System Approach to Analyse the Performance of the current and future EU SST system at Service provision level

Igone Urdampilleta
Introduction

Description of the system engineering tool evolution used to evaluate the performance of EU SST system at service provision level:

- Collision Avoidance (CA)
- Atmospheric Re-entry analysis (RE)
- Fragmentation analysis (FG)

Description of methodology, simulation techniques and hypotheses adopted.

Executed by two different engineering teams with independent tools:

- AS4/Ssasim
- BAS3E

Overall objective: provide decision makers with quantitative analyses, towards a “best value for money” architecture design for the EU SST sensor network.
EU SST in a nutshell

EU SST Consortium:
7 EU Member States
- France, Germany, Italy, Spain, Poland, Portugal, Romania

Cooperation with EU SatCen as Front Desk

Overseen by European Commission
EU SST sensors network (2023)

- **3 Lasers**
  - 3 surveillance, 9 tracking

- **12 Radars**
  - (3 surveillance, 9 tracking)

- **39 Telescopes**
  - (4 surveillance, 12 tracking, 23 surveillance & tracking)
Building an SST scenario: outline

Real World

Sensor Network

Data Processing

Service Provision

Reference setup
what objects are we interested in?

Sensor layer
how do we observe these objects?

Data processing layer
what knowledge do we acquire about these objects?

Service provision layer
what do we do with that information?

Performance evaluation
how well did we deliver?

Simulation test bench

Tasking Requests

National Sensor operation & control + correlation
tracking

National databases / catalogues in LEO / MEO / GEO

data

EU SST Database / EU SST Catalogue

CA Service
RE Service
FG Service

Front Desk
High Interest Events

Users

Synthetic population generated for a SST scenario (illustration with CNES VTS)
Building an SST scenario: outline

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Synthetic population generated for a SST scenario (illustration with CNES VTS)

J.M. Hermoso et al. "System Approach to Analyze the Performance of the EU Space Surveillance and Tracking system", Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), 2021
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Simulation test benches: challenges and features

**Robustness and validity:** Two independent test benches: AS4/Ssasim (DEIMOS/GMV) & BAS3E (CNES)

**Population design** shaped by scenario specifics:
- *Relevant* to analysis at hand: (near-)collisions are needed for CA studies
- *Representative* of real population, to derive meaningful statistics
  - historical/available data (e.g. SpaceTrack, ESA MASTER populations) exploited when relevant
- *Suitable* for simulations under limited computational resources

**Orbital propagation** accounts for modelling mismatches in operational conditions:

<table>
<thead>
<tr>
<th>Simulation Tool</th>
<th>Force model for reference population</th>
<th>Force model for catalogued population</th>
</tr>
</thead>
<tbody>
<tr>
<td>AS4/SSASIM</td>
<td>WGS84 Earth model with 12x12 development Drag: atmospheric model Jacchia Lineberry with constant solar activity (F10.7 = 140 sfu and Ap = 9) 3rd body perturbation (Sun and Moon) Solar Radiation Pressure with Earth eclipses</td>
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</tr>
<tr>
<td>BAS3E</td>
<td>WGS84 Earth model with 12x12 development Drag: atmospheric model MSIS00 with constant solar activity (F10.7 = 140 sfu and Ap = 9) 3rd body perturbation (Sun and Moon) Solar Radiation Pressure with Earth eclipses</td>
<td>WGS84 Earth model with 12x12 development Drag: atmospheric model DTM 3rd body perturbation (Sun and Moon) Solar Radiation Pressure with Earth eclipses</td>
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</tbody>
</table>
The five pillars of performance evaluation

- **Inter-dependent** features affecting overall performance
- **Strong focus on end-user**’s perspective
- **Coverage performance** consist in evaluating the measurements that would be provided by the network and perform statistical analysis.
- **Cataloguing performance** consist in evaluating the capacity of the system to build and maintaining a catalog of orbit.

J.M. Hermoso et al., AMOS, 2021
V. Morand et al., IAC, 2021
Collision Avoidance evaluation of performance centers on
- The capacity of the system to detect a conjunction
- Once detected, the system capacity to follow the event and provide extra measurement
- Assessment of the added value of the system
- The global performance of the system to reduce the risk for on-orbit satellites

Methodology based on the comparison of true conjunctions and detected conjunctions
- Comparison of TCA, missed distance
- Computation of the Probability of Collision (PoC)

Main challenges
- **Build** a reference population of colliding objects
- **Control** conjunction number, TCAs and missed distances
- **Maintain** realistic geometry of conjunction
CA Assumptions and Results

- **Generation of synthetic population for CA:**
  - Primary object propagated until random TCA
  - Secondary object created at TCA with random MD distribution tuned
  - Secondary relative position and velocity selected from a historical dataset of CDMs.

- **CA event** characterization:
  - Conjunction screening with JSPOC safety volume, MD and TCA at local minima
  - Computation of penetration factor ($P_f$)
    \[
    \text{if } P_f > 0 \Rightarrow \text{TCA}
    \]
  - PoC computed with ‘$KsKp$ method’:
    \[
    C = K_p C_p + K_s C_s \quad K_p, K_s \in [0.25, 4]; \text{ 16 steps}
    \]
    \[
    \text{ScaledPoC} = \max(PoC)_{K_p,K_s}
    \]

MD (m) histogram for **LEO synthetic population**
(2500 pair of objects, $>3000$ conjunctions)
CA Assumptions and Results

- LEO CA event (2500 pair of objects, 7 days):

<table>
<thead>
<tr>
<th>Secondary size</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMALL</td>
<td>10</td>
</tr>
<tr>
<td>MEDIUM</td>
<td>79</td>
</tr>
<tr>
<td>LARGE</td>
<td>98</td>
</tr>
</tbody>
</table>

  SMALL, RCS < 0.1m²; MEDIUM, 0.1 < RCS < 1.0m²; and LARGE, RCS >1.0m²

- GEO CA event (2210 pair of objects, 7 days):
RE Performance

- **Atmospheric re-entry analysis performance** focuses on
  - The ability to detect and follow the re-entry during the last days and hours prior re-entry
  - The ability to forecast the re-entry epoch and location

- Methodology based on the comparison of **true re-entry and predicted re-entry**

- **Main challenges** are
  - *Build* a reference population of re-entering objects
  - *Mitigate* model uncertainties in shaping true re-entry epochs
  - *Integrate* tracking sensors, *implement* “no-show” events
RE Assumptions and Results

**Reference population:**
- Every object re-enters the atmosphere within the 15-day-long span
- 2000 historical RE event from SpaceTrack
- Using BAS3E’s each object propagated until RE point (80 km), back-propagated, dispersed and averaged on 12 days
  - 1559 SATs & DEBs and 482 R/Bs

**Current focus on daily coverage statistics in the last days of orbital lifetime:**

<table>
<thead>
<tr>
<th>Survey and tracking radars</th>
<th>RE - 6d</th>
<th>RE - 5d</th>
<th>RE - 4d</th>
<th>RE - 3d</th>
<th>RE - 2d</th>
<th>RE - 1d</th>
<th>RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RE</td>
<td>98</td>
<td>97</td>
<td>97</td>
<td>97</td>
<td>97</td>
<td>96</td>
<td>71</td>
</tr>
</tbody>
</table>
**FG Performance**

- **Fragmentation analysis performance** consists in evaluating:
  - The capacity to detect a fragmentation: timeliness, identification of parent object(s)
  - The capacity to track and catalogue as many fragments as possible

- Methodology based on the use of **simulated fragmentation with known properties**:
  - Parent(s) body and orbit
  - Repartition of the fragments in terms of mass, area, orbit

- **Main challenges**:
  - *Model* measurement process when observing a cloud
  - *Handle* data-to-object observation in dense environments
  - *Perform* Initial Orbit Determination (IOD) upon debris detection
FG Assumptions and Results

- **Generation of population of fragments:**
  - Analysis historical event
  - Fragmentation Generation tool (AS4)
  - MASTER 2009 NASA Breakup Model

- LEO FG event (2459 objects >= 7cm, 14 days):

<table>
<thead>
<tr>
<th>Orbital Regime</th>
<th>FG synthetic population characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO</td>
<td>Collision at 800 km</td>
</tr>
<tr>
<td>MEO</td>
<td>Explosion</td>
</tr>
<tr>
<td>GEO</td>
<td>Explosion</td>
</tr>
<tr>
<td>FG event type</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Parent(s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1190 kg</td>
</tr>
<tr>
<td></td>
<td>500 kg</td>
</tr>
<tr>
<td></td>
<td>~2000 kg NSO</td>
</tr>
<tr>
<td></td>
<td>~2000 kg HEO</td>
</tr>
<tr>
<td></td>
<td>~2000 kg</td>
</tr>
</tbody>
</table>

**Percentage of event followed (survey network):**

- SMALL: 17
- MEDIUM: 98
- LARGE: 100
Conclusions

- System engineering tool evolution towards service provision to evaluate the performance of current and future EU SST network

- Multi-layered performance evaluation, reflecting five features of SST operational needs

- Quantitative analysis of projected sensor networks, supporting decision makers into shaping the future of EU SST

- Future update for integration of new sensors:
  - Space-based sensors
  - Infrared sensors
  - Passive RF sensors

See Virtual Poster: PR solution design to improve CA services
Acknowledgements

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