gendared: THE GENERIC DATA REDUCTION FRAMEWORK FOR SPACE SURVEILLANCE AND ITS APPLICATIONS

Ana-Maria Adriana Piso-Grigore[(1)], Octavian – Angelo Voicu[(2)], Pierre-Guillaume Sprimont[(3)], Bogdan Bija[(4)], Oscar Alonso Lasheras[(5)]

[(1)] GMV Innovating Solutions, 246C Calea Floreasca, Sector 1, 011476 Bucharest, Romania, Email: apiso@gmv.com
[(2)] GMV Innovating Solutions, 246C Calea Floreasca, Sector 1, 011476 Bucharest, Romania, Email: avoicu@gmv.com
[(3)] GMV Innovating Solutions, 246C Calea Floreasca, Sector 1, 011476 Bucharest, Romania, Email: pierre.sprimont@gmv.com
[(4)] GMV NSL, HQ Building, Thomson Avenue, Harwell Campus, OX11 0GD , Oxfordshire, UK, Email: bbija@gmv.com
[(5)] GMV Aerospace and Defence S.A.U., Santiago Grisolía, 4, PTM Tres Cantos, 28760 Madrid, España, Email: oalonso@gmv.com

ABSTRACT

Space Surveillance and Tracking (SST) requires the development of observational campaigns to early identify Earth orbiting objects, estimate their orbital elements and monitor the evolution of their trajectories. In this context, The *Generic Data Reduction Framework for Space Surveillance* - ***gendared,*** prototyped initially by GMV in the frame of an ESA Romanian Industry Incentive Scheme project, is intended to be used in order to support the operational reduction of the image data acquired by optical telescopes. ***gendared*** receives as input the raw images taken by the telescope, and generates as output astrometric and photometric data for the target objects detected in the observation images. As of the end of the prototyping phase and the acceptance of the software by ESA, ***gendared*** has been further developed and used in a number of operational and research & development projects.

1 INTRODUCTION

Space Surveillance and Tracking (SST) requires the development of observational campaigns to early identify Earth orbiting objects, estimate their orbital elements and monitor the evolution of their trajectories.

With a growing number of satellites being launched every year, there is an increasing interest in SST at worldwide level and especially across the EU. In this context, Romania is one of the few EU member states involved in such activities.

SST systems must implement an Image Data Reduction Subsystem, able to timely process the continuous exposures taken in an automatic and continuous way by optical telescopes, analyse these data sets to identify objects of interest (target objects) and retrieve accurate measurements of the apparent position and brightness of the detected objects. In the last step, the tool generates tracklet information for the identified target objects.

In this context, The Generic Data Reduction Framework for Space Surveillance - ***gendared***, prototyped initially by GMV in the frame of an ESA Romanian Industry Incentive Scheme project, is intended to be used in order to support the operational reduction of the image data acquired by optical telescopes. ***gendared*** receives as input the raw images taken by the telescope, and generates as output astrometric and photometric data for the target objects detected in the observation images.

The key aspects that drove the development of ***gendared*** and its advantages include the fact that the software is autonomous and unassisted, can process images in near real-time, can cope with different image acquisition schemas, and is configurable and modular.

As of the end of the prototyping phase and the acceptance of the software by ESA, ***gendared*** has been successfully tested and validated on Romanian telescopes and developed further for various operational use cases of different telescopes, such as the German Aerospace Centre (DLR) telescopes.

Furthermore, since mid-2020, ***gendared*** is part of a larger architecture of GMV products supporting the operational data processing activities in Romanian Space Agency's SST Operational Centre (COSST), which ensures the Romanian contribution to the EUSST Consortium. In this case ***gendared*** is covering, in a centralized architecture, the processing of the data coming from the Romanian optical telescopes involved in EUSST. The software was further upgraded for this purpose, with new algorithms and processing pipelines included.

GMV has also won a Romanian Research & Development grant to upgrade ***gendared*** with artificial

Proc. 2nd NEO and Debris Detection Conference, Darmstadt, Germany, 24-26 January 2023, published by the ESA Space Safety Programme Office
Ed. T. Flohrer, R. Moissl, F. Schmitz (http://conference.sdo.esoc.esa.int, February 2023)

intelligence algorithms. By integrating artificial intelligence techniques into the ***gendared*** framework, the aim was to improve its performance, reduce user involvement and computational costs, as well as increase pipeline autonomy.

2 *gendared* PRODUCT

The Space Surveillance is defined as a comprehensive knowledge, understanding and maintained awareness of:

- the population of space objects,
- the space environment,
- the existing threats and risks.

The overall aim of the Space Surveillance programmes is to support utilisation of and access to space for research or services, through providing timely and quality data, information, services and knowledge regarding the environment, the threats and the sustainable exploitation of the outer space surrounding our planet Earth.

Space Surveillance and Tracking (SST) of both natural and man-made objects requires the development of observational campaigns to early identify Earth orbiting objects, estimate their orbital elements and monitor the evolution of their orbits. This implies:

- the deployment of an observation network based on on-ground (and potentially space-based) optical telescopes, and
- the development of a Data Processing Framework able to process the acquired images, identify potential target objects, correlate object measurements in consecutive exposures according to the observational schema and provide precise measurements of the position and brightness for all retrieved objects.

Considering the increasing interest in Space Surveillance at both European and worldwide levels, a growing number of initiatives are being developed to define new tools or to exploit the existing ones (telescopes) for SST. Nevertheless, it is noted that the observation strategy followed in SST campaigns differs from that used in standard astronomical imagery. In addition, SST requires a quick analysis of the observational data to identify and/or update the orbital data of target objects as soon as possible. Therefore, SST systems must implement an Image Data Reduction Subsystem, able to timely process the continuous exposures taken in automatic and continuous way.

The *Generic Data Reduction Framework for Space Surveillance* (***gendared***) is intended to be used within the Space Situational Awareness system in order to support the operational reduction of the image data acquired during observational campaigns, to collate and deliver astrometric data. ***gendared*** receives as input the raw images taken by the telescope (both observation and calibration images) together with all required additional information (list of images corresponding to the same observation session, defect map), and generates as output astrometric and photometric data for the target objects detected in the observation images.

The key aspects that drove the design and development of such a Generic Framework can be summarised as follows:

- The Image Reduction process shall be fully autonomous and unassisted, able to process incoming images according to a specific logic and not requiring the support of an operator.
- Full Image Reduction process shall be fast enough in order to allow the processing of high image acquisition rates, typically some images per minute, in (near) real time, that is, neither delays nor blockages must occur in the processing of the images taken in a closely continuous acquisition schema.
- Image Reduction algorithms must be able to cope with different acquisition schemas including no tracking, sidereal tracking, precise object tracking and rough object tracking.
- The Data Reduction environment shall be configurable in order to allow the operator to easily define and/or modify the behaviour of the processing to fit specific instrumental and observational characteristics.
- The Data Reduction environment shall be designed in a modular way to easily allow adding or updating specific data reduction processes to ensure the improvement and evolution of the processing algorithms.

The main functionalities of the ***gendared*** product can thus be summarised as follows:

- Autonomously control and monitor the astrometric processing of data acquired from SST telescopes
- Image reduction algorithms to cope with different acquisition schemas
- Modular design allows for an easy integration of new algorithms
- Correlated detections of the same object identified in a sequence of images (tracklet) are provided in CCSDS TDM format (ASCII JSON and KVN)
- User interaction via web interface

2.1 *gendared* MAIN COMPONENTS

A high-level view of ***gendared***'s structure is depicted in Figure 1. ***gendared***'s main components are:

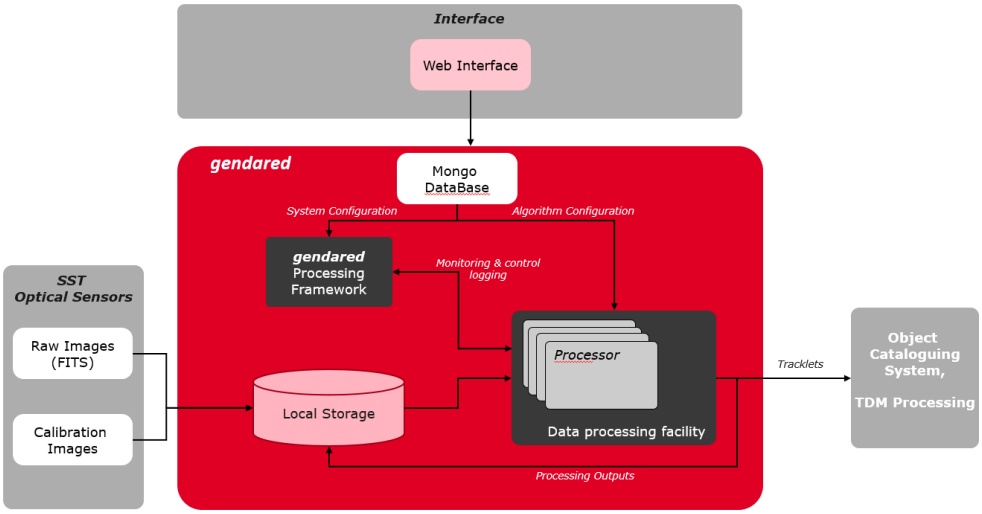

Figure 1: ***gendared*** *high-level structure*

- The processing framework (orchestrator), in charge of controlling and monitoring how the different components of ***gendared*** run from the SW point of view, and driving the overall processing.
- The data processing facility, which is the component implementing the image reduction process. This component is composed by atomic and self-contained elements each implementing a specific step in the reduction process. The execution of these elements is driven by the orchestrator in order to build the required pipeline processing.

The modular design (pipeline implemented as independent, atomic processing steps) allows for the easy definition/integration of pipelines/processors capable of covering additional functionalities

2.2 *gendared* PIPELINE

As described above, the ***gendared*** solution aims the operational processing of image products acquired by Space Surveillance Optical Telescopes. It thus consists of **robust**, **autonomous** and **operational** software. The software processes images obtained by telescopes and compares them with a background star map in order to identify space debris objects and generate astrometric measurements corresponding to the line of sight of the object.

We summarize here the steps to be executed by the different processors in the ***gendared*** pipeline. A schematic of the ***gendared*** workflow and an example of image processing by ***gendared*** are shown in Fig. 2.

Data Pre-processing. The input data is pre-processed. The dataset processing environment is created, the images are extracted from the archive and added to the database, and the configuration associated with the dataset is uploaded to the database.

Image Calibration*:* Raw images taken with a CCD camera are calibrated to correct for non-data elements that are found in each raw data frame such as bias offset, bias structure, dark current or uneven chip illumination.

Background Removal and Noise Estimation: The next step is the removal of the image background. The background estimation is used to account for non-instrumental effects, in order to obtain a precise detection of the objects and correctly measure the flux. The main source of background variations is the star glow.

Object Detection and Discrimination: In this step, all objects in the images are detected, regardless of object type, and further classified into stars and objects of interest (satellites). The algorithm uses a simple threshold technique on pixel values to build clusters of pixels corresponding to astronomical light sources or artificial satellites. These clusters of pixels are then statistically analysed to obtain their precise position and other geometrical characteristics that will further permit us to classify them into point-like and non-point-like classes. This results in a preliminary source list which is used to classify the sources. The list of streak images is then used to build a shape image template, representing the average aspect and relative intensity of the star or satellite streaks present on the images. This template is then cross-correlated with the images to detect with precision all the matching shapes on the images, even the very faint ones if the detection threshold is lowered in the correlation image. Note that other detection algorithms and strategies not based on template matching are included.

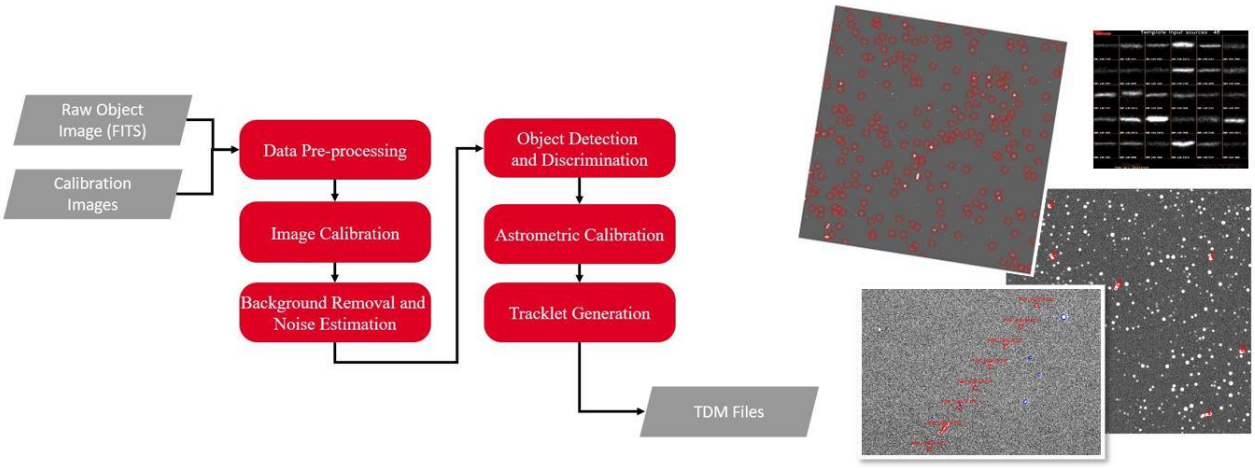

*Figure 2: **gendared** pipeline and example image processing*

***Astrometric Calibration**:* Mapping the image coordinates to astronomical coordinates.

Tracklet Generation: After the per-frame processing of a sequence of images, ***gendared*** will generate tracklets, which contain the trajectory of an object of interest identified in multiple images in the dataset. The tracklet generation step is also a way to remove false positives detected in the *Object detection and discrimination* step.

An example of detections on satellite-tacking images, where stars appear as streaks and satellites as point-like, is presented in Fig. 5. Fig. 6 further shows an example of detections in survey images, where stars appear point-like and the satellites appear as streaks.

Figure 3: Example of detections on a satellite-tacking images. Stars appear as streaks (purple) and satellites as point-like (yellow).

Figure 4: Example of detections on survey images. Stars appear as point-like (yellow) and satellites appear as streaks (purple).

2.3 *gendared* WEB INTERFACE

The ***gendared*** product can be accessed via a web interface. Some of the features of this interactive, use-friendly interface include:

- Setting up ***gendared*** configuration
- Uploading datasets
- Monitoring processing status interactively
- Viewing ***gendared*** operational status
- Viewing charts and statistics
- Different access levels for multiple types of users

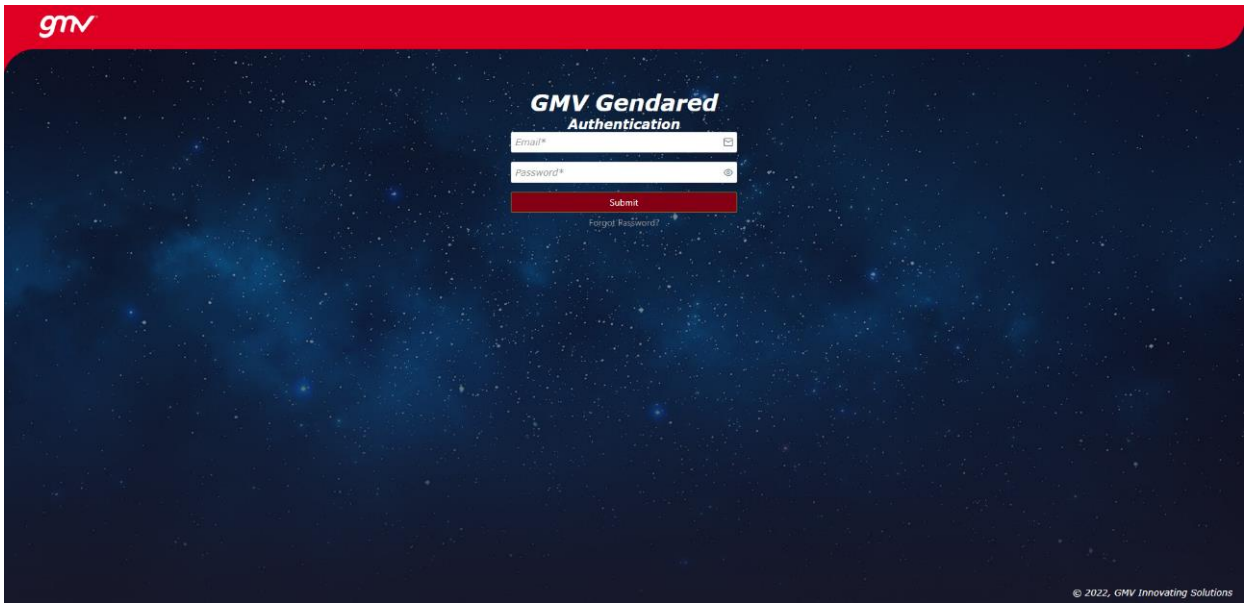

Figure 4: Interface login page

Snapshots of the ***gendared*** web interface are shown in Figures 4 and 5.

3 PROJECTS BASED ON *gendared*

3.1 RONOCOPS

This project consists of operational data processing services for Romania's National SST Operational Centre (COSST). Within this project, ***gendared*** is one of the two key SW elements of a fully automated, operational processing chain for SST service provision:

- Configuration of processing pipelines for a variety of Romanian SST optical sensors.
- Continuous monitoring for the receipt of new SST observations, from the several sensors.
- Timely reduction of the FITS images to obtain tracklets (TDM files) with the positions of the objects of interest identified in the observations (either survey or tracking).

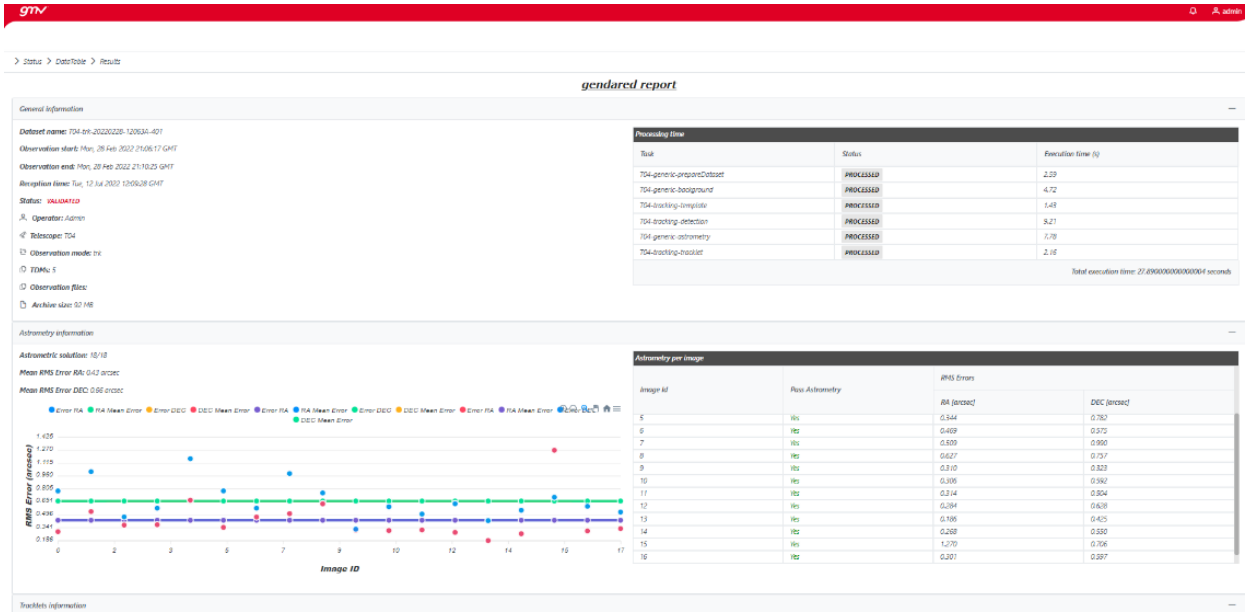

Figure 5: Visualisation of gendared processing results via interface

- Internal interface with the ***sstod*** SW element for the

correlation, validation and upload of TDM files in EUSST DB.

3.2 DLR-ODPS: OPTICAL DATA PROCESSING SOFTWARE

The goal of this project was upgrading ***gendared*** for the operational processing of image products acquired by German Aerospace Centre (DLR) telescopes. This consists of robust, autonomous and operational software in charge of:

- Receiving a continuous and asynchronous flow of data from SST sensors.
- Process received datasets in order to identify objects of interest in the observations, and retrieve accurate measurements of their apparent position and magnitude.
- Generate tracklet information for the identified target objects in appropriate format and send these data to the SST Cataloguing System for further analysis and processing.

3.3 AI4GENDARED

This R&D project aimed to upgrade the ***gendared*** framework for SST data reduction with AI algorithms for astronomical image processing. The project involves a consortium led by GMV, with the Faculty of Automatic Control and Computer Science and the Astronomical Institute of the Romanian Academy as partners, with the following objectives:

- Review state-of-the-art AI algorithms and solutions for astronomical image processing (e.g., [1], [2], [3], [5], [6], [7], [8]), and integrate a selection of the relevant ones into the current ***gendared*** framework.
- Improve ***gendared*** performance by reducing user involvement and computational costs.
- Tailor image detection and multi-frame processing (tracklet generation) pipelines to telescope specifications and characteristics (e.g., [4]).
- Test and validate the algorithms on real telescope data and representative simulated scenarios.

4 CONCLUSIONS AND FUTURE PROSPECTS

The ***gendared*** solution developed by GMV for the operational reduction of astronomical data has proven to be successful and has been developed in several directions under the umbrella of various projects, as discussed in Section 2. Further developments are planned for the ***gendared*** product, including improvements in the detection & discrimination and tracklet generation algorithms, using both AI and traditional methods. In addition, the ***gendared*** graphic user interface is continuously developed. Further plans include the potential to evolve ***gendared*** as a service, as well as improvements for the tool in the operational context.

5 REFERENCES

1. M.P. Levesque, S. Buteau (2007). *Image processing technique for automatic streak detection*. Technical Report – Defence Research and Development Canada – Valcartier, 2007.
2. S. Andreon, G. Gargiulo, G. Longo, R. Tagliaferri, N. Capuano (2000). *Wide field imaging – I. Applications of neural networks to object detection and star/galaxy classification.* MNRAS, 319, 700.
3. E. Bertin, S. Arnouts (1996*). SExtractor: Software for source extraction.* AASS, 117, 393.
4. V.F. Leavers (1992). *Shape detection in Computer Vision Using the Hough Transform*. Springer-Verlag, London.
5. Mark Masias Moyset (2014). *Automatic Source Detection in astronomical images*. PhD Thesis, Universitat de Girona.
6. Rong-Yun Sun, Chang-Yin Zhao (2012). *A new source extraction algorithm for optical space debris*. RAA, 13, 604.
7. C. Zheng, J. Pulido, P. Thorman (2015), *An improved method for object detection in astronomical images*. MNRAS, 451, 4445.
8. A. Vananti, K. Schild, T. Schildknecht (2015). *Streak detection algorithm for space debris detection on optical images*. AMOS Technical Conference, Maui, Hawaii, USA, 15-18 September 2015.
9. https://irsa.ipac.caltech.edu/data/UCAC4/ucac4.html