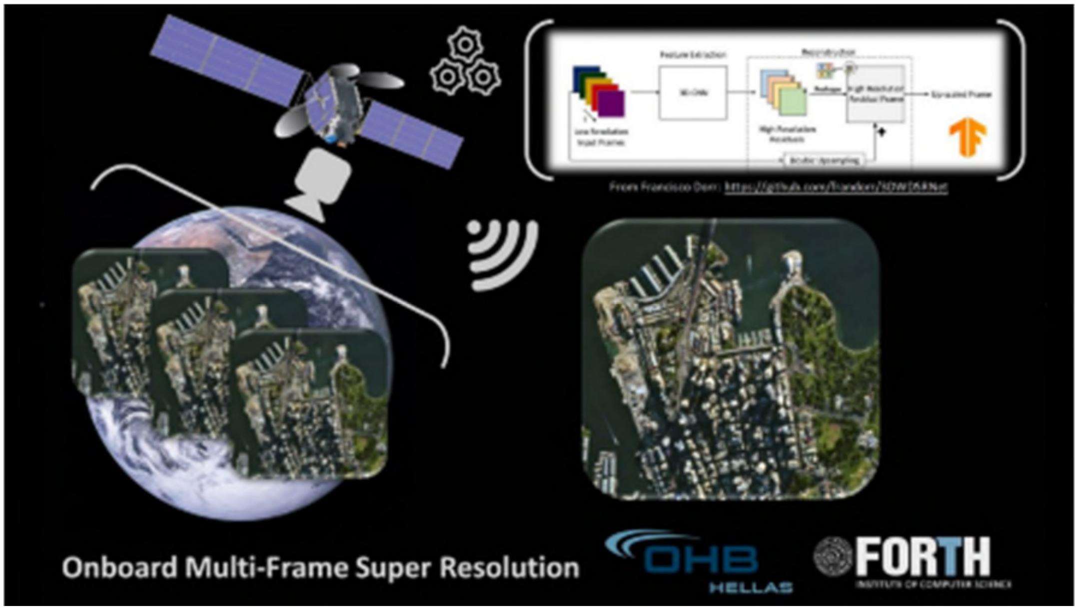

Idea I-2021-03627: Onboard Multi-Frame Super Resolution Image

Executive Summary Report

OPS-SAT Experiments Campaign

Campaign: OPS-SAT Experiments

Strategic Innovation Area: Discovery

Affiliation(s): OHB-Hellas (Prime), FORTH ICS (Subcontractor)

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Activity summary:

Super-resolution refers to the process of improving the spatial resolution, that is, the level of detail, of an image or an acquisition system. Our innovative idea is to use the OPS-SAT powerful on-board computer to deploy a machine learning-based super-resolution algorithm directly on-board the satellite. It has the potential of opening new perspectives of EO applications mainly in time-critical domains like safety and security. In the frame of this experiment, we successfully developed and deployed an AI-based multi-frame super resolution algorithm on board OPS-SAT achieving a notable improvement in image quality and proving the merits of the proposed approach.

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1 Introduction

This document constitutes the Executive Summary Report of the Project, summarizing the findings of the Contract in a concise way. This Summary is not meant to provide an extensive analysis of the work performed during the activity but rather give a high-level overview of it.

2 Applicable Documents

AD No. / Title	Doc. No.	Issue
AD1 Idea I-2021-03627: 2nd Round: Onboard Multi-Frame Super Resolution Image	ESA-OHE-PO-0043	01

3 Related Documents

RD No. / Title	Doc. No.	Issue
RD01 Francisco Dorr, "Satellite Image Multi-Frame Super Resolution Using 3D Wide-Activation Neural Networks", Remote Sensing, 12(22), 3812, 2020		1

4 Executive Summary

Technology miniaturization is a key driver for the next generation of EO platforms utilizing CubeSats, which promises a radical departure from the established paradigm in terms of design and development cost and time, as well as reduced complexity and higher flexibility deployment processes. CubeSats have the potential to revolutionize Earth Observation by exploring different operating points in terms of spatial, temporal, and spectral resolution. While physical limitations, mostly in terms of component size and weight, prevent them from obtaining high-quality imagery, technology miniaturization has allowed such platforms to support impressive capabilities and flexibility in terms of hardware and software.

The key motivation of this experiment is that while the spatial resolution is limited by the physical laws (optics, detector), the temporal sampling rate, i.e., the number of frames per second, is primarily controlled by electronics and is therefore much easier to adjust based on the capabilities of the platform and the imaging requirements. In this work, we investigate the ability of the on-board camera of OPS-SAT to acquire multiple frames, i.e., short video or burst sequences, from the same (approximately) ground location and utilize these frames for increasing the spatial resolution, by effectively fusing multiple Low Resolution (LR) images into a single High-Resolution (HR) one. In this work, we study how one can leverage the capabilities of CubeSats, and the ESA OPS-SAT platform, in particular, to effectively fuse sequences of low-resolution images into a higher resolution one and transmit the generated images instead of the unprocessed ones. By generating a single high-resolution image, different operating points can be explored in terms of the number of frames and spatial resolution. We consider the analysis of scenarios where this process leads to compression of the observations, while at the same time, providing higher quality images.

We formulate the problem as an instance of Multi-Frame Super Resolution (MFSR) where we explore the ability of the onboard HD camera, to acquire multiple frames, i.e., short video or burst sequences, from the same (approximately) ground location and utilize these frames for increasing spatial resolution, by effectively fusing multiple Low Resolution (LR) images into a single High-Resolution (HR) one. To achieve this objective, we consider deep neural networks operating on registered image sequences which can be deployed onboard the satellite. State-of-the-art approaches for MFSR applied on remote sensing imagery are based on different deep learning model architectures, which introduce a non-linear fusion of the LR images and are designed to operate using either unregistered or registered frame sequences. In our case we use a state-of-the-art, light network called 3DWDSR [RD01]. The proposed MFSR system consists of two modules, one deployed on the spacecraft (inference) and one on the ground (training), where we assume the unrestricted availability of computational resources.

In order to train our network, we consider actual observations acquired from OPS-SAT at different locations. Each frame is approximately 4 Megapixels (2000x2000 pixels) and in each case, a sequence of 15-20 frames in quick succession is acquired. In Figure 1 below, we showcase different examples, of the raw (top row) and the contrast-enhanced (second row) versions of OPS-SAT image sequences.

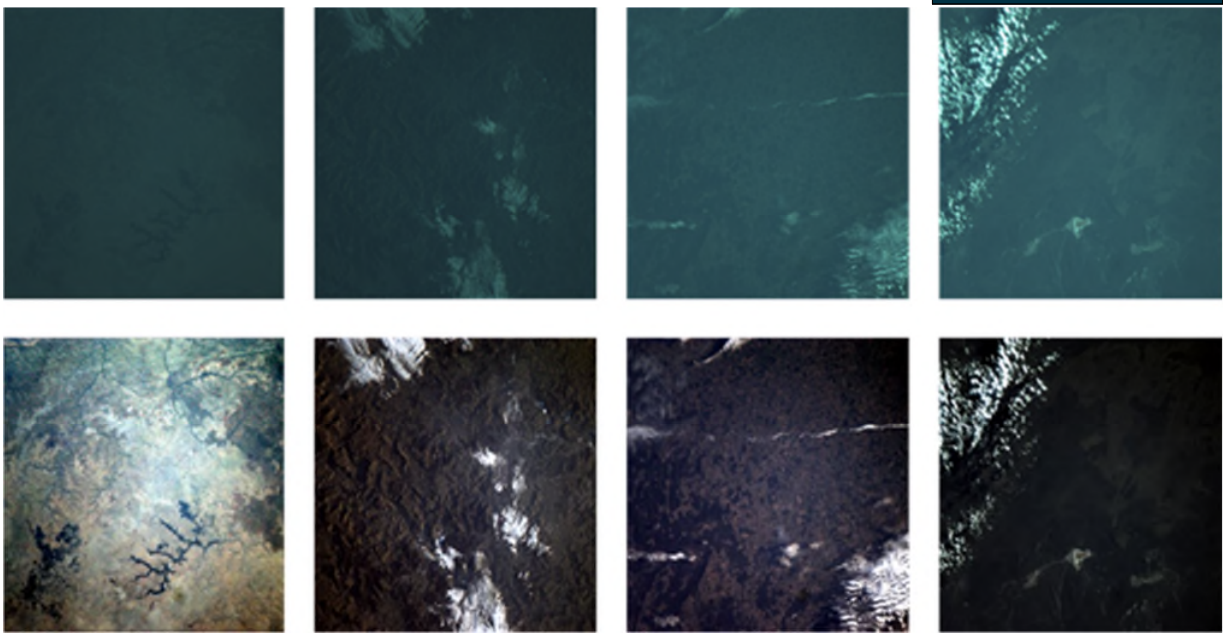

Figure 1: Raw (top) and contrast-enhanced (bottom) images from OPS-SAT

Given the computational and communications resources of OPS-SAT, we focus on the case of x2 super-resolution for the on-board MFSR. We believe that a super-resolution factor of an x2 factor will be able to demonstrate the potential of the method, minimize the additional requirements and offers quantified benefits in terms of “effective” compression. We considered processing sequences of 5 consecutive low-resolution frames and extracting a single high-resolution one. To quantify the performance gains, we consider the amount of data, in terms of Mega Pixels, that need to be stored and transmitted to the ground. In this scenario, the merits of on-board processing versus off-board/ground processing can be enumerated. In the following table we provide an overview of the performance gains for the scenario we deployed on OPS-SAT.

Table 4-1: Performance Overview for Selected Configuration

	Original OPS-SAT Image	Multi-Frame Super Resolved Image	
Upscale Factor	-	x2	x4
Mpixels / frame	4	16	64
# frames	**5**	1	1
Total Mpixels	20	16	64
Gain		**20% reduction**	220% increase

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After computing the multi-frame super resolution image, we need to identify a way to assess how good the final image actually is. Besides typical metrics that measure image quality, we recognise the necessity for an image quality assessment metric to be based entirely on objective criteria that can take into consideration the targeted final application and the image's basic features (e.g., sharpness, edges, etc.). Additionally, the metrics used in our approach are up to a degree interpretable and use straightforward computations.

In absence of a reference image, we developed an Image Quality Assessment (IQA) model that computes an objective score that represents the percentage of the distorted image's quality change in relation with the input image.

The main metrics we use to assess quality improvement are the following:

- Image similarity
- Image sharpness
- Edge appearance
- Color similarity

The outputs of these metrics are combined into an overall "score", giving an indication of the improvement of the output image compared to the input, original, image. In the figure below, two examples are shown of our image quality assessment approach, used on two OPS-SAT images.

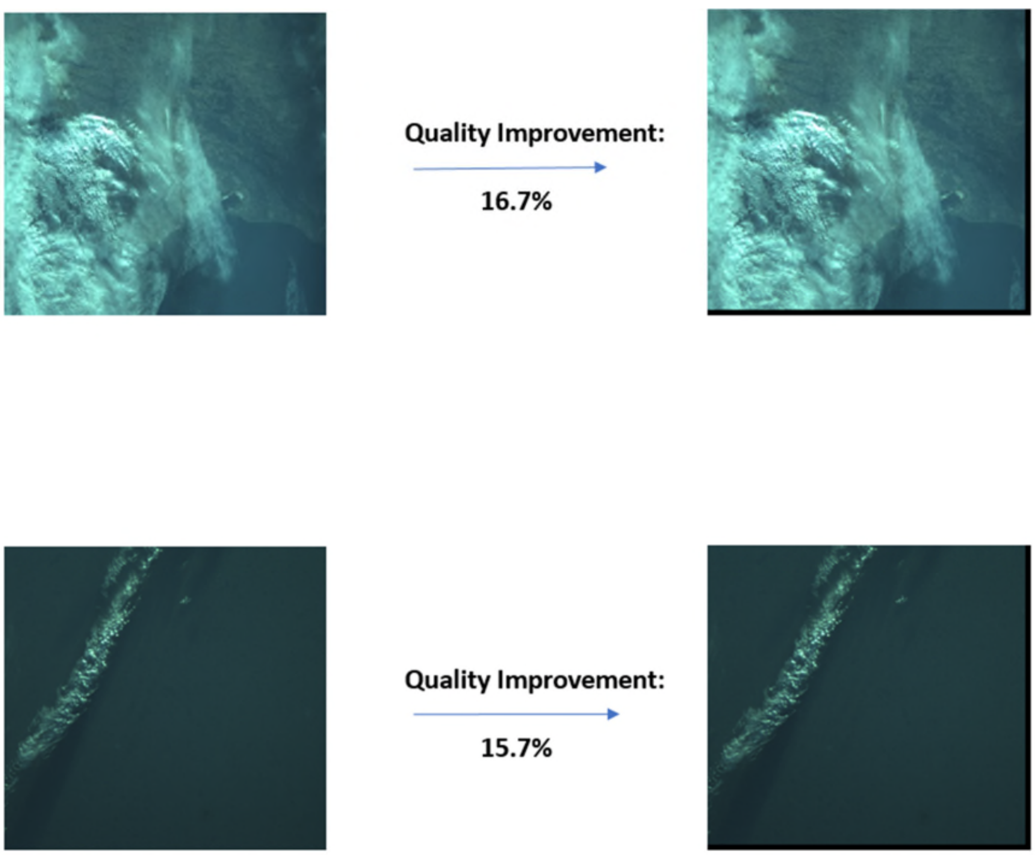

Figure 2: MFSR image quality improvement

Having now an AI model performing MFSR on the OPS-SAT images and in order to deploy the AI algorithm on board the satellite, we have to develop a host application, that is, a software that can run on the satellite computer and execute the AI algorithm it hosts.

The development and testing pipeline followed for the deployment of this SW on-board OPS-SAT is overviewed in the figure below. The development and testing of the application needs to be performed in two steps, the local development and verification of its functionality on the local machine and the adaptation of the application to the OPS-SAT on-board computer through a testing and verification session on the satellite on-board computer replica located at the ESA premises, on ground.

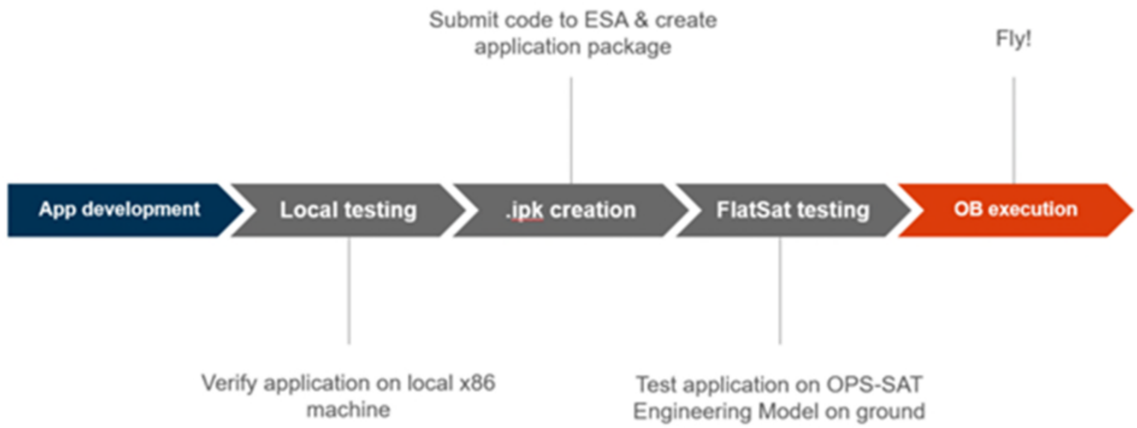

Figure 3: Application development pipeline

Going from a fully functional local application to a piece of software that can run on OPS-SAT is a rather complex task due to the multiple limitations and requirements that stall the development process and also affect the achieved maximum performance.

On one hand, limitations of available SW on-board the spacecraft, versioning limitations and memory constraints do require several iterations of the developed application in order to be compatible with the final platform.

On the other hand, testing on the OPS-SAT HW on ground is also rather restrictive, especially since the HW and SW limitations are not known beforehand.

Concluding, we can confirm the validity of performing multi-frame super resolution on-board OPS-SAT achieving clear, quantifiable benefits for the end user, both in terms of image quality as well as downlink data reduction. Future steps include an optimization of the software implementation to better utilize HW capabilities for efficient processing of the AI algorithm and optimization of the AI model itself targeting a specific use-case scenario.

221207_ESR_Executive Summary Report_EXP211_OHB-HELLAS

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