In-orbit Space-based Surveillance system by High-performance Computer-Vision Algorithms and dedicated HW Avionics

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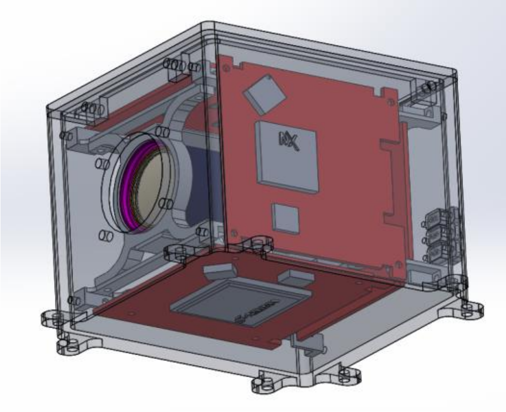


OBDP 2021
European Workshop on On-Board Data Processing
cnes DLR esa
14 - 17 June 2021 | Online Event

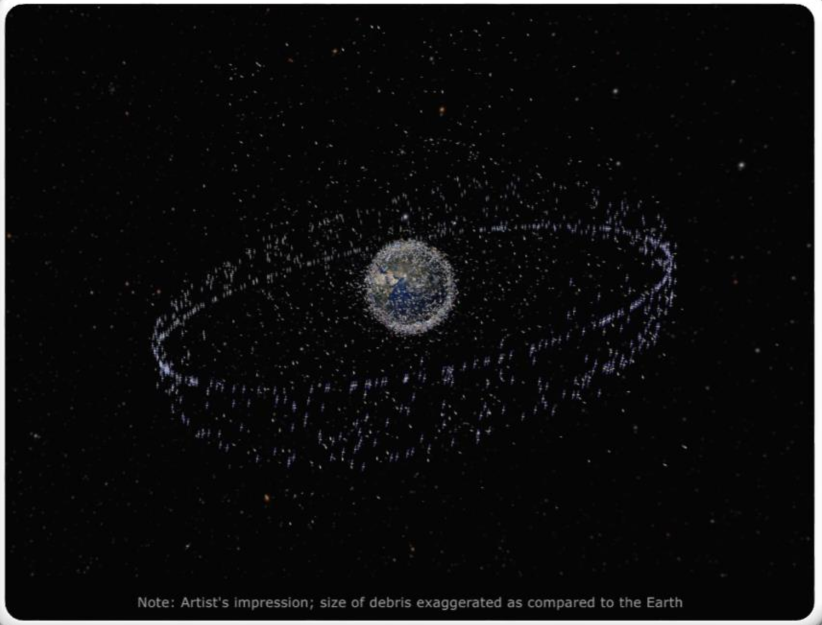
Theme	On-board Data Processing Algorithms and Implementations
Session Details	Session 2: Advances in On-Board Processing in Instruments and Payloads Monday, Jun 14, 2021, 1:55 PM - 3:30 PM

gmv INNOVATING SOLUTIONS

Introduction, Summary and Conclusions

We use 3 slides to pass the take home message

ESA credits: Clean Space website



Miniaturized Space-Based Surveillance System

SBSS-GNSS Introduction

1

Assessment of in-orbit satellite servicing for monitoring and tracking debris in MEO/LEO

2

Experimental Payloads On Board Galileo satellites of Galileo constellation as secondary services

3

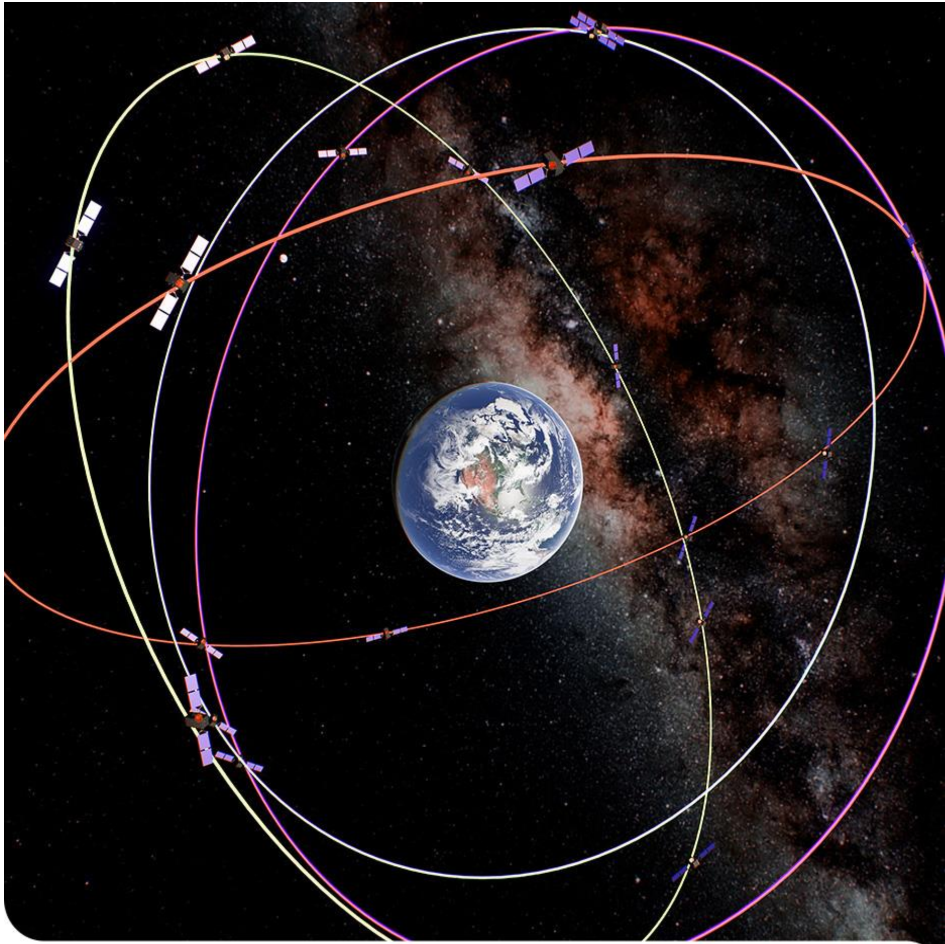
Low-cost solution that complements ground-based tracking.
Space Situational Awareness (SSA)
Reduces data downlink

4

Higher Performances
Absence of atmosphere and good timeliness.
Not weather-based degradation.
Reduction of ground-sat communication

Technical Contribution

- Space-Bases Surveillance System
- Miniaturized Low-Cost Payload
- On-board Galileo Satellites as secondary service
- Trade-off analysis and Experiment
- LEO/MEO Monitoring and Tracking of Debris
- Imaging sensor and Computing Electronics
- On-Board Algorithms detecting light curves and discriminating aritifial objects from known stars
- Autonomy and On-board HW/SW
- Avionics Architecture
- FPGA and PCB Design
- Prototype Manufacturing



Space-Based Surveillance Sytem

Remarks

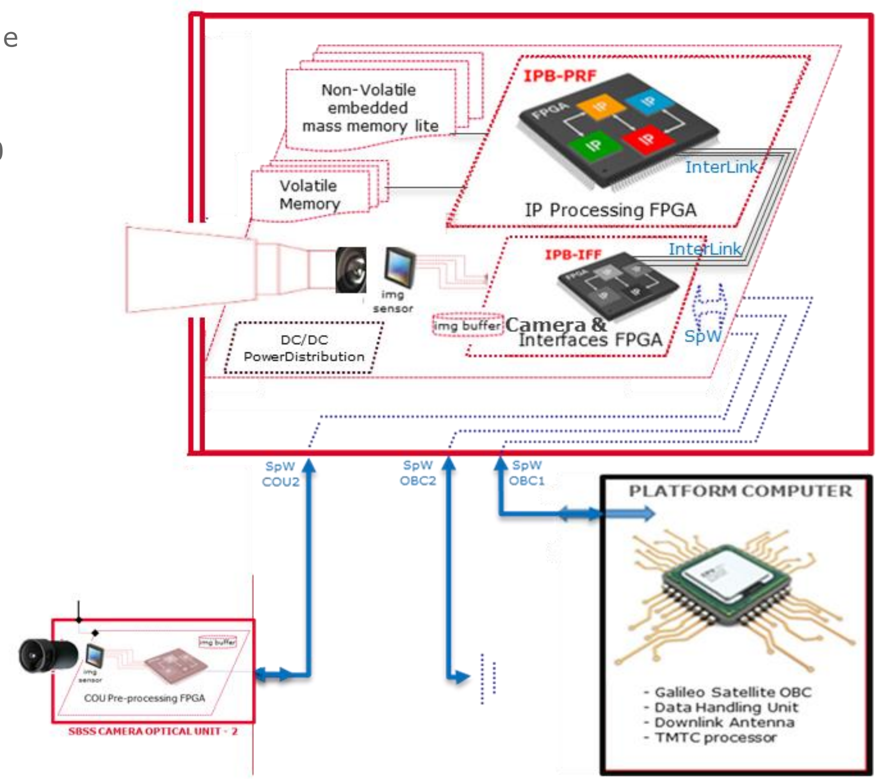
- Full on-board processing in autonomous way. Dedicated HW, space-grade quality.
- Reduced amount of data transmitted to ground, only positive detected and tracked candidates patches of images
- Good detection performance are observed for the presented cases in SBSS-GNSS project
- The debris shall be *sufficiently bright* in the image to guarantee a SNR of 5.
- The debris is detected and tracking with stars in the background
- Stars masking is not fully necessary as IP algorithms detecting lines and motion provides good detection and tracking
- PROOF-SW combined with PANGU and MATLAB-based image generation used for validation.

Entering in details

On-Board Data Processing HW

Integrated Solution

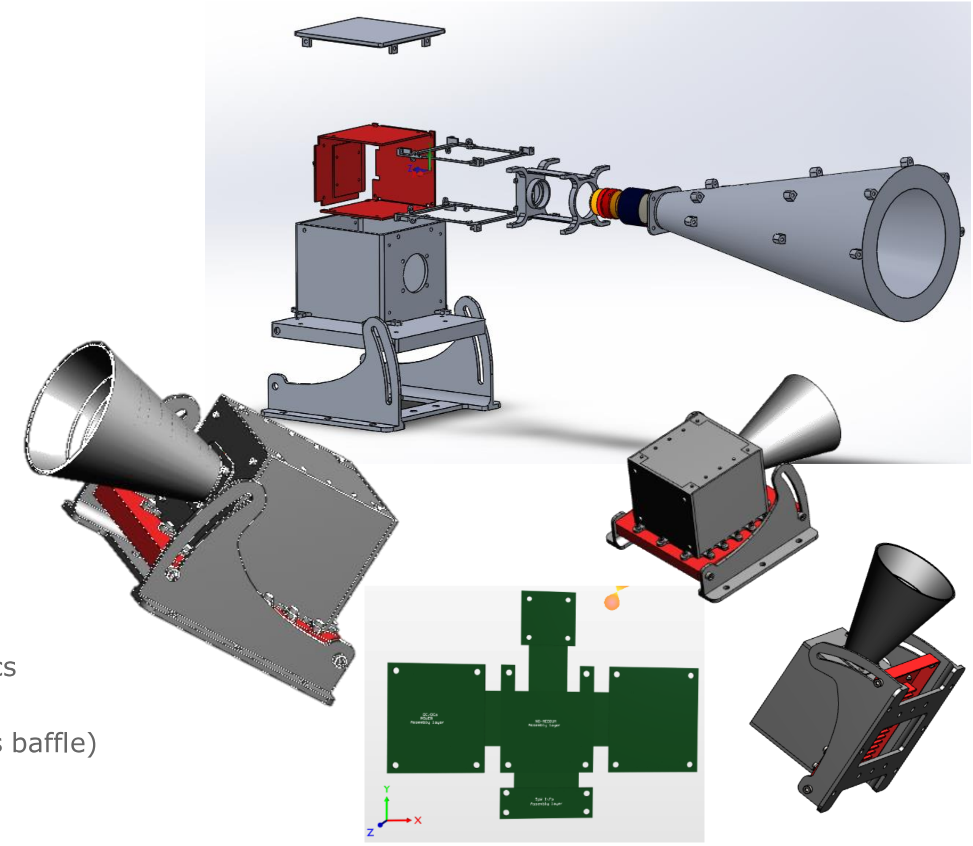
- All in a box. Folded electronics, embedded optics, integrated baffle
- Integrated **Camera Optical Unit + Image Processing Board**
  - 12-bit monochrome CMOS camera with CMOSIS CMV4000
  - 1024x1024 or 2048x2048 images of 10-12 bits
  - **Data I/F:** SpaceWire 90-100 Mbit/s (CCSDS/PUS TMTC)
  - Frame-rate 1 to 10 FPS / configurable integration time
  - Dedicated Memory included
- Processing electronics include **2 rad-hard SRAM-based FPGA**
  - **NG-MEDIUM + Virtex5QV**
- **Image Pre-processing/Correction** functionalities on camera
- Computer-Vision IPs on **co-processor accelerator**
- **Power Distribution** internally
- Possibility for a second external optical head unit (camera)



Avionics HW Design

Smart-sensor named G-Theia1

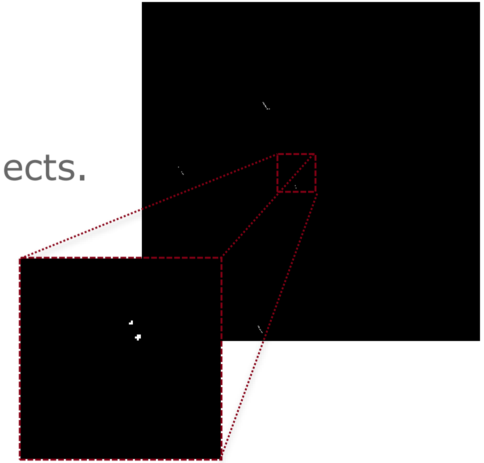
- **Active + Passive Thermal control** and dissipation
- Configurable pointing baseplate (fixed before launch)
- **Radiation-hardened** components equivalence
- **Operational Temperature**: -30ºC to +80ºC
- **Operational Power Consumption**:
  - Camera only <4W
  - Camera + Co-processor <14W
- **Power I/F**: 28V +6V/ -8V unregulated bus
- **Mass budget:** 1,2 Kg including enclosure and electronics
- **Volume budget:** 150mm x 140mm x 150mm (excludes baffle)



Debris Detection Algorithm

Concept Analysis for the project mission

- In the Galileo framework, no possibility of ***active target pointing/tracking***.
- Concept analysis: Mounting, SNR, Apparent Magnitude, Exposure Time, Focal Length, camera sensor, orbit, attitude…
- Algorithm for ***faint target detection*** inherited from previous GMV projects.
- Target and stars as two ***separated populations*** to be identified.
- Number of stars in the background has to be taken into account.
- ***SNR of 5*** is needed for a correct detection of sub-pixel targets.
- Preprocessing follow by candidates screened with segmentation to find separate objects in the frames of accepted candidates pixel



Detection and Tracking IP solution

Combines two technique paths

VDDT path 1

- Analyzes the bright pixels in the image to check whether they were present in previous frames to perform detection of candidates.
- Identify blobs in the confirmed list of candidates in the current image.
- At the end, with 2 or less candidates, the center of brightness coordinates are calculated.

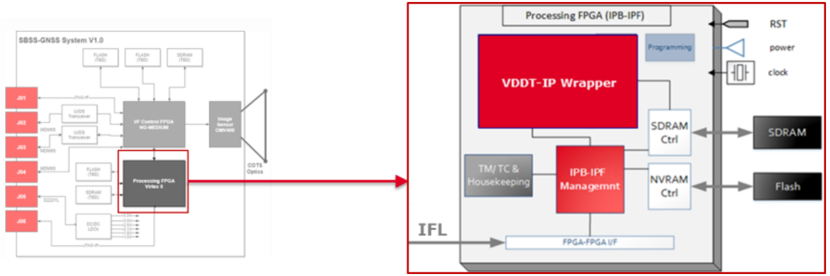
VDDT path 2

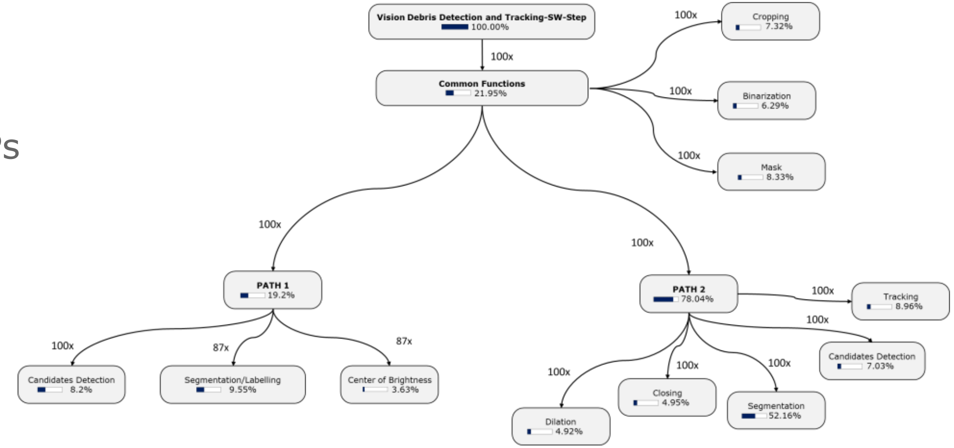
- Extracts information of stars’ direction
- analyse each blob of a time-integrated image
- An angle histogram is calculated and the most repeated value corresponds to the stars direction.
- Candidates are blobs with different orientation outside a boundary around that value.

Co-Processor FPGA hosts algorithm solution

- Analysis and profiling of algorithm
  - Identification of most computationally functions
  - Parallelizable tasks
  - Iterative Operations

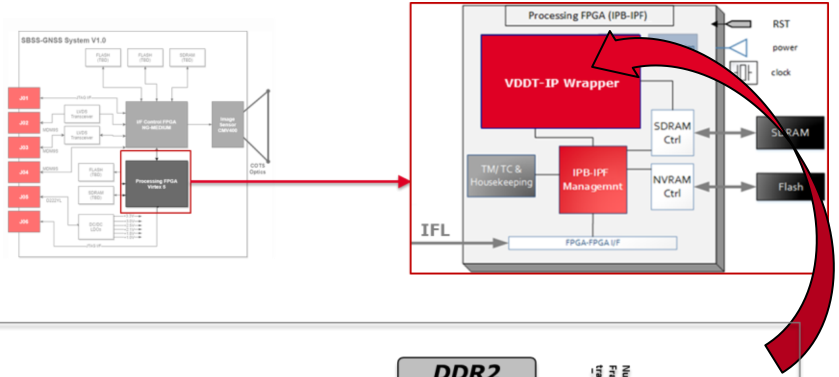
- HW implementation
  - Parallel implementation
  - Pipelining
  - Input streaming
  - Iterative mathematical operation using DSPs
  - Fixed-Point operations
  - Specific Memory Control
  - 2-FPGA allow safe reconfiguration of processing node

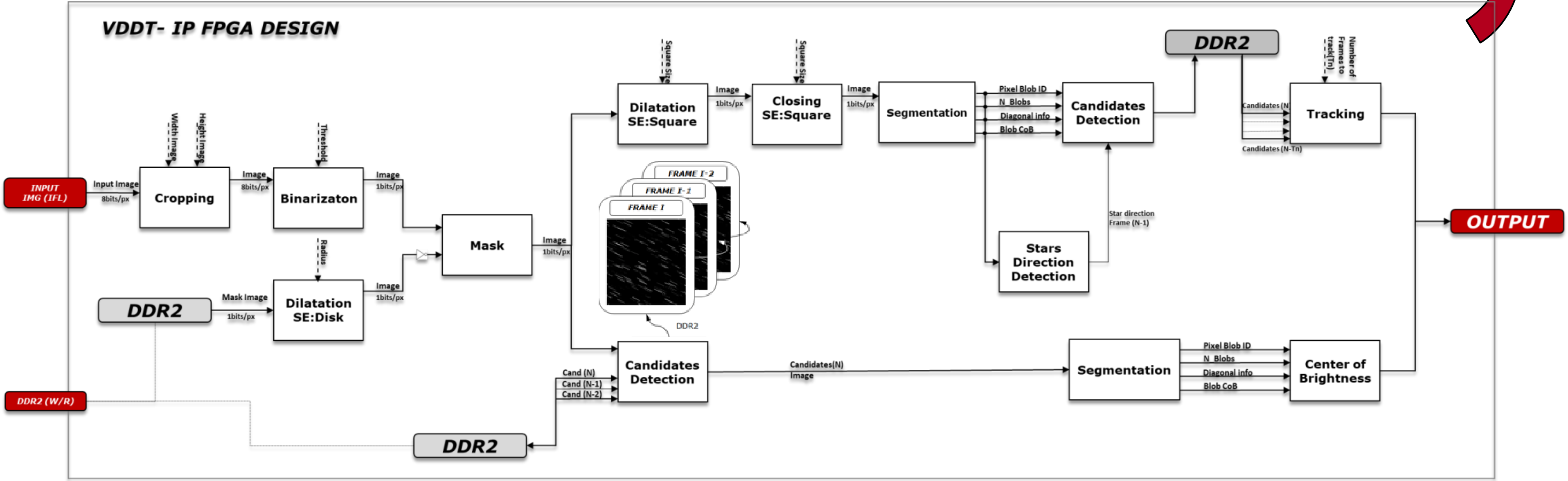




Vision-based Debris Detection and Tracking

- Processing in Streaming after image pre-processing corrections





Some results

Test Case Scenarios

~20 trajectories in MIL and FIL (4 examples in the slides)

Test Cases Parameters

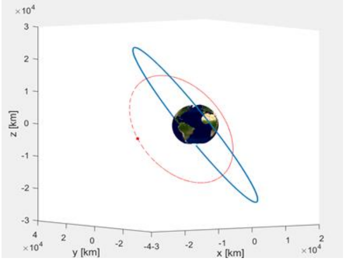
Parameter	Value
Objects	
Debris object	shapes: sphere albedo: 0.3 1-m diameter
Imaging	
Camera model	1) Conceptual camera based on CMV4000 2) 6.41º×6.41º FOV 3) 1024×1024 frame 4) 0.25-Hz frame rate 5) 60º pointing direction in the x-z plane.
Dynamics	
Orbit of the Galileo satellite mounting SBSS at the epoch	a = 29599.8 km [Semi-major Axis] i = 56º [Inclination] ecc = 0 [Eccentricity] ome = 0º [Argument of perigee] OM = 77.632º [RAAN] Yaw-Steering attitude profile
PSF FWHM (point spread function full-width half-maximum)	1.5 pixels TBC (this PSF embodies optics and jitter)
Starry background	
Star catalogue	Tycho-2 up to 12th magnitude stars

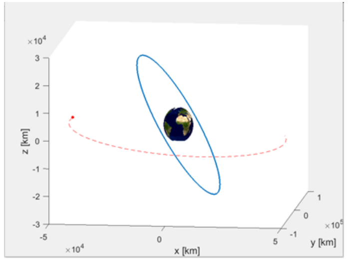
Debris Orbit #1
a = 19652.6 km [Semi-major Axis] i = 62.14º [Inclination] ecc = 0.3355 [Eccentricity] ome = 8.8º [Argument of perigee] OM = 26.75º [RAAN] u = 186.36º [Argument of latitude]
Dwell Rate = 4.1 pxl/s (considering a photometric area of 2x2 pxl)

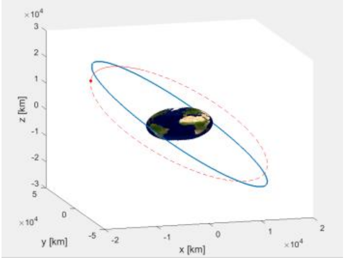
Debris Orbit #2
a = 48596.9 km [Semi-major Axis] i = 7.14º [Inclination] ecc = 0.2779 [Eccentricity] ome = 63.51º [Argument of perigee] OM = 28.40º [RAAN] u = 156.65º [Argument of latitude]
Dwell Rate = 1.4 pxl/s (considering a photometric area of 2x2 pxl)

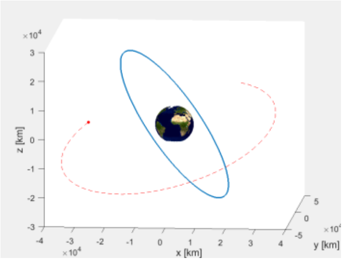
Debris Orbit #3
a = 26570.0 km [Semi-major Axis] i = 63.23º [Inclination] ecc = 0.0053 [Eccentricity] ome = 217.45º [Argument of perigee] OM = 113.58º [RAAN] u = 41.31º [Argument of latitude]
Dwell Rate = 1.5 pxl/s (considering a photometric area of 2x2 pxl)

Debris Orbit #4
a = 37787.9 km [Semi-major Axis] i = 25.54º [Inclination] ecc = 0.2388 [Eccentricity] ome = 111.55º [Argument of perigee] OM = 326.34º [RAAN] u = 186.09º [Argument of latitude]
Dwell Rate = 7.5 pxl/s (considering a photometric area of 2x2 pxl)









Test Cases Results

Lessons learned from 4 selected cases

#1:

- Quite fast object on the camera plane.
- Various target loss but correct tracking.
- Sub-pixel error.

#2:

- Smaller dwell rate more stable debris motion.
- Good detection and tracking and very small error.

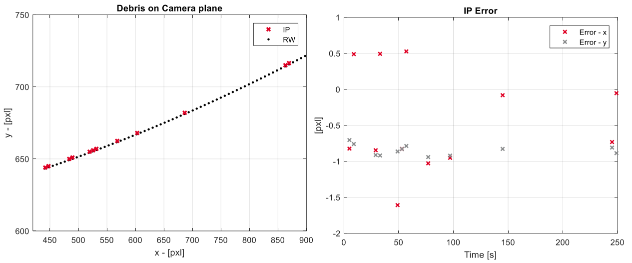
#3:

- Similar altitude and slow motion.
- Successful debris detection with slightly higher error.

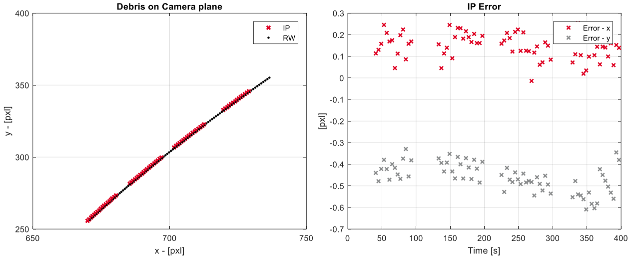
#4:

- Debris moves more than stars.
- Added motion detection to improve results

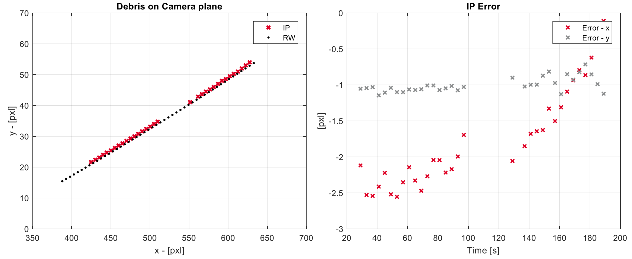
Debris Orbit #1



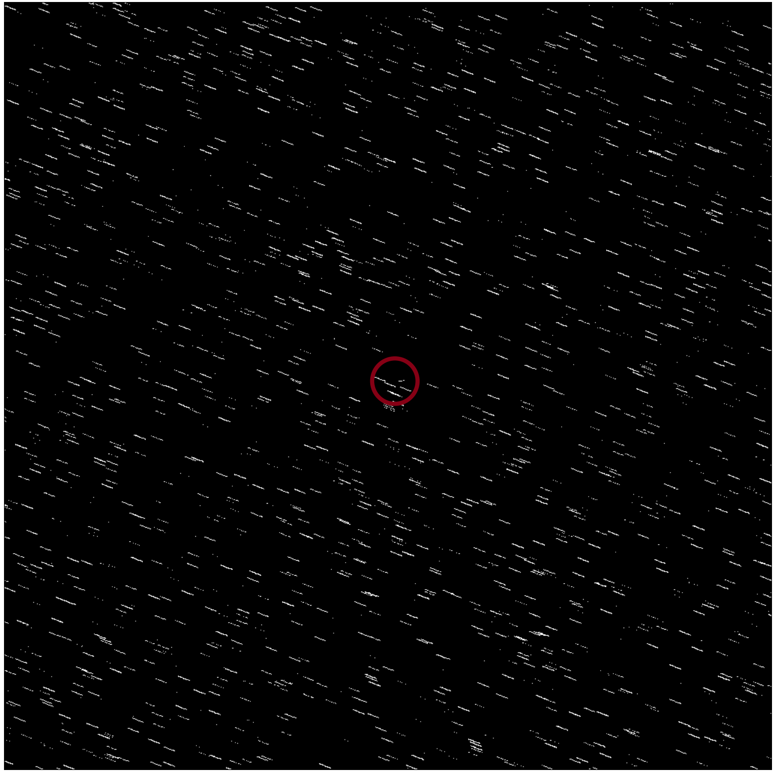
Debris Orbit #2

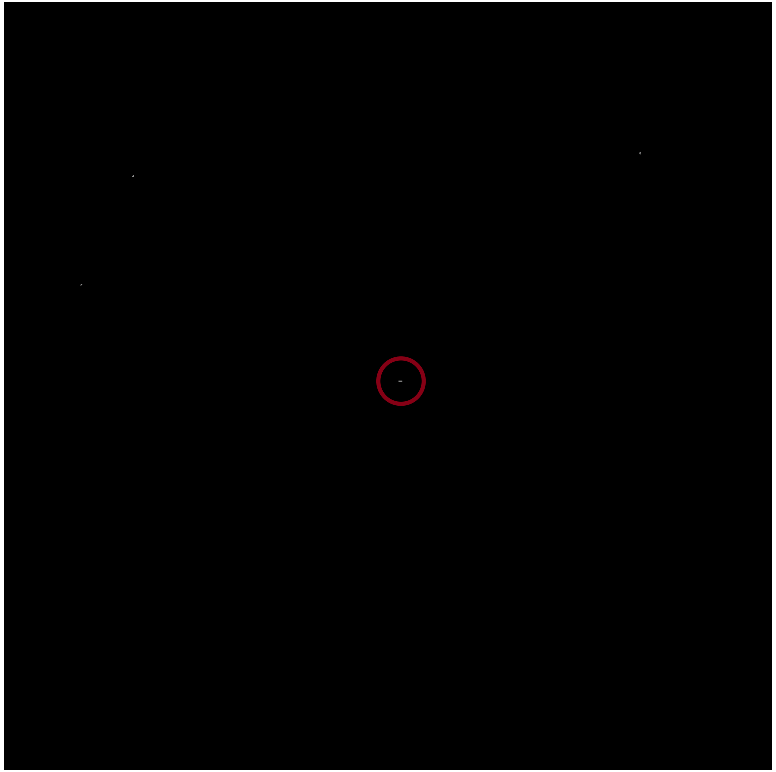


Debris Orbit #3

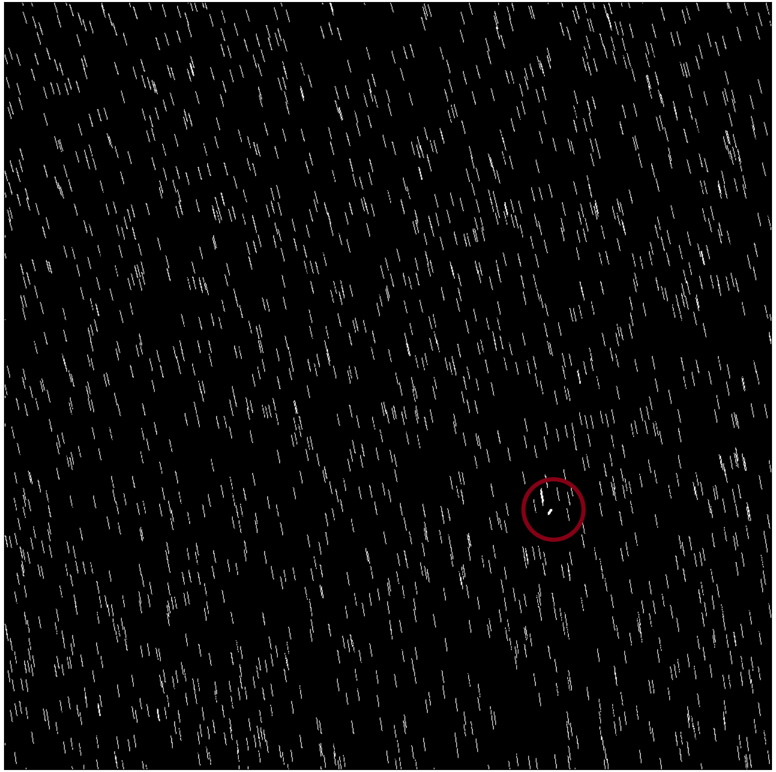


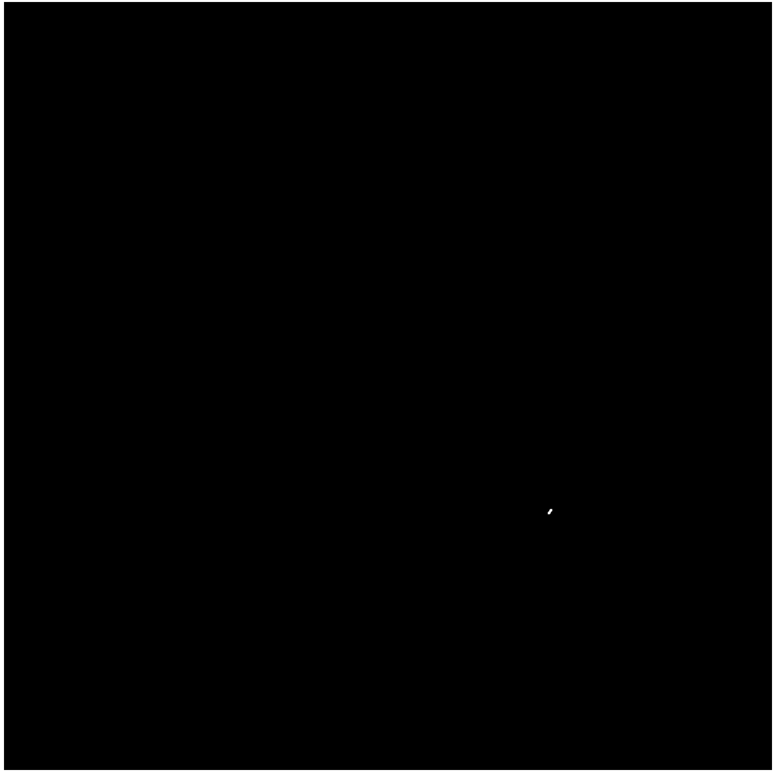
Visual examples (1/2)





Visual examples (2/2)





No conclusions now (see first part of the presentation)

Bonus-Track → AI

NN state-of-the-art

Most of the solution are ground-based

Wide research been developed for on-ground applications.

Motion of the stars is well known and a precise pointing control can be performed to keep the stars background still with respect to the camera image.

Only moving object in the image is the debris and a neural network can be easily trained to perform debris detection

Classification techniques to discriminate between static and moving objects in the image.
Create stars masks to perform image masking and, therefore, to detect possible debris in the image.

Detection and classification need still starry background. This constraint limits the maximum possible exposure time, directly affecting the maximum observable visual magnitude of the debris.

Thank you

Work performed under ESA H2020 programm

Acknolewdges to the GNSS Evolution Team and ESA Technical Officers

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