In orbit fragmentation reconstruction and collision risk estimation.

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Background

- Increasing number of objects around the Earth
  - Several new launches
  - Several breakup events every year
  - New fragments detected by SST

- Needs to
  - Properly track the objects
  - Investigate the origin of newfound fragments
  - Perform collision risk estimations

Evolution of the number of objects

- ESA, “ESA’s Annual Space Environment Report”, 2022
Fragmentation detection

**PUZZLE**

- Initially developed for ASI to support SST services

**Objectives:**
- Detection of fragmentations
- Characterisation of masses and energy

**Main features:**
- No assumption of breakup
- Using *comparison metrics* and *convergence analysis*
- Osculating or *mean* orbital elements

**Functionalities:**
- Short-term (days) investigation
  - Uncertainty propagation (using a GMM approach)
- Long-term (months up to years) investigation

STARLING 2.0

- Developed within an ESA project
- Dual goal
  - Characterisation and Propagation of fragments clouds through a continuum approach
  - Estimation of the probability of impacts with defined targets
- Approach
  - Dynamics agnostic model
  - Up to 6D phase space of slow varying Keplerian elements and A/M
  - Kinetic gas theory analogy

European Space Agency contract 4000133981/21/D/KS
Test case

Definition

Fragmentation detection

- **General:**
  - Collision: Iridium 33 – Cosmos 2251
  - Date of the event: 10 February 2009
  - Size of initial set: 1500 TLEs (including parent(s) and generated fragments - 22 objects)
  - Reference date of initial TLE set: 18 February 2009

- **Objective:**
  - Identification of the event (epoch, involved objects, etc.)

Collision risk analysis

- **General:**
  - Event characteristics (e.g., location): from PUZZLE
  - Timespan of the analysis: 15 years
  - Targets: 175 active objects (2009)

- **Objective:**
  - Collision risk analysis on targets
Test case

Fragmentation detection

- Event epoch (minimum distance between the objects set at 5 km):
  - Estimate: 10 February 2009, 16:55:40
  - Margin: ± 0.417 min
- Families of objects in the estimated interval:
  - 2 orbital families (Collision)
- Objects associated to the event:
  - 22 objects
  - Parent ID: 22675 (Cosmos 2251), 24946 (Iridium 33)
- Computational time*: ~ 9 min

*Intel(R) Core(TM) i7/7700 CPU @ 3.60GHz
Test case

Collision risk analysis

- Fragments cloud generation and propagation
- Estimation of the cumulative collision probability between the fragments generated by the breakup and the targets
- Selection of the 10 most at-risk objects

\[ P_{\text{target}} = \text{cumulative collision probability associated to a single target} \]

\[ P_{\text{total}} = \text{cumulative collision probability associated to the entire set of targets} \]
Test case

Collision risk analysis

Target: DMSP 5D-3 F-15 (cross section: 28.16 \(m^2\))

Impact rate over time between the generated fragments and the target

Mean impact rate and cumulative collision probability over time
Conclusions

- Identification fragmentation as early as possible
- Modelling the fragmentation event detected
- Performs analysis of effects on orbiting objects
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