2023 ESA Clean Space Industry Days

OBJECT CHARACTERISATION AND OPTICAL DATA PROVISION SERVICE IN SUPPORT OF END-OF-LIFE MANAGEMENT

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gmv INNOVATING SOLUTIONS

Contents

Introduction

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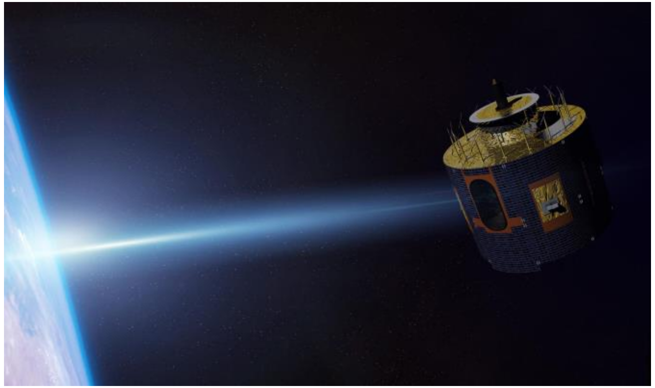
Introduction

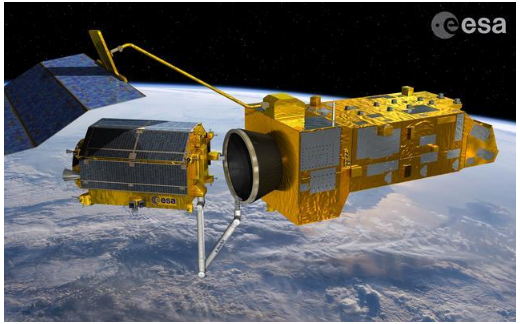
EOL management

- **Facilitate debris mitigation operations**
  - Monitor passivation and graveyard orbit transfer
  - Characterise object for debris disposal
- **Passive attitude monitoring:**
  - Stability state determination
  - Rotation rate and axis determination
  - Object characterization
    - Physical properties
    - Optical properties
- **Other applications:**
  - Contingency modes
  - Military intelligence

Credits: EUMETSAT



Credits: ESA



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Methodology

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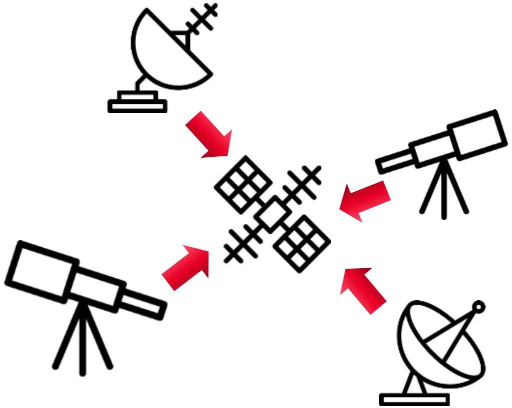
Methodology

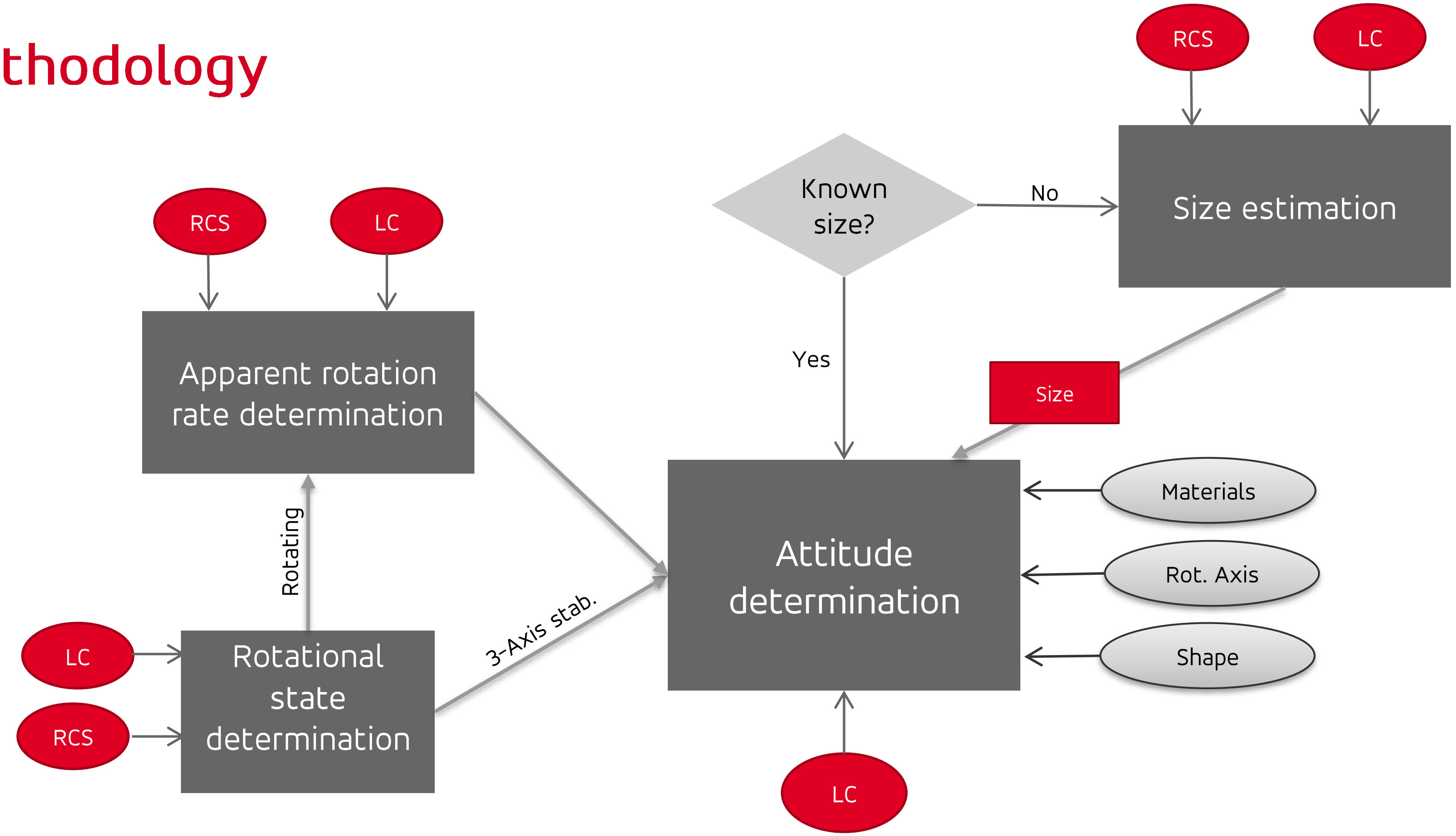
Data availability maximization

- SST sensor networks:
  - Light-curves
  - Radar RCS
  - Laser light-curves
  - Orbital data
- Data fusion:
  - Different types of sensor
  - Different data types
  - Same data types from different sensors
  - Other sources
- Advantages:
  - Better characterization performance than considering each piece of data separately
  - Lessens dependency on individual data sources: Better availability

- Public catalogues
  - RSO Characterization information (shape, size, materials, rotation…) of public objects



Methodology



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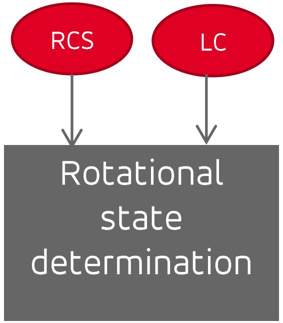
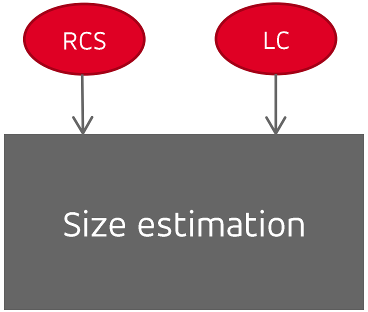
Methodology

Previous characterization steps



- Attitude stability classification
  - Using **ML methods**
  - Stable/Unstable

- Apparent rotation period determination based on **Lomb-Scargle periodograms** + **Epoch Folding** with filtering and folding evaluation



- Size estimation based on M.D. Hejduk (light-curves) and NASA SEM (RCS) models

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Methodology

Attitude estimation

- Based on **Least-Squares Method** (LSM) filter
  - Using light-curves
  - Attitude mode parameters estimation
  - A-priori information can be used (type, rotation, size, shape, materials)
- Inertial rotation rate estimation
- Rotation axis estimation
- If prior knowledge not available:
  - Scale factor estimated for size-vs-materials uncertainty
  - Multi-model approach is possible (i.e., shape/size/materials combinations)
  - Shape description and dimensions may be gathered from public sources

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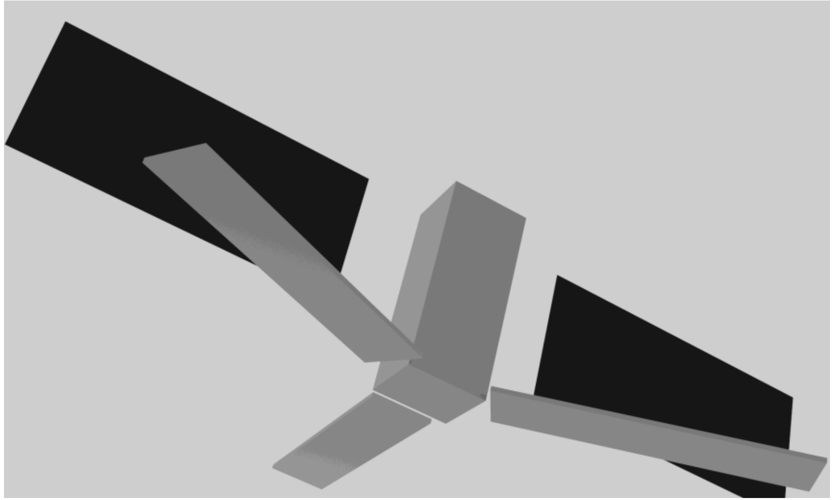
Methodology

Attitude estimation: GMV's light-curves simulator, *GRIAL*

- Bidirectional Reflectance Distribution Function (BRDF) over a 3D shape
  - ratio of reflected light in a direction
  - specular and diffuse terms considered



- Model can be simplified to its main features (body + panels + other large parts)
- Self-shadowing considered
- **OpenGL based (GPU acceleration)**
- High computational efficiency

Credits: ESA

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Results and Discussion

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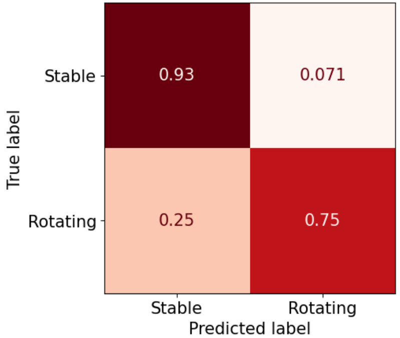
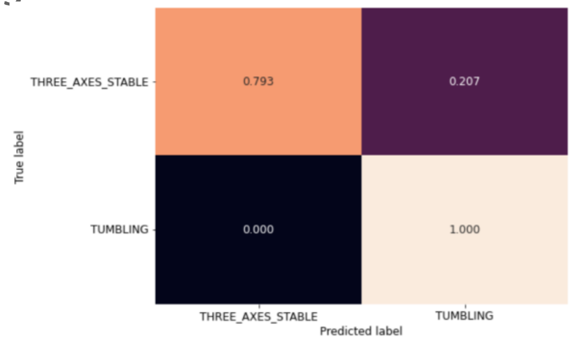
Results and Discussion

Objects stabilization classification results with Machine Learning

- Using light-curves (real MMT9 and simulated data, for training)
- RCS measurements from S3TSR radar

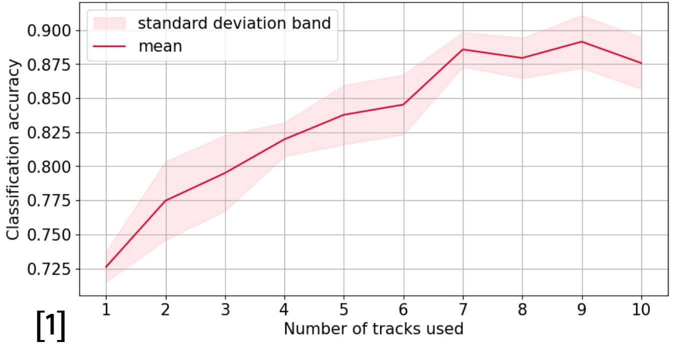




- **~95% accuracy** with simulated data
- **~85% accuracy** with real MMT9 data
- Clear improvement when fusing tracks
- Planned model training improvement with other data sources

[1] Gallego, Ángel, et al. RSO Characterization and Attitude Estimation with Data Fusion and Advanced Data Simulation *AMOS Technologies Conference, Maui Economic Development Board*, Kihei, Maui, HI. 2023.

[2] Paulete, Carlos, et al. AIMLRCS: A Machine Learning approach to spacecraft attitude and object identification based on RCS from the S3TSR. *8th European Conference on Space Debris*, p. 167, 2021



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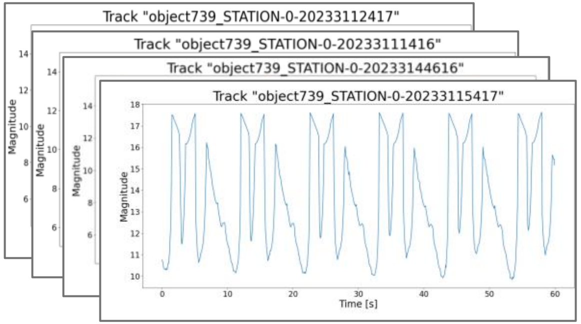
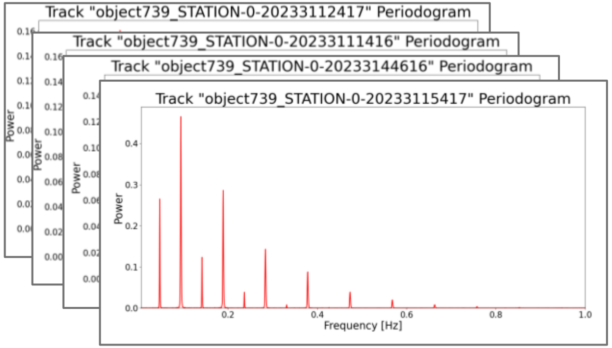
Results and Discussion

Apparent rotation period determination results





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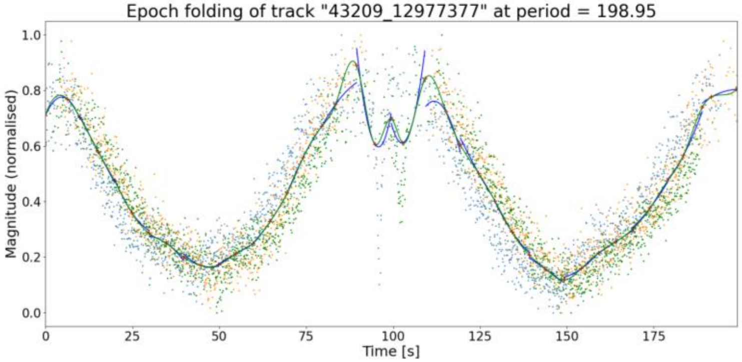

[1]

	Period id accuracy	Multiple of period accuracy
Simulated data	65%	95%
Real data	53%	86%

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Results and Discussion

Size estimation results

- Validation with real spherical objects and real data:
  - **Real light-curves** of STELLA & LAGEOS 1 satellites

Satellite	Real diameter	Albedo = 0,175 (Default for space debris)	Albedo = 0,7 (Aluminium)
		Estimated size	Estimated size
STELLA	0,24 m	0,48 m (x2 real)	0,24 m (exact value)
LAGEOS-1	0,60 m	4,95 m (x8 real)	2 m (x3.3 real)

STELLA

LAGEOS-1

- High dependency on albedo values

- **Real RCS** of COSMOS 660 (Taifun-1) satellite
  - Real diameter = 2m
  - Mean error of 13% over 100 real tracks

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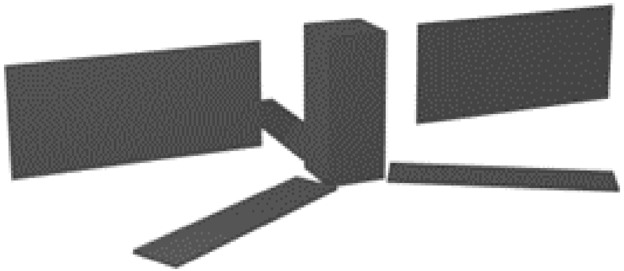
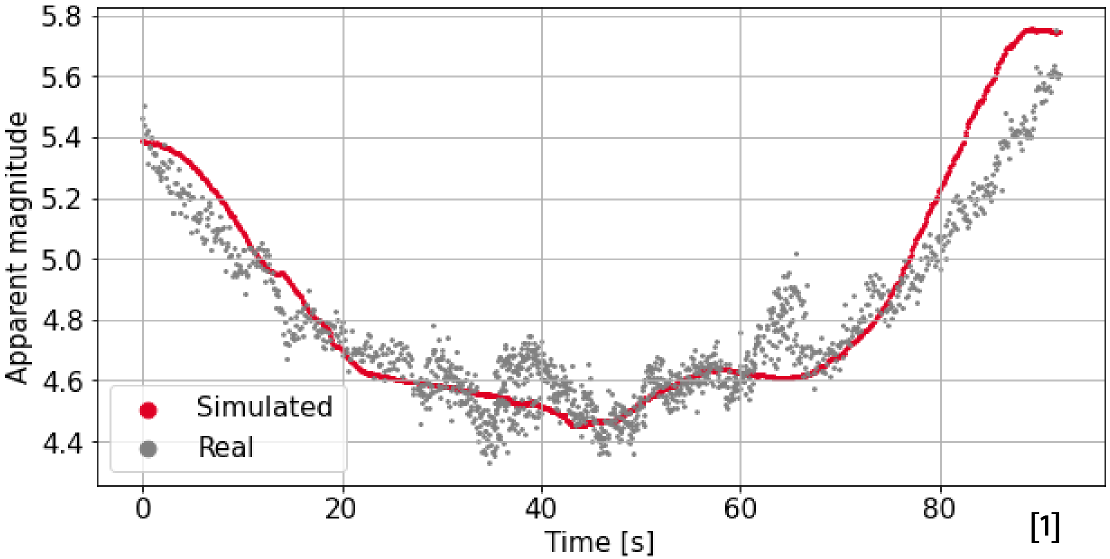
Results and Discussion

GRIAL, light-curves simulation results

- Validation with real light-curves of ESA' SMOS satellite
  - Available attitude ephemeris at time of observations





- Simplified SMOS model
  - 2 materials (panels + body)
- Simulated vs Real measurements:
  - Mean error 0,01
  - STD 0,12
- Reference performance: 250 obs/s with Intel UHD Graphics GPU

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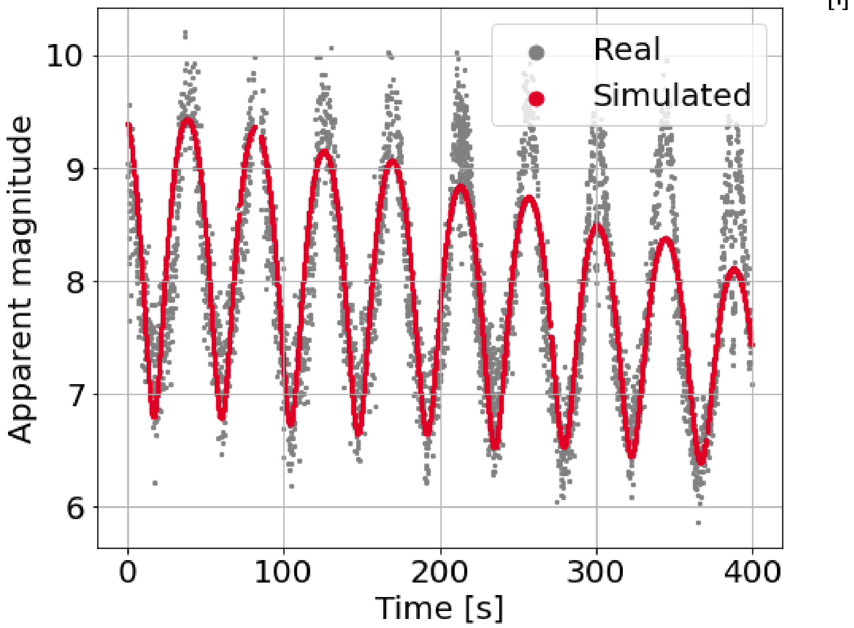
Results and Discussion

Attitude estimation results

- Case of study: Falcon 9 upper stage rocket body (rotating object) with **real** MMT9 observations
- Model: Simple cylinder of correct proportions according to DISCOS.

- Assume rotation axis knowledge
  - Estimated parameters:
    - Initial orientation

- RMS error: 0,42



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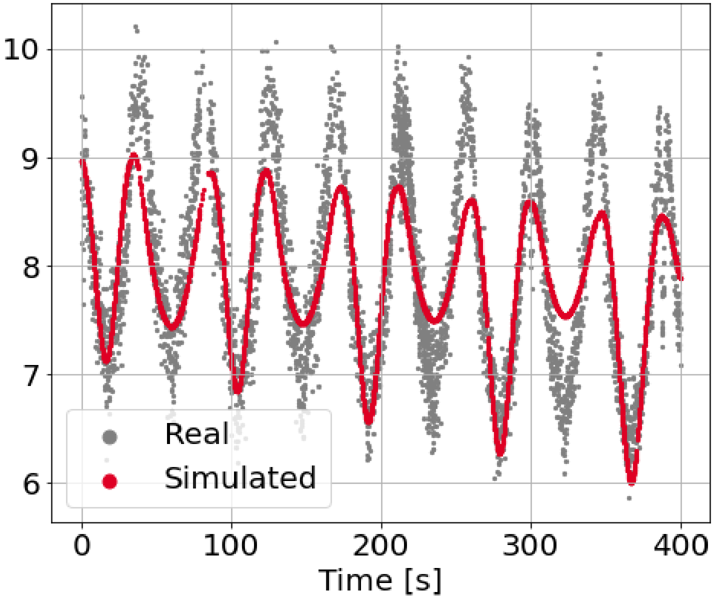
Results and Discussion

Attitude estimation results

- Case of study: Falcon 9 upper stage rocket body (rotating object) with **real** MMT9 observations
- Model: Simple cylinder of correct proportions according to DISCOS.

- Assume no attitude knowledge
- Estimated parameters:
  - Initial orientation
  - Rotation axis
  - Rotation rate

- Restituted attitude:
  - Rotation axis: 11º from perpendicular to axis.
  - Rotation rate within 0.04%
- RMS error: 0,68



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Conclusions and Future work

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Conclusions and Future Work

- Conclusions
  - Accurate results can be obtained with **low prior knowledge** of the object
  - Decision tree approach with data fusion allows for **incremental characterisation**
  - Good results with this preliminary methodology, **improvements expected** with further refinement.

- Future work and improvements

- Attitude classifier
  - Expansion to **larger dataset** for robustness
- Rotation rate estimator
  - **Inertial rotation rate** estimation
- Size estimator
  - Albedo values parametrization

- Attitude determination
  - Try **other filters** (UKF, EKF, etc) for improved robustness
  - **Multi model approach** to reduce dependency on prior object knowledge
  - Consider **prior uncertainties** for continuous characterisation
  - Consider **solar panel attitude** (already in advanced state with promising results)

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Optical data provision service in support of EOL operations

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Overview of the optical data provision service

- Optical data provision service to support EUMETSAT MSG and MTG GEO constellations.
  - Main products: Optical data (tracks) + ephemeris

- GMV + 6ROADS:
- Flight dynamics and orbit determination expertise by **GMV**
  - Operational and extensively used software (*FocusSST*)
- Global sensor network from **6ROADS**.
- High reactivity and accuracy required.
- Routine and event triggered OD and manoeuvre estimation.

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Study case: Meteosat-8 EOL operations

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Study case: Meteosat-8 EOL operations

Event summary

- **Objectives of the EOL operations:** Increase the SMA of the satellite at least 300 km, while maintaining a low eccentricity. Achieved through a series of manoeuvres, generally 2 per day.
- **Challenges encountered:**
  - **Observation difficulties:** Occasional difficult weather and limiting illumination conditions.
  - **Large number of manoeuvres:** Short free-flight periods leading to possible OD accuracy degradation.
- **Results:**
  - 12 manoeuvres successfully characterised over 6 days.
  - Using only 2 telescopes, 4000 observations provided for a total of 384 mins of observation time during EOL operations.
  - Additional 444 observations after EOL.
  - Successfully fulfilled demanding accuracy requirements by optimizing observation strategy.

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Thank you

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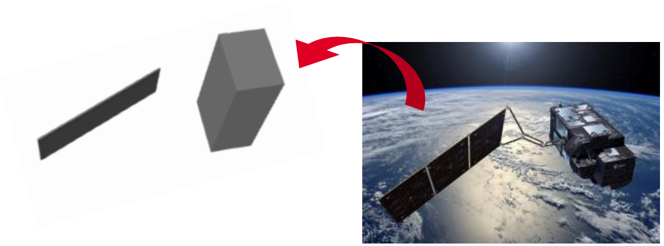
GMV Team

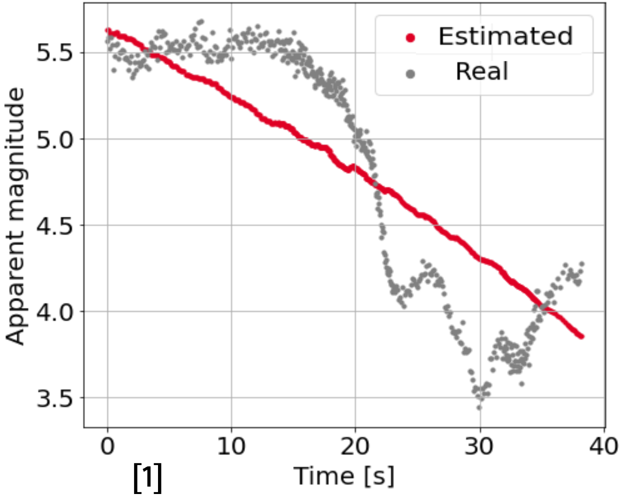
Results and Discussion

Attitude estimation results

- Attitude mode estimation with <u>real</u> MMT9 observations
- Known attitude ephemeris for observation period
- Several attitude modes attempted
- Lowest RMS chosen



Yaw compensation



[1]

RMS error: 0,34

Earth pointing

RMS error: 0,39

Inertial pointing

RMS error: 0,43

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